# 24th World Mining Congress

MINING IN A WORLD OF INNOVATION

October 18-21, 2016 • Rio de Janeiro /RJ • Brazil

24th World Mining Congress **PROCEEDINGS**

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Luiz Mello

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It is a pleasure for us to participate in the 24th edition of the World Mining Congress - WMC 2016, being held for the first time in Brazil, and we can introduce you to some of the technological, research and innovation solutions in the Mining Sector. It is our commitment to share knowledge, innovation and technology towards the sustainable development of the operations and processes in global mining.

I hope that everyone enjoys the most of the World Mining Congress!

***Luiz Mello***
*CEO of* Vale Institute of Technology
*Technology and Innovation Executive Manager of Vale*

# José Fernando Coura

On behalf of the Brazilian Mining Association - IBRAM and its associates, I would like to offer a warm welcome to all the participants of the 24th edition of the World Mining Congress - WMC 2016. This is the first time that the WMC, recognized as one of the most important world mining events, is being held in Brazil. The central theme of this congress is "Mining in a World of Innovation", one of the most current and important issues in the management of mining-sector businesses.

The 24th WMC began to take shape in 2012 when representatives from businesses and entities of the mining sector, as well as the Brazilian government, joined forces to support the country's bid, before the International Organizing Committee, to host the congress (IOC). This was well-deserved, given Brazil is one of the international exponents of mining.

The presentation of the Brazilian bid was made by IBRAM's presidency in conjunction with our Director of Mineral Issues, Marcelo Ribeiro Tunes. It fell to him to deliver the speech underlining the qualities that make IBRAM suitable to organize such an event, of the city of Rio de Janeiro (RJ) to attract and host event participants, and the Brazilian mining industry; factors which proved decisive in convincing the IOC members to choose Brazil as the host of the event in 2016.

With this significant vote of confidence, we are certain that the 2016 WMC will be the stage of an intense diffusion of knowledge, of discussions on the best way forward, and deep analyses of the current and future landscape of the mining industry. Without a doubt, it will also serve as a way to strengthen relationships and enable dialogue between the most diverse actors of the sector's extensive production chain on an international level.

We know that the last few years have been challenging for the mining industry and "innovation" is the key word for new business and the future of the sector itself. The economic environment has altered the rhythm of supply and demand, impacting ore prices and making it more difficult for mining companies to outline their next steps both locally and globally. Nevertheless, this moment offers an opportunity for mining to lay the way for a return to greater productivity in the future.

This is the proposal of the 24th edition of the WMC, amongst others. We also intend to technically and scientifically promote and support cooperation to develop more stages in the sustainable development of operations and processes in the mining sector.

With an optimistic vision of the prospects of the mineral sector, I hope that IBRAM, via this grand event, can awaken the public interest to debate the future of mining and identify innovative actions to further strengthen the mining industry around the world.

We wish everybody an excellent World Mining Congress!

**José Fernando Coura**
CEO of the Brazilian Mining Institute

# Murilo Ferreira

Brazil has a historic vocation for mineral extraction activities, and since the mid-18th century they have practically dominated the dynamics of its economy. Rich in world-class minerals, the country has emerged as one of the leading global players in the mining industry, and it is now the second largest iron ore producer and one of the most significant agents in international trading and exports of this commodity.

The mining industry has become one of the most important pillars of Brazil's development. Despite the decline in iron ore prices and demand in the international markets, especially due to the slowdown in Chinese consumption, and despite the end of the super-cycle, the mining sector has continued to play a key role in maintaining Brazil's balance of trade surplus.

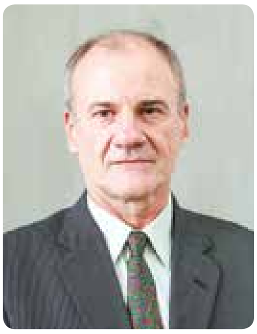
In addition to its positive impacts in the macroeconomic sphere in Brazil, mining has also become a driver of social development, particularly as it has a multiplier effect on other economic activities, contributing to the expansion of various production chains and consequently to the generation of jobs and income. It is noteworthy that in the municipalities where mining companies operate, Human Development Index ratings have been higher than the average figures for their respective states, and much higher than in non-mining municipalities.

In a country like Brazil, whose economic growth, as already mentioned, is strongly dependent upon the expansion of mining activities, the creation of the Brazilian Mining Association, which will turn 40 in December, was essential and absolutely necessary. This is a date to be celebrated, above all because IBRAM has played its role to support and strengthen mining activities with dynamism, efficiency and innovative practices. The sector's companies and organizations can count on a body that assertively and competently represents, coordinates and integrates them, defending their interests and generating conditions conducive to the sustainable development and competitiveness of their businesses.

The holding in Brazil of the 24th edition of the World Mining Congress, organized by an entity of IBRAM's quality, is a milestone and an excellent opportunity for the sector to share ideas, discuss, reflect and find stimuli and feasible ways forward at a time when we need to face the end of the mining super-cycle. The theme of the Congress could not be more appropriate, and I am sure that by its end, promising directions will have been mapped to strengthen the mining industry across the world.

**Murilo Ferreira**
Chief Executive Officer, Vale S.A.

# Professor Jair Carlos Koppe



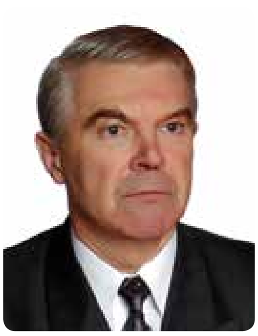
Mining has been extremely important to the World's economic growth and prosperity for centuries. The mining industry is currently facing an economic and social crises that can impact strongly the mineral production and productivity. In this scenario several challenges must be addressed, among them complex mineral deposits of low grades, water, social and environmental issues as well as declining commodity prices. Considering that the world is changing dramatically in all aspects this is the moment for innovation in mining. The WMC 2016 is under the umbrella of Mining in a World of Innovation in the proper moment. This is a nice opportunity to change our ways in mining technology considering the new evolving technologies such as automation, sensors, cloud computing, data analytics that can increase the mining production and efficiency in the entire value chain. Let's take this moment to spread our experience among academy, industries, practitioners and professionals of the mining sector focusing in the future of a world in constantly innovation.

We would like to thanks all the contributions done by the authors invited speakers and participation of delegates that will make WMC 2016 a very successful meeting. Special thanks to the members of the Scientific Committees that helped in the paper analysis ensuring the quality of the conference.

Welcome to the WMC 2016.

**Professor Jair Carlos Koppe**
Congress Chairperson

# Józef Dubiński



Hermínio Oliveira

The 24th World Mining Congress is one of the most important mining events worldwide and is going to be held in Rio de Janeiro, Brazil, from October 18 to 21, 2016. The premiere of the World Mining Congress took place 58 years ago, in September 1958, in Warsaw, Poland. Currently, the WMC organization gathers 45 mining nations from all over the world.

Each World Mining Congress, which takes place in a different host-nation, is always a great mining occasion for the international community that represents science and industry figures involved in the exploration of mineral assets. We can assert that this congress points to the most significant directions for global mining development and determines priorities for the activities of all institutions related to mineral activity. The same approach is going to be adopted during the 24th World Mining Congress, which is going to concentrate on the theme of "Mining in a World of Innovation". Nowadays, and increasing number of countries hold great knowledge potential on mining. The challenges aforementioned demand mutual cooperation, exchange of technical knowledge and professional experience, as well as assistance to those in need. Personally, I believe that our generation of the world mining society – the heirs of our illustrious ancestors – will follow their accomplishments and guide the organization of the World Mining Congress into a new direction, to assure many more years of effective services to global mining and to the people who have taken part in this challenging activity, yet still necessary for all humankind.

**Józef Dubiński**
Professor and Doctor of Engineering
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# Summary

# A RISK-BASED FRAMEWORK FOR MANAGING MINE CLOSURE

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24th World Mining Congress
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# A RISK-BASED FRAMEWORK FOR MANAGING MINE CLOSURE


## ABSTRACT

There is a shared understanding among industry leaders, regulators and academics that mine closure planning should be considered since the inception of a new project and existing mines should develop and regularly update closure plans. Key recommendations include engaging with stakeholders, making cost estimations and sufficient financial provisions. However, the extent to which these and other generally accepted recommendations are actually practiced is largely unknown. In this paper we explore the adoption of a risk-based approach to mine closure planning by developing a framework to consider, in a systematic way, risks associated with mine closure in the strategic and daily management of mining companies. The proposal seeks to harmonize the ISO 31000 model of risk-based management with steps and tasks characteristics of mine closure planning. An on-line survey conducted with mine managers in Brazil and a workshop with closure specialists of major mining companies were used to validate the framework. A risk-based framework of mine closure should be performed by a Steering Committee led by the mining company and including stakeholders. There should be a work plan stating objectives and responsibilities. The plan is structured around a consequence and probability matrix (ISO 31010) focused on risks at closure. This matrix defines the environmental and social risks to be managed, conciliating operation and mine closure. Closure risk factor , obtained from the matrix, is used to rank risks, allowing a mining company to better allocate human and financial resources for closure actions. An audit plan should be established to assess the effectiveness of this management structure.



## KEYWORDS

Mine closure, risk-based management, consequence and probability matrix


## INTRODUCTION

Historically, mining companies have generally had little concern for the decommissioning stage, seen by many as only a cost that could be postponed as much as possible, not affecting the feasibility of the project and the financial results of the operation. As a result, abandoned areas are frequent in countries with a mineral history and new projects undergo difficulties to obtain environmental licensing, because the sector's image is predominantly negative and related to environmental degradation and negative effects on communities.

Therefore, governments and corporations must set forth laws and standards, respectively, for the temporary or definitive closure of mines, with parameters and criteria to be followed. There is a shared agreement, among scholars, that a successful closure is well-planned since the inception of a project, integrating it to the operation and carrying it out during its life cycle, with a reduction in environmental liabilities and accidents. Hence, there should be: stakeholders' engagement, management of uncertainties, definition of post-closure use, financial provisions, preparing it to be performed at any time (Souza, 2003; Wiid, 2006; ICMM, 2008; Fleury&Copley, 2008; Nguyen, 2011; Goodbody, 2013; Sánchez et al, 2013; Neri, 2013; Kabir*et al*, 2014). The sooner a mine decommissioning is planned, the better the control of environmental and socioeconomic impacts and the greater the acceptance of its post-closure use by stakeholders (Kabir et al, 2014).

Even with legal requirements and availability of guides on good practices, companies usually adopt strategies to delay the full implementation of decommissioning projects, without their integration to the operation. This partly occurs because of the lack of a suitable understanding of the consequences of such delay to the companies themselves. Goodbody (2013) and Neri (2013) argue that mine closure costs tend to increase if closure actions are delayed on a long-term basis. De Jesus & Sánchez (2013) discuss the effects of such delay regarding the reclamation of an area within a clay pit in Brazil, where costs increased, in addition to subsequent legal issues.

A way to change such situation would be the adoption of an effective management of the decommissioning stage, by means of a risk-based approach. Risk-based management identifies the actions required to control and mitigate environmental impacts, facilitating the sustainable use of the area in the future and reintegrating it to the local landscape. According to Butler & Bentel (2011), there are successful mine closure cases, such as Polaris, in Canada, Bottle Creek and Beenup, in Australia, and Contact Lake, in Canada. Other cases mentioned by Bradley

(2006), such as in Yatela mine, in Mali, and by Karmacharya et al (2011) on Gregg River, in Canada. Risk-based management elements were adopted in such cases.

In view of such challenges, this study aims to harmonize the ISO 31000:2009 model of risk-based management with steps and tasks characteristics of mine closure planning. It also aims to assess the consequences of the delay in performing or not a closure plan, adopting a posture to conciliate operation and mine closure, or developing actions only at the decommissioning stage. Thus, it assesses the acceptable risk, mentioned by Pritchard (2000), on each decision. By establishing a reference framework for this management, it is worth noting that the following factors are crucial for suitable risk management: stakeholders' engagement from the onset of the project to the discussion of the decommissioning stage; human resources; financial provisions, consistent with the impacts generated throughout its life cycle; reclamation of degraded areas and development of social projects concurrent with the project's life cycle.

Therefore, risk-based management of mine closure should be performed by a Steering Committee, which has a work plan with objectives and responsibilities. The work foundation is the consequence and probability matrix, proposed by ISO 31010, developed from the closure plan. The risk control evolution is analyzed by using CRF – closure risk factor (Laurence, 2006), obtained from the matrix. Critical analysis meetings shall guide the actions, based on the matrix and CRF. An audit plan shall be established to assess the effectiveness of this management.

In order to reach the objective of developing a reference framework of risk-based management on mine closure, this study considered the following development stages: definition of risk analysis tools, based on ISO 31010, and their practical application; validation of a practical case at a workshop; and, finally, the status quo analysis of the risk-based management on mine closure of mining companies, through the application of an online survey.

## EXPERIMENTAL

### Risk-based management practice tools

A consequence and probability matrix, recommended by ISO 31010, was adopted as the main tool that would support risk-based management.

All mine closure data from a Brazilian company were considered. Such company has five operational units. All of them have a closure plan by company initiative. The closure plan implementation is based on its physical and financial schedule, which lists the actions to be performed after the production end, at the decommissioning stage. Thus, decommissioning is not part of the operational strategy, not being consistent with the mine closure operation and management.

Thus, a risk matrix was developed, following the ISO 31010 guidance, considering the risks identified in the closure plan. The difference was the analysis of the current scenario, *i.e.*, if the current actions developed by the company are enough, so that in the future, when its mines are decommissioned, the closure objectives are reached – reclamation of the area regarding the local landscape, with engagement and acceptance of stakeholders.

The next step was the performance, on Sep 30$^{th}$, 2015, of a workshop at the University of São Paulo. This workshop was attended by five experts on mine closure and risk management, representing mining companies that operate in Brazil, two of them being national companies. In addition, one representative of an international consultancy company also attended the workshop. This consultancy company operates in Brazil in the mining sector, by developing mine closure studies. The objective was to promote a discussion and validation of the proposal and the matrix and CRF criteria, the latter used as an indicator to measure the effectiveness of risk-based management.

### Status quo analysis of risk-based management on mine closure

The final study stage involved the analysis of the existing gap between risk-based management and the practice at mining companies that operate in Brazil, proposing improvements. An online survey was performed, which is a data collection method fully used in research (Presnallet al, 2014; Dillman, 2007; Boni & Quaresma, 2005; Gunther, 2003).

The survey was conducted with the support of IBRAM - Brazilian Mining Association, to mining companies that receive their daily briefings. A total of twenty professionals who work in mining companies operating in Brazil answered the survey. Some of these mining companies are headquartered in other countries. This corresponds to approximately 1% of all emails sent. Due to the anonymous status of the survey regarding respondents and their companies, it is likely that more than one employee from the same mining company answered it.

### Management model proposal

The methods proposed by Pereira (2004), Bonici and Junior (2011) and Sanches, Meireles & Sordi (2011) were used with all the data collected and validated through the workshop and online survey data analysis. A reference framework of the risk-based management was proposed according to the concepts established by ISO 31000. This model aims to reduce the gaps found in the survey.

## RESULTS

### Conceptual development

*Risk analysis tools*

The management process start regarding the closure of a mining enterprise is the gathering of relevant information and action programs into a closure plan, which may contain guidelines and technical projects to be adopted during the operation of a mine, as well as during the decommissioning and post-closure stages. Based on several sources (Anglo American. (2008, 2015), Kabir *et al.* (2014), Vale (2014), Goodbody (2013), Sánchez *et al* (2013), Bothan et al (2011), Sánchez (2011), Rio Tinto (Spinger, 2011), Butler & Bentel (2011), Kaemacharya *et al* (2011), Fleury & Copley(2008), ICMM (2008), Votorantim Metais (2008), Bradley (2006), Laurence (2006), Wiid (2006) and Taveira (2003)), the items that should be provided in this document are shown in Table 1.

Table 1 – Items that compose the guidelines for the implementation of mine closure plans.

| Macro-items of the closure plan | Required items in a closure plan |
|---|---|
| Closure plan | Definition of closure objectives<br>Definition of closure targets<br>Definition of closure indicators<br>Definition of the future use for the mining enterprise area<br>Established frequency for the closure plan updates<br>Definition of an internal team in charge of the closure plan management<br>Engagement of the community impacted by the mining enterprise, and other stakeholders, in the definition of the closure plan, in its updates and performance |
| Risk analysis | Development of the preliminary environmental diagnosis of the location before the mining enterprise<br>Update of the environmental diagnosis during the mining enterprise operation<br>Risk analysis – environmental and social factors – in the operation, decommissioning and post-closure stages<br>Definitions of future use restrictions of the area in the post-closure stage<br>Definition of custody transfer criteria |
| Risk control | Development of an action plan with risk mitigating measures for the physical environment (soil, surface and underground water, air) and biota (fauna and flora)<br>Development of an action plan with risk mitigating measures for the anthropic environment (employees, service providers, vendors, local public administration and communities)<br>Closure cost appraisal (implementation of risk-mitigating measures)<br>Establishment of financial provisions for the closure<br>Definition of the physical-financial schedule of mitigation actions, from the operational to decommissioning and post-closure stages<br>Definition of actions to be adopted in case of early closure |
| Verification of effectiveness and critical analysis | Definition of the environmental and social monitoring plan, which includes the post-closure stage<br>Establishment of periodic meetings for the critical analysis of the closure plan implementation results<br>Performance of (independent) audits regarding the closure plan and the provision of financial resources, throughout the project life cycle |

One of the items that has been quite overlooked in the closure plans is the risk analysis so that actions aimed at the business risk reduction can be founded, *i.e.*, to support risk-based management. When such risk analysis is conducted, it is limited to risks aimed at the human health and environmental liabilities (Pritchard, 2000; Candía & Oblasser, 2008; Davies *et al*, 2010), or to risks concerning failure of proposed measures (Wong, Wong & Baker, 1998; Didier & Leloup, 2006). Management integration involving implementation, operation and decommissioning, in regard to the decision-making process aimed at the final objective, does not make use of: sustainability of the mining enterprise, by means of an effective mine closure process, also resulting in the social licensing, cited by Case (1999).

Risk management starts with the identification, analysis and assessment of the risk. Therefore, known techniques are used that can be used in the mine closure plan, such as: brainstorming, PHA (Preliminary Hazard Analysis), consequence/probability matrix, FMEA (Failure Mode Effect Analysis), fault tree analysis, etc. (ISO 31010:2009).

Brainstorming and PHA can be commonly used for the preliminary identification of risks from feasibility to future use. The consequence/probability matrix should be used for risk identification and analysis. More in-depth analysis can be carried out by using these tools. In order to analyze the failure probability of a certain control measure, *i.e.*, the risk of an accident and its magnitude, the FMEA or Fault Tree Analysis can be used, associated with mathematical models, dispersion studies or toxicological risk analysis, which measure risks.

Thus, it is recommended that every closure plan has the PHA and consequence and probability matrix of the whole closure plan, starting at the feasibility stage and ending at the post-closure stage, as well as the definition of future use, regarding the risks associated with such use, by setting forth future restrictions. Roberstson & Shaw (2010) and Wiber & Berthelot (2006) discuss examples of the use of this matrix to assess risks at the decommissioning stage of mining enterprises.

*Closure risk factor*

In relation to the definition of a numerical index that allows following the risk-based management evolution of mine closure, the CRF (closure risk factor) was adopted, in accordance with an adaptation of Laurence's proposal (2006). It aims at classifying plans per risk, considering the environment where the mine is inserted. Hence, it allows that a large corporation makes decisions concerning resources and priorities among its several sites. It can also be used as an evolution indicator of the risk control and treatment of closure plans, throughout the years. Another analysis that can be made with this methodology is which risk category has the highest impact on the closure of a mine. Therefore, the manager will be able to follow the evolution of risk-based management.

The CRF is the sum of the following items: $R_E$ (environmental risk), $R_{SH}$ (safety and health risk), $R_c$ (community/social risk), $R_{LU}$ (future land use risk), $R_{LF}$ (legal and financial risk), $R_T$ (technological risk), as follows.

$$CRF = \sum (P_{RE} \times R_E + P_{RSH} \times R_{SH} + P_{RC} \times R_C + P_{RLU} \times R_{LU} + P_{RLF} \times R_{LF} + P_{RT} \times R_T)$$

However, there is no impediment for the inclusion or exclusion of risk categories. The risk (R) score and its corresponding weight (P) are defined from an expert-guided analysis, based on the scenarios presented by Laurence. This methodology was tested, according to the author, in an Australian mine.

**Empirical information**

*Consequence and probability matrix – case study application*

The Brazilian mining company whose five mines are in operation and with life cycle forecast between 10 to 50 years, conducted the PHA in the closure plans, considering the structures to be decommissioned and its own criteria to analyze consequence and likelihood. This analysis was performed for a future scenario, when risk control measures are implemented at the decommissioning stage, without considering the current closure risk management scenario, and conciliating operation and decommissioning. Thus, it was found that residual risks are weightless, as long as proposed measures are effective during the decommissioning stage. Hence, the closure plans are managed in accordance with the schedule, which identified actions to be implemented during the decommissioning stage. Therefore, the company did not visualize what should be developed during the operational stage, for the closure of its sites.

As a study goal, the risk analysis for the decommissioning of the five sites was remade, considering the current stage of the closure risk control, *i.e.*, if the operation is being prepared for decommissioning, regardless of the period in which it will happen. A matrix template developed for one of the sites is shown in figure 1.

Figure 1 – Consequence and probability matrix of the decommissioning stage of an operating mine which is starting risk-based management for closure

| Residual risk matrix (closure mine) | | Likelihood | | | | | |
|---|---|---|---|---|---|---|---|
| | | rating | | | | | |
| | rating | | Remote | Rare | Unlikely | Possible | Likely |
| Consequence | | Catastrophic | | | | 2 | 1 |
| | | Critical | | 2 | 1 | 2 | 2 |
| | | Serious | | | 1 | 1 | 2 |
| | | Moderate | | 2 | | 1 | |
| | | Weightless | 6 | | | | |

Note: 1- the number indicated in the matrix corresponds to the number of risks to be addressed, according to priority criteria
2 – green – weightless risk; yellow – moderate risk; orange – serious risk; red – critical risk. Yellow, orange and red require additional control measures to reach the weightless range.

Because of this new assessment, the current residual risks were identified. It was found that many of them are not controlled and it is necessary to develop actions and studies to conciliate operation and decommissioning. Thus, the main gain for the company in question is in prioritizing risks. There was no view of the risks that required addressing to achieve effective risk control actions (reaching weightless risk) at the decommissioning stage. Some risks impact operational decisions, in terms of mining and the disposal of tailings and waste.

*Closure risk factor – case study application*

In the case study, the CRF application considered the residual risk arising from the consequence and probability matrix (figure 1), since it is necessary to know which closure plans have the highest current non-controlled risks, in order to guide the action. Therefore, table 2 shows the risk values per component, adapted from Laurence's methodology (2006). In addition, this table shows the weights, seeking to reflect the hierarchy of the most important situations against others, due to the environment where the mines are located. Consequently, weights were assigned to CRF items, according to Laurence's proposal (2006) and weight assignment techniques presented by Gomes *et al* (2009). Since the risks contained in the CRF are considered in a cardinal form and not in ordinal form, the Direct Weight Assignment or Direct Rating methodology was adopted. Hence, a workshop was conducted, mentioned in the Experimental section. Thus, the validated weights were:
- 1 (least relevant): the analyzed risk category is of little relevance to stakeholders due to the surrounding characteristics, as well as in economic terms.
- 2 (moderately relevant): the analyzed risk category is of moderate relevance to stakeholders due to the surrounding characteristics, as well as in economic terms.
- 3 (moderately high): the analyzed risk category is very relevant to stakeholders due to the surrounding characteristics, as well as in economic terms.

For other applications, weights must be validated with the stakeholders. However, based on the site description and the knowledge of one of the authors regarding the analyzed areas, a weight score is proposed, in accordance with table 2.

Table 2 – Closure risk factor (CRF) calculation among sites in operation of a Brazilian mining company – case study

| CRF items (closure risk factor) | Site 1 (operation 2054) | Site 2 (operation 2027) | Site 3 (undefined operation) | Site 4 (operation 2026) | Site 5 (operation 2036) |
|---|---|---|---|---|---|
| $R_E$ (Environmental) | 3 x 840<br>**2520** | 3 x 1476<br>**4428** | 2 x 780<br>**1560** | 2 x 1188<br>**2376** | 2 x 748<br>**1496** |
| $R_{SH}$ (Safety and health) | 3 x 1040<br>**3120** | 3 x 864<br>**2592** | 1 x 288<br>**288** | 1 x 288<br>**288** | 3 x 288<br>**864** |
| $R_c$ (Community) | 3 x 184<br>**552** | 2 x 144<br>**288** | 3 x 72<br>**216** | 2 x 144<br>**288** | 3 x 216<br>**648** |
| $R_{LU}$ (Future land use) | NA | NA | NA | NA | NA |
| $R_{LF}$ (Legal and financial) | 3 x 4<br>**12** | 3 x 4<br>**12** | 2 x 4<br>**8** | 2 x 4<br>**8** | 3 x 4<br>**12** |
| $R_T$ (Technological) | 2 x 208<br>**416** | 3 x 208<br>**624** | 1 x 208<br>**208** | 1 x 208<br>**208** | 3 x 208<br>**624** |
| **CRF (closure risk factor)** | **6620** | **7944** | **2280** | **3168** | **3644** |

Sites 1 and 2 take priority in the studies, in view of the uncertainties that currently occur and that may also impact the external community, in the future. Concerning the social aspect, sites 1 and 5 require greater attention, with the development of social projects, for both the internal and external public. Site 3 may be decommissioned at any time, despite its lesser complexity and risks. It is a point to be considered in the priority of actions. The use of weights impacts the analysis of results, especially for sites 4 and 5. Site 5 has issues of security and reliance on the community regarding the enterprise, which in the community's view, have a greater impact than site 4.

*Current scenario of risk-based management practices on mine closure – survey result*

The survey was answered by 20 people, a total of fourteen (70%) work in companies headquartered in Brazil, two of them work in companies in North America, and four work in Europe. Companies included in the survey, which have more than 5 mines in operation, corresponded to 60% of the answers.

In relation to positions, a little more than 30% of respondents have a top management position (director, manager or supervisor) and are responsible for the mine closure management, whereas 50% of the total respondents work in related areas, with or without leadership positions.

Regarding the experience of respondents, 30% of them have experience in closure plan implementation, and 10% work with risk management. It means that most respondents do not have practical experience in the implementation of closure plans, in spite of a part of them be responsible for the issue where they work.

Regarding a total of sixteen people, who answered the second part of the survey (Closure plan structuring), 94% of them have their own guidelines for the implementation of mine closure plans. In addition, 75% of companies also make use of governmental guidelines.

In addition to this information, the items composing these guidelines were assessed. This part was structured in accordance with the PDCA cycle. The results are shown in tables 3 to 6, considering a total of 16 answers.

No company headquartered outside Brazil met all PDCA items included in a closure plan. In relation to the companies headquartered in Brazil, only two of them met all PDCA items: one company with 1 mine under operation and another company with more than 10 mines under operation. However, in the last case, the respondent was at a supervision level that does not perform operations in the closure area and without experience in the subject.

Table 3 – Adherence percentage to the planning items of the closure plan guideline

| Items that compose the mine closure guideline in planning structure | Percentage | Percentage of companies headquartered overseas | Percentage of companies headquartered in Brazil |
|---|---|---|---|
| Definition of closure objectives | 87,5 | 80 | 91 |
| Definition of closure targets | 62,5 | 80 | 54,5 |
| Definition of closure indicators | 44 | 20 | 54,5 |
| Definition of the future use for the mining enterprise area | 87,5 | 100 | 82 |
| Established frequency for the closure plan updates | 75 | 100 | 64 |
| Definition of an internal team in charge of the closure plan management | 56 | 40 | 64 |
| Engagement of the community impacted by the mining enterprise, and other stakeholders, in the definition of the closure plan, in its updates and performance | 62,5 | 80 | 54,5 |
| Mean | 68% | 71% | 66% |

Note: (1) all planning items, in the survey, were answered

Table 4 – Adherence percentage to the risk analysis items of the closure plan guideline

| Items that compose the mine closure guideline in risk analysis | Total percentage of answers | Percentage of companies headquartered overseas | Percentage of companies headquartered in Brazil |
|---|---|---|---|
| Development of the preliminary environmental diagnosis of the location before the mining enterprise | 75 | 100 | 64 |
| Update of the environmental diagnosis during the mining enterprise operation | 81 | 80 | 82 |
| Risk assessment – environmental and social factors – in the operation, decommissioning and post-closure stages | 87,5 | 100 | 82 |
| Definitions of future use restrictions of the area in the post-closure stage | 81 | 100 | 73 |
| Definition of custody transfer criteria | 37,5 | 20 | 45 |
| Mean | 72,5% | 80 % | 69% |

Note: (1) all risk analysis items, in the survey, were answered

Table 5 – Adherence percentage to the risk control items of the closure plan guideline

| Items that compose the mine closure guideline in risk control | Total percentage of answers | Percentage of companies headquartered overseas | Percentage of companies headquartered in Brazil |
|---|---|---|---|
| Development of an action plan with risk mitigating measures for the physical environment (soil, surface and underground water, air) and biota (fauna and flora) | 87,5 | 90 | 91 |
| Development of an action plan with risk mitigating measures for the anthropic environment (employees, service providers, vendors, local public administration and communities) | 75 | 90 | 73 |
| Closure cost appraisal (implementation of risk-mitigating measures) | 87,5 | 100 | 82 |
| Establishment of financial provisions for the closure | 75 | 90 | 73 |
| Definition of the physical-financial schedule of mitigation actions, from the operational to decommissioning and post-closure stages | 81 | 100 | 73 |
| Definition of actions to be adopted in case of early closure | 44 | 60 | 36 |
| Mean | 75% | 88% | 71% |

Note: (1) all risk control items, in the survey, were answered

Table 6 – Adherence percentage to the items regarding the verification of effectiveness and critical analysis of the closure plan guideline

| Items that compose the mine closure guideline regarding the verification of effectiveness and critical analysis | Total percentage of answers | Percentage of companies headquartered overseas | Percentage of companies headquartered in Brazil |
|---|---|---|---|
| Definition of the environmental and social monitoring plan, which includes the post-closure stage | 81 | 100 | 73 |
| Establishment of periodic meetings for the critical analysis of the closure plan implementation results | 37,5 | 20 | 45 |
| Performance of (independent) audits regarding the closure plan and the provision of financial resources, throughout the project life cycle | 44 | 40 | 45 |
| Mean | 54% | 53,33% | 54,5% |

Note: (1) all items related to the verification of effectiveness and critical analysis, in the survey, were answered

In the last part of the survey, where the Likert scale was used, the respondent's perception was assessed in regard to risk-based management practice in mine closure, performed by the company where they work. The risk management structure used was the one established in ISO 31000. Data were analyzed by using the methodologies proposed by Pereira (2004); Bonici & Junior (2011) and Sanches, Meireles & De Sordi (2011). A total of fourteen answers were obtained for this part of the survey. Table 7 shows the assessed items and the results.

Table 7 – Percentage of answers of the professionals' perception who responded the survey regarding the functionality of risk-based management in mine closure, at the companies they work.

ANSWERS OF PART 3 OF THE COMPANY SURVEY

| ITEM | SUBITEM | % IN 14 ANSWERS<br>I disagree | I partially disagree | I neither agree nor disagree | I partially agree | I agree | I do not know/do not |
|---|---|---|---|---|---|---|---|
| Risk identification, analysis and assessment | At the company I work. qualitative environmental risk assessments are conducted (brainstorm. PHA. risk matrix or others) to prepare or update the closure plan | 0 | 0 | 0 | 36 | 57 | 7 |
| | At the company I work. assessments of the previous item are complemented by quantitative studies. such as: hydrogeochemical studies. atmospheric dispersion. mathematical modelling. etc. | 7 | 7 | 0 | 43 | 36 | 7 |
| Risk treatment | At the company I work. risk assessments. contained in the closure plan. were conducted with the engagement of the community and other stakeholders | 43 | 7 | 7 | 29 | 7 | 7 |
| | At the company I work. the priority in which actions are performed in the closure plan is defined on risk assessments | 7 | 7 | 14 | 36 | 29 | 7 |
| | At the company I work. for non-mitigated risks. complementary actions are established until the residual risk is "acceptable/weightless" | 7 | 0 | 0 | 36 | 50 | 7 |
| | At the company I work. there is an organizational structure (work team or committee) for the closure plan management. with defined roles. responsibilities and targets | 7 | 7 | 0 | 64 | 14 | 7 |
| structure conception to manage risks/term of office and commitment | At the company I work. the local community and other stakeholders take part in the closure plan work team. being one of the approvers of the actions and plans to be adopted during decommissioning and follow the closure plan development | 43 | 21 | 7 | 21 | 0 | 7 |
| | At the company I work. leaders and work team are capable in aspects related to concepts and closure plan management | 14 | 7 | 0 | 50 | 21 | 7 |
| risk management implementation throughout the life cycle of the mining enterprise | At the company I work. the closure plan is contained in the strategic planning of the company. thus. influencing the decision-making process | 7 | 14 | 0 | 50 | 21 | 7 |
| | At the company I work. there are enough financial resources for implementation of the closure plan. from the operation until the post-closure stage | 0 | 0 | 0 | 36 | 50 | 14 |
| | At the company I work. it is ready to implemente the closure plan for an early closure | 0 | 29 | 0 | 29 | 29 | 14 |
| | At the company I work. there are reserves for contingencies for non-mitigated (residual) risks at the post-closure stage | 21 | 0 | 0 | 50 | 21 | 7 |
| monitoring and critical analysis and continuous structure improvement | At the company I work. the work team that manages the closure plan conducts critical analysis periodically on the evolution and defines new actions based on results | 21 | 14 | 7 | 29 | 21 | 7 |
| | At the company I work. the closure plan and its provision are audited by third parties. defined by the top management | 43 | 7 | 0 | 7 | 36 | 7 |
| | At the company I work. the closure plan has its progress monitored by the competente governmental bodies | 36 | 21 | 0 | 14 | 21 | 7 |
| Conclusive question | At the company I work. we use mine closure risk management to reduce our business risks | 7 | 7 | 0 | 50 | 36 | 0 |

Note: QT = 14. Median = column within the semantic referential in which respondent 7 is inserted (14/2)

## DISCUSSION

From the analysis of the survey answers, in order to assess the level of risk-based management in mine closure, it is noted in the implementation of closure plans, the emphasis on planning structure and risk analysis, which correspond to P in PDCA (tables 3 and 4), and on risk control, which is D in PDCA (table 5). There is a greater importance of this planning in companies headquartered overseas.

The risk planning and control items that reached more than 75% adherence in the survey answers, were: definition of objectives and future use of the post-closure area, environmental diagnosis, risk assessment, restricted use, definition of the action plan and schedule, costs and provisions, review frequency. These items are recommendations of: Kabir *et al* (2014); Vale (2014), Sánchez *et al* (2013), Spinger (2011), Bothan*et al* (2011), Sánchez (2011), Nguyen (2011), Goodbody (2013), ICMM (2008), Votorantim Metais (2008), Wiid (2006), Laurence (2006).

Conversely, the least observed items in risk planning and control are: definition of indicators, definition of teams in charge of the closure, community engagement, definition of transfer criteria and early closure. In regard to community engagement, this is largely recommended by several authors such as: Kabir *et al* (2014), Goodbody (2013), Sánchez *et al* (2013), Butle&Bentel (2011), Nguyen (2011), ICMM (2008), Wiid (2006). In the case of Brazil, when this engagement takes place, it is related to the information of how the company-defined closure will occur, by placing it as something that will happen in the long-term. It is deemed of little relevance to be discussed in a licensing process. Kabir *et al* (2014) compare the closure guidelines in practice in Canada and Australia. They highlight that the identification and addressing of social impacts, as well as stakeholders' engagement in strategic decisions, are not sufficient.

In relation to the lack of a defined team in charge of the closure, that can contribute to a difficulty in putting it into practice, since only 30% of professionals who answered the survey have practical experience in the implementation of closure plans. This becomes more serious because of the lack of top management engagement, as audits and critical analysis meetings are not recommended practices in most guidelines, since they scored lower than 50%, as per table 6. Consequently, the inclusion of mine closure in strategic planning is yet difficult to occur, including the preparation for an early closure (Sánchez, 2011).

When the closure guidelines of companies headquartered in Brazil are compared with the guidelines of companies headquartered in North America and Europe, there are similarities, especially in regard to the difficulty in putting them into practice, engaging the community and top management. Kabir *et al* (2014) report the recent concern for companies, entities associated with the mining sector and governments, in Canada and Australia, to establish mine closure guidelines.

When the opinion of the professionals who answered the survey (table 7) is analyzed, in relation to the practice of the closure plan guidelines (table 3 to 6), the difficulties found in the planning are reflected in practice. Concerning the use of qualitative and quantitative risk assessments for the development of closure plans, approximately 90% of respondents agreed that the technique is used. They also define complementary actions for the residual risk be rated as "weightless". However, only 36% of them engage the stakeholders in the discussion, and 64% do not engage the community in the closure plan management. Examples of the use of risk analysis in closure plans are addressed by several authors, such as: Davies et al (2010), Didier &Leloup (2006), Wong, Wong & Baker (1998), Candía & Oblasser (2008). However, with the community's engagement, these examples become rare, but there are some quotes, such as: Bradley (2006), Mackenzie et al (2010), Karmacharya et al (2011). Only a part of companies use risk assessment to define priority actions, corresponding to 64%.

A percentage of 78% answered that it is company practice to define a team to act in the closure plan. In addition, 71% of top managers are trained in mine closure concepts. It is worth mentioning that these items are not part of most closure guidelines. Moreover, a few number of responsible parties have already taken part in the implementation of a closure plan, *i.e.*, the subject is still at a conceptual level. With the orientation that mine closure must be performed since the feasibility stage, it is necessary to assess the objective, or the formation of the dedicated team. Furthermore, in relation to the analysis that 71% of respondents said that the closure plans are part of strategic planning, even if that includes exceptions (I partially agree), it is confirmed that it may be necessary to improve risk-based management concepts in mine closure.

Regarding early closure, in the guidelines of the companies developing closure plans, this item is the least performed in risk control (table 5). However, 71% of respondents stated that the companies where they work are ready, or are partially ready, to perform an early closure (table 7). In the references, there are examples of liabilities left by abandoned or poorly closed mines. In the case of Brazil, there is a known gap in audits regarding the implementation of closure plans, throughout the life cycle. It is a crucial item for the satisfactory performance of an early mine closure, if required. This is corroborated by the fact that only 21% of respondents agreed that environmental bodies monitor the development of closure plans (table 7). Once again, there may be deficiencies in the concepts under consideration.

Due to market demands, reinforced by NYSE (2015), the provision of funds for mine closure is generally performed by large corporations, which corresponds to most respondents. In relation to the reserve for contingencies, a recommendation of Sánchez *et al* (2013) and Wiid (2006), 71% of respondents said that this item is fully or partially considered. However, only 43% of companies have audits conducted by third parties in their closure plan and in the provision.

In the final assessment of the risk-based management practice for mine closure, 86% of respondents agree, or partially agree, that the companies where they work, use closure risk management to reduce business risks. Conversely, items deemed essential for this practice success, such as engagement of the community, government and top management, were the ones with the highest score of disagreement or partial disagreement (table 7). Even in the other survey items, where there was agreement, most partially corroborated the opportunity for improvement of the effective mine closure management, in Brazil and overseas. However, a first step is necessary, which is to explain what risk-based management would be, because, according to the survey answers, it is worth noting that there is little knowledge of what it would be and represent to the company.

## RISK-BASED MANAGEMENT PROPOSAL

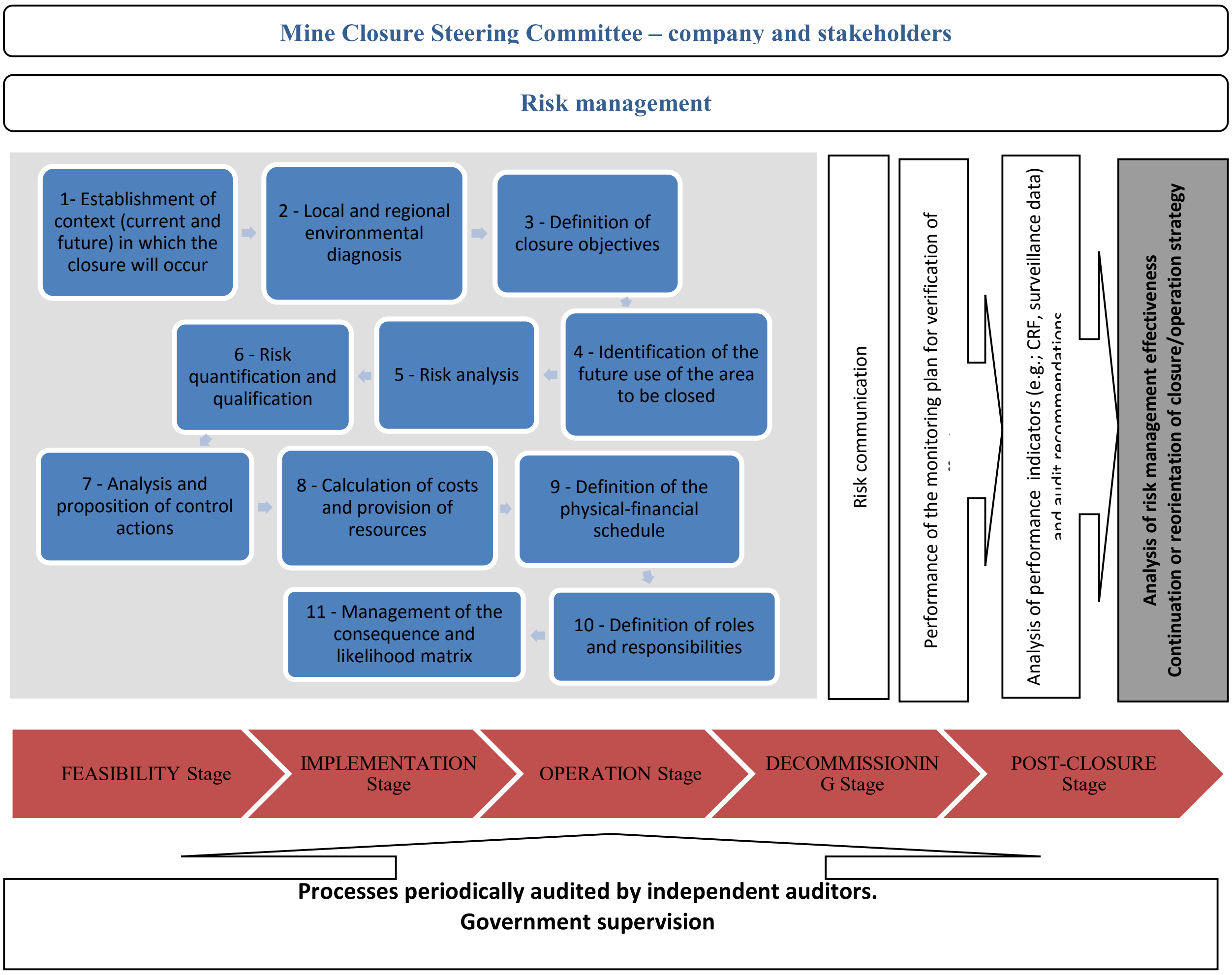
According to literature, six points are critical for closure management: established technical guidelines (closure plan); responsible team for the matter at the company; stakeholders' engagement in the decision-making process; top management engagement; financial resources and decisions made, based on risk, integrating the several mining stages and the aims of society and mine.

This study aimed to demonstrate that is crucial to manage closure according to risks, with the engagement of top managers and stakeholders, providing the company with image and financial gains. Such proposal can be achieved with the use of approaches such as "participative management" (Predebon & Sousa, 2014; Souza, 2014) and stakeholders' engagement (IFC, 2012).

The participative management model (Predebon & Sousa, 2014; Souza, 2014) can be used by a mining enterprise, since the feasibility stage. As the closure involves several areas of an organization, it is necessary that all of them are part of the group. The group leadership, also named Committee, should be the top management of the company, because the responsibility for the closure is of those who extract the mineral asset. As external members, leaders from local communities, organized into entities, should be empowered, as well as the local public administration. The objective is that all decisions are jointly made, because the area will be reintegrated to the local landscape in the future. Moreover, the committee should be decision-making body, only regarding the matters related to mine closure management. Kabir *et al* (2014) states that in some states in Australia, a Community Advisory Committee is established with local community representatives, government and entrepreneurs. Nonetheless, this has not ensured that the social aspects are addressed in a suitable manner, since the risk analysis contained in mine closure plans is superficial.

The tools that would support the discussions and decision-making process of the committee would be: closure plan, developed as per table 1, and the consequence and probability matrix, as per figure 1. In order to check the effectiveness of actions aimed at reducing business risks, the CRF would be used, as per table 2. As a guideline of the Committee's work, the items addressed in table 7 should be considered. Figure 2 shows the reference framework for risk-based management in mine closure.

Figure 2 - Reference framework for risk-based management in mine closure




## CONCLUSION

Mining is viewed by society as an activity that causes damages to society, in detriment to its benefits. That is due to the environmental liabilities left behind, a consequence of the lack of decommissioning planning, because it is often dismissed as part of the project.

The path to reverse this situation is to conduct risk-based management during the decommissioning stage, including it since the feasibility of the project. This study depicted successful cases when the project was adequately planned, considering the decommissioning stage and stakeholders' engagement.

The main points to achieve a successful risk-based management are:

- top management engagement, in the leadership and decision-making process of the decommissioning stage, throughout the project development;
- stakeholders' engagement in decisions related to the decommissioning stage, through the formation of a Steering Committee;
- decisions made based on the risk management of the decommissioning stage, using a consequence and probability matrix and the CRF, integrating feasibility/operation/decommissioning stages;
- a formal and effective critical analysis process of the actions, based on independent audit results. These audits would include the analysis of how effective the adopted technical actions are and the compatibility and availability of financial resources, which would ensure the implementation of actions.

Thus, uncertainties and liabilities would be managed in such way that the feasibility of the project is assertive and grounded. The risks of an early or temporary closure would also be controlled, which, without the perennial risk management, would turn into liability.

It is of primary importance that the environmental licenses granted and renewed by the government should have their closure plan implementation approved and audited, with a risk-based management view.

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# ADDRESSING CLIMATE CHANGE - EFFORTS OF COAL INDIA LIMITED

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# ADDRESSING CLIMATE CHANGE - EFFORTS OF COAL INDIA LIMITED


## ABSTRACT

The climate is changing and entire planet is feeling its heat. The earth is warming up, the rainfall pattern going astray and there is now concerned scientific consensus that it is happening, human induced, primarily and also due to building up of the Green House Gases (GHG) in the atmosphere. The world mostly agrees that something urgently needs to be done about global warming and climate change to save the planet. In order to address the climate change issue, an international convention for climate change, 'United Nations Framework Convention on Climate Change' (UNFCCC), was signed by over 150 countries at the Rio Earth Summit in 1992. India is a major emitter of greenhouse gases, ranking fourth globally in overall terms (behind US, China & EU) and contributing around 5.5 per cent of global emissions and requires mitigation efforts by all the sectors. Coal India Limited (CIL), is the single largest coal producing company of the world. Production and environmental sustainability goes hand in hand in CIL. It does not face direct risk to climate change, as all the mines are located away from the sea shore. CIL has taken in its stride integrated mine planning incorporating environmental concerns by introducing eco-friendly mining technologies, transport systems, coal beneficiation to reduce the greenhouse emissions and taking substantial efforts to increase green cover by way of massive afforestation. Activities of CIL is greatly contributing to the overall intended nationally determined contribution (INDC) of Government of India in addressing the climate change. Post 21$^{st}$ Conference of Parties (COP) in Paris, it is planned to have more structured approach for capacity building. CIL also intends to enhance its adaptation and mitigation measures to join hands with the global community to limit average global temperature increase to below 2°C by the turn of this century.



## KEY WORDS

Climate, CIL, GHG, UNFCCC, CBDR-RC, INDC, UN, MNREGA, toe


## INTRODUCTION

Global climate change is a far-reaching environmental issue that has received wide attention in recent years. At the dawn of the new millennium, environment occupies top place in the agenda of nations. It is no longer possible to talk about development without looking at its close links with environment. In the new economic environment, it is imperative that the industrial production is energy efficient and resource efficient with no or low waste generation.

The climate is changing and every one on this earth is feeling the heat of it. The earth is warming up, the rainfall pattern going astray. Some parts of the earth are experiencing drought, others are experiencing floods. The reduced raining days are impacting the crop yields leading to farmers searching for alternate means of irrigation. It is anticipated that warming of the global climate due to greenhouse gas emissions may also be increasing the risk of cyclones. Our food system, our economies, our cities and our communities — they're all adapted to the climate we currently live in. But what if the climate changes too fast for us to keep up? The fate of the one and only planet we've ever called home is uncertain.

Massive amounts of carbon are stored in tropical forests. When we destroy these areas to clear land for ranches or farms, that carbon gets released into the atmosphere and accelerates climate change. Studies show that deforestation accounts for 11% of all human-caused greenhouse gas emissions.

Global warming affects water sources in three general ways: changes in annual rainfall; increases in sea levels; and increased runoff which results in decreased raw water quality. The climate change also has impact on the topography of the earth as it may lead to increased temperature in Antarctica. The temperature rise above $0^o$ C will lead to quicker melting of the ice caps and quicker erosion of the soils. This degradation is likely to lead to deeper valleys and deposition of more sediments in the oceans. The glaciers are likely to put increased amount of sediments in the plains leading to reduced availability of drinking water.

The major factor for climate change in greenhouse gas emissions (GHG) and both developed and developing countries are responsible for it. As evident in Table 1, China tops the list of GHG emitting countries whereas India ranks fourth.

Table 1: Top 5 Countries with the highest Carbon Di-oxide Emission (2011)

| Total Emissions: Country | Rank in terms of Total Emissions | Total Carbon Dioxide Emissions from the consumption of energy (million tonnes) | Per Capita Carbon Dioxide Emissions from the consumption of energy (tonnes of carbon dioxide per person) |
|---|---|---|---|
| China | 1 | 8715.31 | 6.52 |
| USA | 2 | 5490.63 | 17.62 |
| Russia | 3 | 1788.14 | 12.55 |
| India | 4 | 1725.76 | 1.45 |
| Japan | 5 | 1180.62 | 9.26 |

*(Source: The Outlook, 2015)*

Climate change will make monsoons unpredictable. As a result, rain-fed wheat cultivation in South Asia will suffer in a big way. Total cereal production will go down. The crop yield per hectare will be hit badly, causing food insecurity and loss of livelihood. The rising levels of the sea in the coastal areas will damage nursery areas for fisheries, causing coastal erosion and flooding. The Arctic regions, Sub-Saharan Africa, small islands and Asian mega deltas, including the Ganga and Brahmaputra, will be affected most.

Changes in climate around the globe are expected to trigger a steep fall in the production of cereals. It is estimated that a rise of 0.5 degree celsius in winter temperatures could cause a 0.45 tonne per hectare fall in India's wheat production. The average per hectare production in India is 2.6 tonnes. The available land may not remain suitable for the present crops for too long. Farmers may have to explore options of changing crops suitable to weather. Climatic changes could lead to major food security issues for a country like India.

A 2006 report on an Integrated Energy Policy prepared by an expert committee of the Planning Commission now ‘Niti Aayog’ predicts huge coastal erosion due to a rise in sea levels of about 40 cm resulting from faster melting of glaciers in the Himalayan and Hindukush ranges. It can affect half-a-million people in India because of excessive flooding in coastal areas and also can increase the salinity of ground water in the Sunderbans and surface water in coastal areas.

The report also states that India needs to sustain an 8 to 10 per cent economic growth rate, over the next 25 years, if it is to eradicate poverty and meet its human development goals. Consequently, the country needs at the very least to increase its primary energy supply three or four -fold over the 2003-04 level. India's economic growth would "necessarily involve increase in (greenhouse gas) emissions from the current extremely low levels." According to the report any constraints on such emissions by India, whether direct, by way of emission targets, or indirect would reduce growth rates.

However, the report also added, that India should be willing to contain her (greenhouse gas) emissions as long as she is compensated for the additional cost involved. India has been arguing at all climate negotiations that though it is among the top 10 emitters of carbon dioxide, the per capita emission is still one-sixth of the global average. Further, it has managed an 8 per cent growth with only a 3.7 per cent growth in energy consumption. India may oppose any move to seek its commitment to further reduce greenhouse gas emissions and will ask the developed world to transfer Intellectual Property Rights with the clean technologies.

Studies on climate change have underscored two points. First that the Earth's carbon absorbing capacity is finite and depletable and that growth of greenhouse gases (GHG) emissions, even at their present level pose a threat to humankind. Secondly, it has been established that per capita GHG emission is strongly correlated with economic prosperity. Thus, the more we economically prosper, the more GHG emissions we contribute. However, in Indian context, the major thrust is on poverty alleviation. The above report also states that coal shall continue to be cheapest and affordable source of energy and is also available in abundance in India. Thus the dependence on coal for promoting inclusive growth in Indian context is likely to continue in future.

## INTERNATIONAL EFFORTS

Seventy years ago, the United Nations was created from the ashes of World War II. Seven decades later, in Paris, nations have united in the face of another threat –the threat to life as we know it due to a rapidly warming planet. Governments have ushered in a new era of global cooperation on climate change –one of the most complex issues ever to confront humanity. In doing so, they have significantly advanced efforts to uphold our Charter mandate to “save succeeding generations”. The United Nations' Framework Convention on Climate Change (UNFCC) entered into force on 21st March, 1994 and 195 countries have ratified the Convention, called parties to the Convention. The UNFCC is a “Rio Convention” adopted at the “Rio Earth Summit” in 1992.

The recently concluded “Paris Agreement” in December, 2015 reached on account of Conference of Parties (COP) 21, is a triumph for people, the environment, and for multilateralism of the world. It is a health insurance policy for the planet. For the first time, every country in the world has pledged to curb their emissions, strengthen resilience and act internationally and domestically to address the threat of climate change. It is a good sign that together, countries have agreed that, in minimizing risks of climate change, the national interest is best served by pursuing the common good.

What was once *unthinkable* is now *unstoppable*. The solutions are increasingly affordable and available, and many more are poised to come, especially after the success of Paris Convention. COP21 underscores its commitment to reaching an ambitious agreement in 2015 that reflects the principle of Common but Differentiated Responsibilities and Respective Capabilities (CBDR-RC), *in light of different national circumstances*”. By pursuing the Intended Nationally Determined Contributions (INDC) and implementation of the action plan for reducing the carbon emissions, nations are now poised to play a significant role for reducing the carbon footprints on the planet and make it safe and secure.

## ADDRESSING CLIMATE CHANGE – INDIA’S COMMITMENT & EFFORTS

India accounts for 2.4% of the world surface area, but supports around 17.5% of the world population. It houses the largest proportion of global poor (30%), around 24% of the global population without access to electricity (304 million), about 30% of the global population relying on solid biomass for cooking and 92 million without access to safe drinking water. The average annual energy consumption in India in

2011 was only 0.6 tonnes of oil equivalent (toe) per capita as compared to global average of 1.88 toe per capita. No country in the world has been able to achieve a Human Development Index (HDI) of 0.9 or more without an annual energy availability of at least 4 toe per capita. With a HDI of 0.586 and global rank of 135, India has a lot to do to provide a dignified life to its population and meet their rightful aspirations.

India is a developing country with a per capita GDP (nominal) of around USD 1408 per annum. However, this does not reflect the wide disparities amongst its people and regions. Around 363 million people (30% of the population) live in poverty, about 1.77 million people are houseless and 4.9% of the population (aged 15 years and above) are unemployed. The per capita electricity consumptions stands low at 917 kWh, which is barely one third of the world's average consumptions. As evident from Table 2, population of India is likely to grow from 1.2 to 1.5 billion by the year 2030 requiring electricity to the tune of 2499 TWh and a growth in GDP of INR 397.35 trillion.

Table 2: Micro-indicators of India

| Indicator | India in 2014 | India in 2030 |
|---|---|---|
| Population (billion) | 1.2 | 1.5 |
| Urban population (million) | 377 (2011) | 609 |
| GDP at 2011-12 prices (in trillion) | INR 106.44 (USD 1.69) | INR 397.35 (USD 6.31) |
| Per capita GDP in USD (nominal) | 1408 | 4205 |
| Electricity demand (TWh) | 776 (2012) | 2499 |

*(Source: India's INDC to UNFCCC, 2015)*

Given the development agenda in a democratic polity, the infrastructure deficit represented by different indicators, the pressure of urbanization and industrialization and the imperative of sustainable growth, India faces a formidable and complex challenge in working for the inclusive growth towards a secure future for its citizens. However, in spite of the complex challenges before us and commitment for pursuing the development goals, India's adherence to provisions and principles towards addressing climate change is remarkable. India believes that *international partnerships must be at the centre of its efforts, whether it is development or combating climate change. And the principle of common but differentiated responsibilities is the bedrock of its collective enterprise. When we speak only of climate change, there is a perception of our desire to secure the comforts of our lifestyle. When we speak of climate justice, we demonstrate our sensitivity and resolve to secure the future of poor from the perils of natural disasters.* It is this principal of this *climate justice* that lays the foundation stone of all actions towards addressing climate change in India.

Climate change can be mitigated in many ways, such as improving the efficiency of energy - intensive devices, vehicles and buildings, all of which involve direct and indirect gas emissions. Developing countries like India must adopt new energy - efficient technologies. Fuel - efficient vehicles, hybrid vehicles, and affordable and safe public transport need policy support in the form of lower taxes and promotion of usage. The government can mandate that buildings integrate green technologies such as solar photovoltaic systems, which are particularly relevant in a country with plentiful sunlight. The energy efficiency of end user equipment can be ensured through appropriate tax brakes and certification systems. The improved cooking stoves and high efficiency lighting, heating and cooling devices are available even today. What they need is promotion.

Government of India is implementing the National Action Plan on Climate Change (NAPCC) with a view to enhance the ecological sustainability of India's development path and address climate change. The Government regularly reviews the progress under the NAPCC, based on the information provided by the concerned nodal ministries.

Some of the salient points of INDC of India submitted to UNFCC in 2015 are:

i. To reduce the emission intensity of its GDP by 33-35% by 2030 from 2005 level.
ii. To achieve about 40% cumulative electric power installed capacity from non-fossil fuel based energy resources by 2030 with the help of transfer of technology and low cost international finance including from Green Climate Fund (GCF).
iii. To create an *additional carbon sink* of 2.5 to 3.0 billion tonnes of $CO_2$ equivalent through additional forest and tree cover by 2030.

*India is on course to fulfil its global commitment, having voluntarily cut its carbon emission intensity (emission per unit of GDP) by about 12% between 2005 and 2010, as per the* ***Biennial Updated Report (BUR)*** *submitted to UNFCC. The trend shows that the country is in line to reach its 20-25% reduction target by 2020 and subsequently the 30-35% emission intensity reduction goal by 2030 as promised in country's climate action plan submitted to UNFCC. This also shows the country's resolve for a safe and secure planet despite challenges to provide better quality of life to its people.*

In order to create national fund for mobilizing financing adaptation, mitigation and financing measures, India imposed a cess on Coal in 2010 @ INR 50 (USD 0.8) per tonne of coal. It was quadrupled to INR 200 (USD 3.2) per tonne of coal and in the recent budget of Government of India presented in February, 2016, it has been enhanced to INR 400 (USD 6.4) per tonne of coal. The coal cess translates into a carbon tax equivalent, using the emission factor of coal of around USD 2 per tonne. This forms the corpus for the ***National Clean Environment Fund*** used for financing clean energy, technologies, and projects related to it. The total collection of INR 170.84 billion (USD 2.7 billion) till 2014-15 is being used for 46 clean energy projects worth INR 165.11 billion (USD 2.6 billion).

## CLIMATE CHANGE ISSUES IN INDIAN COAL MINING SECTOR

The coal mining sector has significant contribution in India for meeting the energy requirement of the country. Nearly 63 percent of the India's total energy requirements are met from coal. Government of India has set a target of producing 1.00 billion tonne of coal by the year 2020. The available coal reserves in India are sufficient to meet our needs for at least another 100 years. Thus, in the future also, the coal sector is likely to play a major role in ensuring energy security of the country. India now ranks 3rd amongst the coal producing countries in the world. The coal mining as such, does not have significant contribution towards climate change as it does not involve burning of coal. However, it is affected by climate change which has now become a global phenomenon. The impact of climate change in the coal mining sector are as hereunder:

### 1. Disturbance to mine infrastructure and operations

The coal mining operations are confined to Eastern and Central India and are away from sea shore. The rising sea water level therefore will not affect the coal mining operations and mine infrastructure. The mining machineries are designed to withstand the climatic conditions prevalent in the country and hence unlikely to affect their performance in the years to come. However, there is possibility that hotter and drier conditions may increase affecting the working hours. There are chances to have reduced amounts of water available for mining, processing, and refining activities leading to escalation in cost of water. Rising temperatures may increase energy demand to cool underground mines and surface facilities in OC mines.

**2. Changing access to supply chain and distribution routes**

Increasing temperatures, greater precipitation at some places, shifting storm patterns which are some of the effects of climate change, may have little impact on transportation services that supply goods and services in the command area of operation of CIL.

**3. Challenges to Workers Health and Safety Conditions**

Rising temperatures may increase the risk of heat related illnesses and decreasing productivity. Underground cooling systems may be inadequate to handle changes in temperature and availability of water and energy. Precautionary measures and change in planning of mine operation at project level may be required to handle the situation in future.

**4. Challenges in Environmental Management & Mitigation**

Water scarcity and hotter temperatures will make it more difficult to mine working and re-establish vegetative cover both during progressive and final closure of the mine, and will put stress on other environmental mitigation measures like air pollution control. Increased $CO_2$ and longer growing seasons will have beneficial effect on vegetation efforts during reclamation and after closure. It is likely that availability of key inputs such as water and energy will physically and financially constrain the establishment of new operations or make existing operations costlier.

**5.Pressure of Surrounding community**

The coal mining sector often operates in areas with marginal physical environments, high poverty, and significant social and economic challenges. The surrounding vulnerable host communities stand to suffer from environmental stresses such as drought, rising temperatures, and water scarcity. The coal mining sector may face direct risks to operation over competition for resources such as water hence planning for water conservation may become crucial to its operations due to climate change. There may be opportunity for more meaningful engagement with local communities and other key stakeholders, regarding collaboration on land, agriculture, and water management.

It has been estimated that fossil fuels such as coal, or natural gas when extracted, produced, processed or transported, emit significant amount of methane to the atmosphere. The total emission from these two sources, comprise only of $CH_4$ emission and India emitted 31.69 million tons $CO_2$ eq. It constitutes 97.8% of the total $CH_4$ emitted from the energy sector. It was estimated that coal mining lead to 0.73 million tons $CO_2$ eq. emissions which is insignificant.

## OPTIONS FOR ADDRESSING CLIMATE CHANGE

Currently, there are three ways of combating climate change and they are termed as mitigation or adaptation efforts. The first way, which is the focus of traditional climate talks, involves reducing emissions of greenhouse gases. It is vital that we reduce emissions as hard and fast as humanly possible. But because we have let emissions grow for decades, it will be all but impossible, using this approach alone, to avoid breaching the 2°C `safety rail' beyond which we face increasing risk of seriously destabilizing Earth's climate system.

A second way involves planetary geo-engineering, for example, by injecting sulphur into the stratosphere to cool earth's surface. A fundamental objection to geo-engineering is that it is a *`band-aid solution'* which does nothing to address the root cause of the problem. Because of the high probability of unintended consequences, most scientists consider geo-engineering extremely high risk - for example it may destabilise the south Asian monsoon. Despite the risks, some countries which face serious consequences from climate change are investigating it.

A third way of combating climate change is to draw enough $CO_2$ out of the atmosphere to make a difference to our climate future. This is a huge task, a drawdown of 18 gigatonnes of $CO_2$ being required to decrease atmospheric concentrations of $CO_2$ by 1 part per million. Until recently it has been unclear whether this is even possible, but it is estimated that by 2050, *third way technologies* might be drawing 40% of current emissions (around 16 gigatonnes) from the atmosphere annually.

## REDUCING CARBON FOOTPRINT OF COAL INDIA LIMITED

CIL is the single largest coal producing company in the world. Spread over 14 coalfields in different states of India, CIL is an apex body with 7 wholly owned coal producing subsidiaries and 1 mine planning and consultancy company spread over 8 provincial states of India and its current annual production stands at over 494 million tonne. CIL produces around 81.1% of India's overall coal production, meets 40% of the primary commercial energy requirement of India, commands nearly 74% of the Indian coal market, feeds 82 out of 86 coal based thermal power plants in India, accounts for 76% of total thermal power generating capacity of the utility sector. It supplies coal at prices discounted to international prices and makes the end user industry globally competitive.

It is estimated that:

- India's GHGs amount to only 3% of the Global contribution (in 2009 with 1850 as the Base year), and that of CIL is insignificant from global level point of view.
- 92% of GHG emissions are contributed by the company's mining operations (Scope-1 activities), out of which 71-76% are 'Fugitive GHGs' and 23-30% are due to diesel consumption.
- 28 kg $CO_2$e emission per ton of coal produced is the Carbon Footprint, out of which OB removal contributes 2.3 kg $CO_2$e, Coal breaking-20.8 kg $CO_2$e, coal removal-2.3 kg $CO_2$e, coal stocking & cleaning-1.9 kg $CO_2$e, monitoring & maintenance-0.2 kg $CO_2$e emissions per ton of coal produced.
- CIL operations' total Carbon Footprint would be 13.83 MT $CO_2$e for 494 MT coal produced in 2014-15 (*i.e.* 2.8% of coal produced).
- According to Forest Survey of India (FSI) forest inventory study (2002-2008) the carbon sequestration potential in the coal bearing states is about 360 tons $CO_2$e per hectare over a period of twenty years.
- 213.33 tons $CO_2$e per hectare has been sequestered by 3-tier ecological restoration at BCCL's Tetulmari site in three years (as per study done in dry season in 2015), the carbon sequestration would be more in rainy season and would attain upto 400-500 tons $CO_2$e per hectare in 10-15 years.
- Based on the above facts, it has been assumed that the average carbon sequestration potential of CIL's afforestation sites would be 400 tons $CO_2$e per hectare.
- CIL had done afforestation over 35000 hectares on its mined out & backfilled areas and avenue plantation over non-mining areas till date. Though the carbon sequestration potential of the forests in the tropical regional has been estimated to be 3.2 to 10 tonnes per hectares (Brown et al., 1996), site specific analysis in CIL has found the potential to more. Taking an average sequestration potential of 5 tons $CO_2$e per hectare, afforested areas in CIL are sequestering an estimated amount of about 0.18 million tonnes $CO_2$e. per annum

## EFFORTS OF CIL IN ADDRESSING CLIMATE CHANGE

CIL is pursuing a range of adaptive and mitigation practices to respond to current and potential disruptions tied to climate change as a part of promoting sustainable coal mining operations. In some cases, these practices are intended to restoring the value of existing or potential assets. In others, they are aimed at creating value for the benefit of the society and mitigating climate change. The efforts of CIL in terms of component of climate change is summarized hereunder:

Figure-1: Large Scale Plantation over Mined Out area and water conservation in Northern Coalfields Limited

One third of geographical area of India is degraded. It is planned to created moderate forests on the degraded lands in next 15 years. Plan is there to involve private players and provide degraded land on lease. There are many patches of forest land but no actual forests on them. Ministry of Environment, Forests & Climate Change, Government of India is planning to create such lands into actual forests. Plan is there to create urban forests too. Government of India is also contemplating to involve villagers under Mahatma Gandhi Rural Employment Guarantee Act (MNREGA) schemes. Efforts are also being made to improve the survival rate which is at present 20-60% only. This will provide ample opportunity for CIL to participate in Government's endeavor to create afforestation for addressing climate change apart from regular and routine reclamation, block and avenue plantation undertaken in its mining areas.

**1. Mitigation Centric Efforts**

The reduction in emission in coal mining operations is already achieved by making the HEMMs emission compliant. There is substantial efforts to avoid the road transportation and increased use of coal handling plants, rapid loading system, dealing with fire in Jharia coalfield *etc.* All the major mines are now being planned with coal handling and rail transportation system for coal evacuation. There is also thrust on induction of mine machineries like surface miner having lesser emission. One such area where we can venture is development of solar parks in mines. This will help in reduction of energy requirement for the coal projects. CMPDI has taken lead by installing roof top solar system in its office.

**2. Adaptation Centric Efforts**

CIL is already taking a number of efforts to promote environmentally benign mining operation in its command area. It is taking substantial efforts for reclamation, water treatment and reuse, post-mining sustainable land use, water conservation, use of reclaimed land for income generation for the local community etc. As per an estimate, about 3.3 billion m3 of water resources is likely to be created in the mine voids which will be of great help not only for coal mining but also for the local community as well. Possibility is also being explored to utilize the mine voids for pisci-culture. CIL has taken up massive afforestation (till date over 81 million of plant sapling planted over an area of 34000 ha) programme in its command area. A project proposal is also being formulated under Indo-US joint collaborative project for sustainable use of land after cessation of mining activities. We require more such joint collaborative projects and technology transfer for sustainable coal mining in India.

Water Conservation Efforts by CIL

The water storage in the mine voids is considered best practice approach in Indian context in view of the water stress situation being faced by the local community, growing industrial and domestic requirement, shrinking fresh water resources and thrust given by regulatory agencies. Voids created on account of mining is being treated as infrastructure for storage and subsequent reuse by coal mines, industries and local community at large for irrigation and domestic water requirement. The rain water harvesting measures will also supplement the water conservation measures undertaken by CIL to augment the water resources for benefit of the community. In Korba coalfield, by converting the terminal voids of largest opencast mines into pit lakes, a string of water reservoirs with a total holding capacity of around 2.118 billion $m^3$ can be developed which can meet the growing future water demand in the area.These can also be used to promote tourism, aquaculture, scientific study and socio-economic development of the area.

**Action Plan for Combating Climate Change in CIL**

a) Massive afforestation/ ecological restoration program for carbon sequestration: Keeping in view the fact that about 55% of carbon emissions could be sequestered by afforestation/ ecological restoration, CIL proposes to increase its tree plantation programme manifold both in area and numbers. To achieve this, it would adopt high density 3-tier ecological restoration with native species and Miyawaki methods for creating forests. It is also planning large scale tree plantation program beyond its lease hold jurisdiction.

b) Restoring biodiversity: CIL shall restore the biodiversity over its coalfields by adopting large scale ecological restoration methods. It has already started at few places in its subsidiary companies.

c) Net Present Value and Compensatory Afforestation Charges: CIL has paid net present value of over INR 1.75 billion and compensatory afforestation charges of over INR 0.50 billions to the Government. This can be utilized for creating additional forests resources thus helping in combating climate change.

d) Introducing Clean coal technology/ CBM:

- Commercial development gained momentum with announcement of CBM Policy in 1997
- 33 Blocks allotted with 1.8 trillion cubic metre (TCM) resource in 17400 Sq. Km area through global bidding.
- Production potential from these blocks : 45 Million Cubic Meter per day
- Current production of CBM is about 0.8 MSCMD (million standards cubic meter per day), likely to increase many fold soon.
- More blocks are likely to be allocated through competitive global bidding.
- CBM industry has taken shape and around 500 wells/slim-holes have been drilled.
- CIL is generating CBM specific data to augment CBM resource in India (CBM resource: 3.4 TCM, CMPDI estimate);

e) Introducing alternative renewable energy: CIL is planning to introduce solar energy at all its subsidiary companies by 1000 MW by 2019 thereby preventing carbon emissions of about 1.5 MT per year. It has signed an MoU with SECI (Solar Energy Corporation of India, a Government of India Enterprise) for setting up of solar panels for 1000 MW capacity.

f) Thrust on Underground Mining: The thrust is now being given for increasing the coal production from the existing level of 35.00 MTY to 100.00 MTY. The underground mining is environmentally friendly and there is little land and forest degradation. The mechanization of underground mines through Continuous Miner is now gathering momentum but the existing production level of Continuous Miners (1500 –1700 tonnes per day) may not absorb the cost of technology effectively and therefore, suggested that higher level of production from these machines.

g) Underground Coal Gasification (UCG): The UCG is a method for exploitation of energy from coal resources. It is an eco-friendly physico-chemical process by which coal is converted in-situ into combustible gas comprising of Hydrogen, carbon monoxide, methane and carbon di-oxide. The gas recovered can be processed to remove its carbon-dioxide content. Thus a clean energy with minimal GHG emissions is obtained. The UCG Policy has been formulated by Government of India in December, 2015.

## NEW DEVELOPMENT IN ADDRESSING CLIMATE CHANGE

In the fight against climate change, trees are an ally. They suck in carbon dioxide, reducing the harmful greenhouses gases in our air. But there's a problem — we're asking them to work overtime. Trees can't absorb enough of the carbon dioxide humanity is throwing at them, unless we turn every inch of available land into a dense forest. But what if trees-or machines modelled after them-had superpowers? Artificial trees with otherworldly abilities are a great hope against climate change, as environmental experts say it's not realistic to expect humanity to release significantly less carbon into the atmosphere. Our best bet may be to capture the excess carbon and store it or convert it into something useful such as fuel.

Five years ago, a Boston group developed artificial city trees. The trees they envisioned offered shade and would absorb carbon dioxide. The thinking was to place the trees where soil was too shallow to host traditional trees. The group delivered beautiful mock-ups, but so far little else has come from it. Finding funding is a challenge. In theory, one square kilometer of artificial trees could remove 4 million tons of carbon a year, according to the Center for Negative Carbon Emissions, which is developing a technology to work in open spaces. But much more growth is needed before carbon capture and storage makes an impact on climate change. According to the Global Carbon Capture and Storage Institute, the 15 large-scale projects operating around the world can capture 28 million tons of carbon dioxide per year. To keep climate change in check, we'll need to process 4 billion tons in 2040 and 6 billion in 2050.

The Center for Negative Carbon Emissions, USA is developing technology that it says is 1,000 times as effective as trees, *per unit of biomass*. The group is located in the desert because their technology responds well to warm, dry air and requires less energy in that environment. Operating in cooler climates such as Boston would add expenses. Once the technology is fully built out, they expect to remove a ton of carbon dioxide for about $100 a ton. Their long-term estimate is less than $30 per ton. As is, there's no resemblance to a tree as scientists including those at Arizona State focus on making the carbon removal process effective and affordable rather than beautiful to look at.

## CONCLUSION

The world has now joined hands together to combat the climate change, a major problem now being faced by global community. India has also joined hands with the world though the development agenda remains its top priority. Coal is the cheapest and affordable source of energy is India. The coal reserve is in abundance and therefore the dependence on coal will continue for providing energy security to the country. CIL, the major supplier of coal in the country, operates to promote inclusive growth and has taken a number of steps through massive afforestation, water conservation, reducing energy consumption *etc.* for promoting sustainable mining in and around its command area resulting in carbon sequestration and reduction in GHG emissions. There is greater thrust to introduce environment friendly mining technologies having lower emissions, avoiding road transport, eco-restoration of reclaimed land, water conservation and massive plantation. It is working on to improve efficiency of energy and water uses. CIL shall continue its efforts to reduce GHG emissions.

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# APPLICABILITY OF SOIL BIOENGINEERING TECHNIQUES IN THE PROVISION OF ENVIRONMENTAL SERVICE: STUDIES ON MINING RECLAMATION

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**Keywords** soil bioengineering, environmental services, reclamation of mining areas.

**ABSTRACT**

The reclamation of mining areas requires geotechnical stabilization of superficial processes, intensified by the production activities. This stabilization comprises the use of methods and technique to revegetation and aims at protecting the exposed soil and rock surfaces. In this context, revegetation practices rarely seeks a significant improvement of biodiversity and consequently the quality of natural resources, thus contributing to increase the supply of environmental services. Soil bioengineering, which uses living plants or part of living plants structured with soil or associated with inert elements, tends to enhance biodiversity benefits. Its application progresses in sectors such as transport, recovery of river banks and road slopes, but is still not adopted in the mining sector. This paper presents results of an ongoing research on the applicability of soil bioengineering (SB) techniques to recover degraded areas from mining and the provision of associated environmental services. This paper presents results of resource by applicability of SB techniques in the recovery of degraded areas by mining and association provision of environmental services. The study considers experiments using idealized models to recover degraded areas related to the Cajati mine (owned by Brazilian mining company Vale), located in São Paulo, Brazil. The research objectives include: i) identify the ability of the SB techniques used in Brazil in different contexts of degradation to mitigate or enhance the effects of natural processes (biophysical) in mined areas; ii) to analyze the applicability of the SB in the recovery phase of mined areas; and iii) identify the potential environmental services associated with SB techniques applied in the study area. Research results intend to contribute to the adoption of sustainable recovery of degraded areas models as well as the insertion of environmental services approach in the mining sector.

**Key words:** soil bioengineering, environmental services, reclamation of mining areas.

## INTRODUCTION

The step of post-use reclamation of mining areas is a legal requirement in Brazil since 1989 (Brasil, 1989). According to Almeida & Sanchez (2005, p. 47), "[...] the recovery of degraded areas by mining typically involves activities aiming to restore vegetation." Revegetation has been adopted regularly, especially in mines localized in rural areas (Bitar, 1997). The first systematic studies of recovery of mined areas aimed at rapid revegetation for soil cover that, in most cases, focused only on erosion control (physical stability) and to be compliant with legal requirements (Dias & Assis, 2011), or to mitigate the visual impact (Mechi & Sanches, 2010), not reaching the expected level of success in ecological terms (Almeida & Sanchez, 2005).

In the last twenty years, the accumulated knowledge on the dynamics of natural ecosystems along with the experience gained on the restoration of degraded areas led to a significant change in recovery projects (Jakovac, 2007) towards the reconciliation between the speed of soil covering and important ecological goals, considering a successional approach (Griffith, Dias & Jucksch, 1996).

In order to diversify the techniques of recovery of degraded areas by mining, in addition to conventional ones, Soil Bioengineering (SB), which advances in sectors such as transport, recovery of river banks and roadcuts, can be considered to the recovery of degraded areas by mining. SB is a technology that employs the use of live materials, alone or in combination with inert materials. Live materials are arranged in different constructive models, combining structural and ecological functionality, to recover areas in different degradation contexts (Gray & Sotir, 1996; Sutili, 2007; Evette *et al.,* 2009;. Fernandes & Freitas 2011 ).

In an environmental sustainability perspective, the maintenance of physical stocks of natural capital or the provision of ecological functions and processes can be measured by the provision of environmental services (Cavalcanti, 2004), namely, the direct and indirect benefits obtained by ecosystems (Costanza *et al.*, 1997; Groot, Wilson & Boumans, 2002; Millennium Ecosystem Assessment, 2005).

In this context, this study shows the first results of the research, in progress, on the applicability of SB techniques to recover the upper slope of a waste dump located in the Cajati mine owned by Brazilian mining company Vale, considering the provision of environmental services. The objectives of the study include: i) identify the ability of the SB techniques used in Brazil in different contexts of degradation to mitigate or enhance the effects of natural processes (biophysical) in mined areas; ii) to analyze the applicability of the SB in the recovery phase of mined areas; and iii) identify the potential environmental services associated with SB techniques applied in the study area.

## MATERIAL AND METHODS

The study area –waste dump – belongs to the Cajati mine complex owned by Brazilian mining company Vale, located in the central area of the municipality of Cajati – north of its urbanized area –, in the Ribeira Valley, São Paulo State, Brazil (Fig. 1). The mine covers an area of 17.91 $km^2$ and is located between the coordinates 24º40 'and 24º45' S and 48º05 'and 48 º10' W.

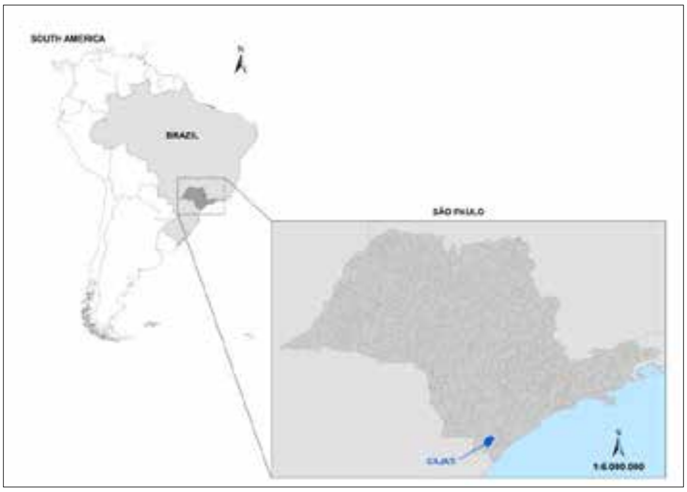


Figure 1 - Cajati mine complex owned by Brazilian mining company Vale.

The Cajati mine complex is an integrated industrial complex, operating since the early 1980's, with the production of phosphate rock (apatite), lime for cement production, agricultural lime, production of sulfuric and phosphoric acids and dicalcium phosphate, the latter to attend the animal nutrition market (Martin, H. M, 2014).

In order to develop the recovery models, a field research was conducted to identify SB techniques, installed throughout Brazil in different contexts of degradation, that could be applied in the study area (Figure 2), considering its characteristics: high declivity, presence of rocks and high porosity.

Figure 2 – Study area –waste dump located in the Vale's Cajati mine complex.

Examples of SB techniques applied in Brazil in different contexts degradation were identified and analyzed to verify their ability to control the biophysical processes, its applicability in recovering mined areas and their potential in generating environmental services.

The analysis considered the potential of the SB techniques analyzed to be adapted and used in areas related to mining activity (ranked as high or restricted potential). To do so, the main areas of a mining project defined by Fornasari Filho *et al.* (1992) were considered: mined areas (benches and slopes); disposal areas (waste dump and waste dam); industrial area (surrounding processing units); and support areas (storage, roads, offices and workshops). The identification of potential environmental services resulting from the application of SB techniques was held, based on scientific literature.

Once recognized SB techniques in the visited projects of recovery of degraded areas, the environmental diagnosis of the study area along with experimental tests for verifying the fundamental characteristics the SB structures should have were the starting point for developing prototypes of the SB structures.

In this way, an experimental test was carried out with the placement of soil/fine-grained substrate on the study area, aiming to assess soil-retention. Rainfall was simulated in order to analyze the loss of soil on the surface, under moderately severe conditions of infiltration, percolation and runoff of water.

The results of the study for recognition of SB techniques in projects of recovery of degraded areas, alongside the results of the environmental diagnosis of the study area and of the experimental test on soil retention made possible the idealization of prototypes of SB structures. The prototypes were then built to verify the potential to retain the soil in conditions of high steepness and high porosity/permeability.

An experimental test was carried out in an artificial slope in order to assess the prototypes' performance in relation to local environmental conditions in an established period of time. The experimental test was also relevant to: adapt the structures to similar conditions observed in the study area; assess the ability of the structures to retain soil; assess the structures' potential to provide proper conditions for seed germination and for the development of vegetation; estimate the quantity of building materials needed to install the structures in the study area; assess the environmental services related to the structures in order to foster the selection of environmental services indicators; and to assess the feasibility of installation of the structures in the study area –waste dump – in Cajati.

The performance of the prototypes was evaluated considering its potential to retain soil in the specific climate, geometric and geotechnical conditions. This allowed designing the structure models, with minor modifications related to size and building material.

The study area was covered with a layer of about 10 cm of limestone sand before the installation of the models. The study area was monitored for the verification of the performance of SB models in recovering the area and generating environmental services.

## RESULTS AND DISCUSSION

### Recognition of soil bioengineering techniques and environmental services

Six recovery techniques were identified in the field research, five of which supported on the SB concept: (a) live slope grating, (b) wood palisade combined to herbaceous species, (c) hydroseeding combined with biomantle, (d) green channel and (e) the stones and wood gutter. The first three techniques – (a), (b) and (c) – showed similarities with the ones most frequently used in stabilizing fluvial and artificial slopes described in the scientific literature (Gray & Sotir, 1996, Eubanks & Meadows, 2002; Durlo & Sutili, 2005; Fernandes & Freitas, 2011). The green channel and the stones and wood gutter (techniques (d) and (e)), are developed for controlling gullies and for re-naturalization of hidden streams and are not described in the SB literature. Topsoil transposition, although not described in the SB literature is frequently used to revegetate cut and fill slopes and to restore the vegetation of mined areas.

The environmental services associated with the techniques analyzed were: support services (increased biological diversity), regulation services (erosion control) and cultural services (recovery of scenic beauty).

**Development of Prototypes/Models**

Three prototypes were developed considering the results of the field research and also the SB techniques described in the literature: "guirlanda", "colmeia" and "solo-retentor", using the natural materials jute and vegetable textile fibers as main construction material.

The "guirlanda" is a circular structure, filled with organic material (litter), designed to receive seeds in its inner portion, where the soil remains confined even in heavy precipitation events. The "colmeia" was designed based on the architecture of hives built by bees and the geocells used in geotechnical engineering works. This structure was also designed to receive seeds in its cells. The "solo-retentor" was designed based on existing techniques used to fill gullies.

Prototypes received soil and seeds of herbaceous legume species with rapid growth potential, in order to create local conditions for the development of small and medium rustic vegetal species.

The three models – "colmeia", "guirlanda" and "solo-retentor" were prepared, placed in the slope and installed using wooden stakes. Except for the "solo-retentor", that was installed in the slope already filled with soil and herbaceous legume seeds, the models "guirlanda" and "colmeia" were filled with soil and seeds after installation.

**Applicability of SB techniques in mined areas**

In mining complexes, waste dump, composed of mixed-sized blocks of rock, with high level of steepness, porosity/permeability and absence of fine-grained material, do not provide necessary conditions to promote plant and successional development.

The analysis of the results of the field research in projects of recovery of degraded areas showed that, in terms of functionality, the role of the SB techniques observed is of controlling erosion, some used in high level erosion, and in the stability of river embankments and natural and built slopes (cut and fill). Nonetheless, such techniques are not ideal to recover the study area because the techniques cannot be applied in an area with steepness greater than 45 degrees, fairly porous and with composition consisting of fragments of millimetric to metric varying sizes of sterile waste from mining activity.

The main functions of the SB models installed in the study area are to: retain soil; receive seeds of leguminous plants; allow the development of plant roots that will act as a structural and mechanical support for soil retaining. The expected results of the models installation are then to: improve the drainage and the stability of the slope; to enhance the potential the generation of environmental services; and to provide a more natural aspect to the slope, improving the local landscape.

The use of herbaceous legumes was an alternative measure for soil protection, due to its multifunctional character, combining aspects of soil conservation and fertility maintenance. This is a result of the ability of herbaceous legumes for: fixing carbon and nitrogen; maximizing nutrients cycling; and promoting the soil's biological activity. They have a high biomass production potential and favor a higher occurrence of arbuscular mycorrhizal fungi, promoting the stabilization of soil aggregates (Nogueira, Oliveira, Martins & Bernardes, 2012). Their deep root system also provides stabilization of unstable soils (Pereira, 2006).

The surface of the slope in the study area was covered with limestone prior to the installation of the SB models, providing fine-grained substrate and lime that filled holes between the blocks of rock. The expected result from this process is to favor the development of vegetation along the surface of the slope.

After ten months of installation, the monitoring of the study area showed the following results (Fig. 3): SB models were kept in slope, with little displacement; SB models retained soil in the area; SB models favored the germination of seeds and the development of the plants; SB models contributed to the generation of environmental services.

Figure 3 - Study area after ten months of installation.

The environmental services associated with the recovery method adopted were related to support and regulatory categories, as follows: construction of anthropogenic soil or substrate (support); habitat formation (support); enhancement of carbon stocks (support); improvement of nutrient flow (support); and erosion control and sediment stabilization (regulatory).

## CONCLUSIONS

This study aimed at researching, identifying and analyzing SB techniques applied in different degradation contexts in Brazil and their potential in generating environmental services in order to verify their applicability in degraded areas by mining activity.

The analysis showed that for the study area, SB techniques should act in soil retention in order to promote recovery through revegetation. It should be adopted green fertilization, aiming at improving soil productivity via the introduction of seeds of legumes, favoring the development of vegetation by nitrogen incorporation (Pereira, 2006) to receive seedlings of tree rustic species.

After the planting phase, the research project will evaluate the environmental performance of SB implanted models and associated environmental services, namely: enhancement of biological and genetic ecosystem diversity; enhancement of carbon stocks; improvement of nutrient flow; construction of anthropogenic soil or substrate; hydric retention; habitat formation; waste reuse; erosion control and stabilization of sediment; and scenic beauty.

Although preliminary, the results show that the SB models developed and installed in the study area had the expected role they were designed for, favoring: the soil retention, the development of herbaceous species and the generation of environmental services.

The recovery of sterile and waste disposal sites from mining activities using SB techniques is a challenge. Thus, there is much to be investigated in terms of: improvement of SB techniques in order to broaden their potential use and generation of environmental services; development of new SB techniques adapted for slopes of waste dump piles; and the analysis of other SB techniques, described in the literature, that could be adapted to the context of mined areas.

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# APPLICATION OF ENVIRONMENTAL MANAGEMENT TOOL FOR CLEANER PRODUCTION IN ROCK BLASTING USING EXPLOSIVE SUBSTANCE

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# APPLICATION OF ENVIRONMENTAL MANAGEMENT TOOL FOR CLEANER PRODUCTION IN ROCK BLASTING USING EXPLOSIVE SUBSTANCE


## ABSTRACT

Mining activity is required for the development of society. However, the rock blasting operation using explosive substances has caused socioenvironmental problems, reflecting on the life quality of workers and the surrounding community's welfare. The evil damage to the environment seem to be tied to digging, the vibrations, the emission of dust and gases after the detonation, the increase of noise, besides the visual and landscape changes. The objective of this study was to examine how the implementation of cleaner production in rock blasting operation, using explosives, can contribute to improving the health and well-being of the worker and the population surrounding to mining. This study was conducted in urban quarry and Minerações e Construções Ltda, situated in the municipality of Macaíba/RN. The study followed some methodological steps: survey of references, readings, annotations, and field research. The results show that the adoption of the principles of cleaner production methodology in the urban quarry Minerações e Construções Ltda involved several improvements, among which the reduction of the aforementioned problems and the life quality transformation of the mining surrounding population are highlighted.



## KEYWORDS

Cleaner production, Environmental impacts, Rock blasting, Surrounding populations.


## INTRODUCTION

Mining activity is required for the country's industrial development in most diverse productive sectors over the years and was one of the pillars of economic and political powers. This economic activity demands a series of extractive procedures that have caused environmental impacts. The rock blasting is defined by Gama (2003) as the set of procedures used to carry out the fragmentation of determined volume of rock from a rock massif; being divided into three major groups: mechanical, hydraulic and explosive blasting; therefore, this concept can be established by the massif geomechanics. The use of explosive substances without application of specific techniques in rock blasting activity, in areas close to urban centers, such as the current study, can generate several environmental impacts, as those related to vibrations in the grounds, phenomenon that happens whenever uncontrolled detonation occurs due to the energy transmitted to the rock massif (BERNARDO, 2004). The problems generated by this phenomenon usually reflect the disruption caused to surrounding communities, also in damage to the neighboring structures and equipment.

The rock blasting aimed at producing crushed stone to be used directly in civil construction has taken advantage from human discomfort and environmental impacts, harming the health of workers exposed to this activity as well as the health of the population from the surrounding areas. Human exposure to diverse effects caused by rock blasting can be felt by the digging, the noise generated by the movement of machinery and equipment, the dust generated by exhaust gases after the detonation, the vibration caused by the excess explosive, and the changes in the physical, chemical and biological properties of the environment. In this sense, the control and minimization of these effects is an important practice that must accompany the planning and execution of rock blasting works (SÁNCHEZ, 1995).

Therefore, to incorporate the environmental concern and the social welfare with the worker's health requires aggregation of cleaner production techniques, since the intention is to reduce costs and add indexes of productivity, improving the image before the society.

The cleaner production consists of a preventive and integrative strategy, which is applied to the whole production cycle to (a) increase productivity, ensuring a more efficient use of raw material, energy and water; (b) promote better environmental performance, by reducing waste and emission sources; (c) reduce environmental impact throughout product lifecycle through an environmental design with effective low cost (UNIDO, 2006).

However, due to continued relations established between the dynamics of the city growth, particularly in recent decades, as the conflicts arising from the soil use and the environmental impacts, highlighted by the fact that few companies practice their activities in order to avoid such a situation, the company Minerações e Construções LTDA, subsidiary of Votorantim Cimentos, located in the municipality of Macaíba/RN - object of this research – although with certain importance in economic and social context for the city and committed with the good man-nature relationship, had receiving some complaints from the surrounding population regarding vibration, digging, dust, and noise emission.

According to the research problem here presented, the objective of this study was to examine how the implementation of cleaner production in rock blasting activity can help to minimize the negative environmental impacts and improve the health and well-being for workers and surrounding populations.

## MATERIAL AND METHODS

The impacts of the company Minerações e Construções Ltda. were assessed in accordance with the methodology of environmental tool system, considering the following steps:

- Characterization of the enterprise and legal zoning of urban area - the study was carried out on the company Minerações e Construções Ltda. located in Gja. Ferreira Torto, s/n, ZIP code 590280-000, Macaíba/RN. It is a private company operating for more than five years in mining, extracting and benefiting granitic rocks, participating directly in the civil construction market;
- Analysis of techniques used in rock blasting - activities of sand, gravel or boulder extraction and processing associated with production carried out by open-pit mining method, in pits, with downward benches. The steps of the pits are developed as follows: drilling with pneumatic drills, blasting with explosives and accessories, loading with excavator, being the transport performed by dump trucks to the crushing unit located 500 m from the mining area. Based on the flowchart (Figure 1), it is possible to enumerate every step of the activities developed in Minerações e Construções Ltda., local object of this study, such as: preparation for starting the mining work, deforestation, mountaintop removal, opening of access routes, blasting, including direct and indirect operations, loading and transportation of dismantled material, crushing operation and the recovery of degraded areas;

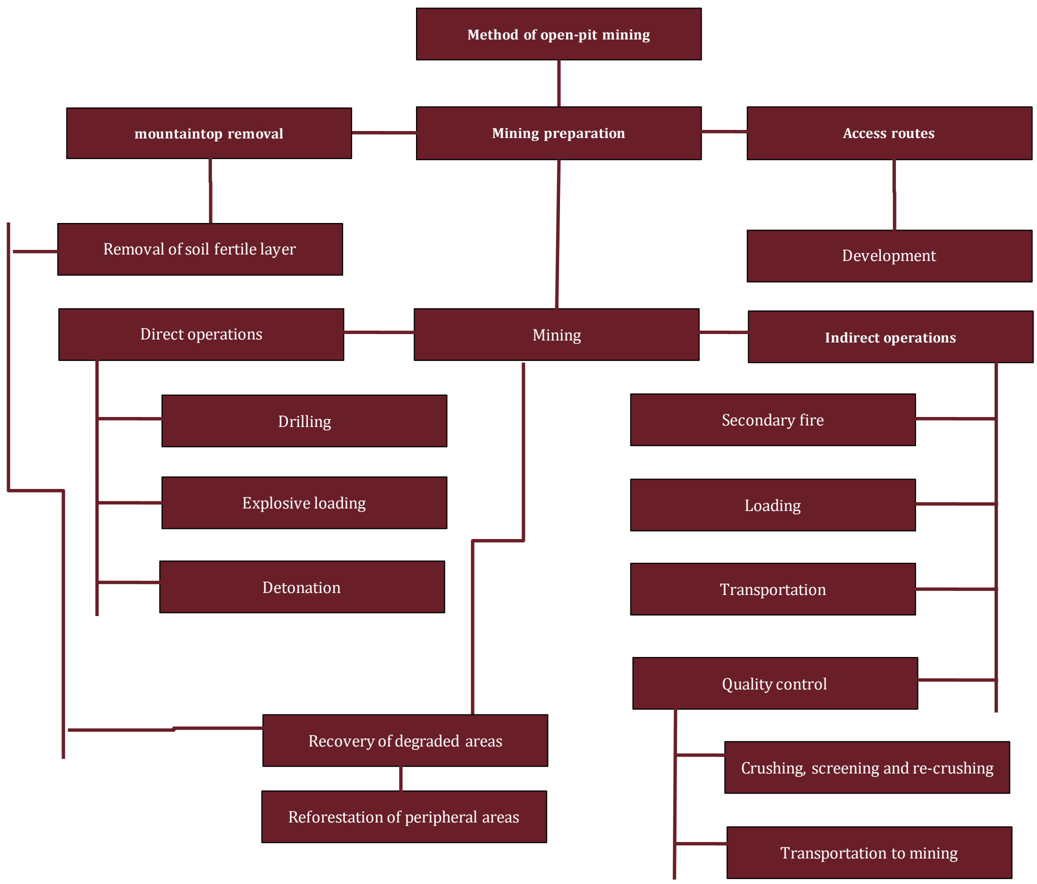


Figure 1 - Flowchart of the mining and processing method

- Evaluation of socio-environmental variables of the surrounding population - to assess the variables relating to dimensions of social, environmental, cultural, and urban management processes, based on the system of environmental management tool, an exploratory research including interviews with the population adjacent to the venture was performed, which second Gil (2008) aims to provide greater understanding of the studied problem. The applied interviews aimed to gathering information about the relationship of surrounding community with quarry activity;
- Investigation of pollutants spread in the environment driven by the activity of the rock blasting - This research is carried out by field activity, following the work of rock blasting, observing the techniques currently used by the company and, subsequently, adopting procedures to minimize the impacts caused to the surrounding population.

In this way, the positive and negative impacts of the project were investigated through quantitative and qualitative experimental research impacts resulting from the blasting rock activity with explosive, object of this study, which has shown a number of environmental concerns.

## RESULTS AND DISCUSSION

In the face of the theoretical supports and observation of collected data, it is analyzed that the main environmental impacts resulting from the blasting rock with explosives are associated with the dissipation of the energy fraction released by the explosive on the detonation that is not transformed into useful work. Such energy fraction dissipates mostly through the surrounding massif in the form of vibrations, and the atmosphere in the form of noise and atmospheric pressure, which is caused by the movement of the material removed or power loss during the detonation of explosive charges (releasing gases confined improperly). Additionally, generates dust and may cause damage to the remaining massif and digging.

Through the process flowchart, presented earlier, the 20 industrial processes were contemplated ranging from open-pit mining method, preparation of the pits, mountaintop removal, access roads, removal of fertile layer of soil, development, pits, direct operations, indirect operations, drilling, secondary fire, explosive loading, detonation, transportation, quality control, recovery of degraded area, crushing, screening, re-crushing, recovery of degraded area, reforestation of peripheral area until the transportation to mining. It was also assessed all process stages of rock blasting and insertion of the cleaner production principles, aiming at the continuous improvement of the environment.

Through exploratory research, the positive and negative impacts were surveyed, regarding the physical, biotic, and anthropic medium, presented by Table 1.

Table 1 - Impacts of rock blasting with explosives: activity and affected medium

| Environmental Factors | Physical medium | | | | | | Biotic medium | | Anthropic medium | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | Neighborhood | | | | | | | | |
| | water | Air | | | | Soil | Fauna | Flora | Economic activity | | | | Health | | Population | | |
| Aspects/Activities | Interference in superficial water | Gases and dust | Vibrations | Noise | Digging | Mining erosion | Migration of birds/mammals | Interference in vegetation | Job creation | Tax raising | Real estate depreciation | Supply raw material | Occupational accident | Diseases and health risks | Increase of neighboring population | Visual and landscape changes | Conflicts in use and soil occupation |
| Mountaintop removal | N | N | N | N | - | N | N | N | P | P | N | N | N | - | N | N | N |
| Bench drilling | N | N | N | N | - | - | N | - | P | P | - | P | N | N | - | - | - |
| Loading the holes with explosive | - | - | - | - | - | - | - | - | P | P | - | P | N | N | - | - | N |
| Fire ligation | - | - | - | - | - | - | - | - | P | P | - | P | N | N | - | - | - |
| Detonation | N | N | N | N | N | N | N | N | P | P | N | P | N | N | - | N | N |
| Loadng and transportation | N | N | N | N | N | - | N | N | P | P | N | P | N | N | - | N | N |
| **P = Positive impact** | | | | | | **N = Negative impact** | | | | | | **(line) = without impact** | | | | | |

Through the performed study, it has tried to identify the environmental aspects related to the rock blasting, the pressure on worker's health and environmental well-being of the surrounding community. In Table 2 is presented the diverse environmental aspects of inputs and outputs in the various stages of this activity and the risks in which workers and surrounding populations are exposed.

Table 2 - Analysis of the pressure on worker's health and surrounding populations from the environmental aspects

| Environmental aspects | Pressure on worker's health and surrounding populations | | | | |
|---|---|---|---|---|---|
| | Physical | Chemical | Biological | Mechanical | Ergonomic |
| Deforestation | x | | | | |
| Erosion | x | | | x | |
| Raw material consumption | | x | | | |
| Consumption of explosive substances | x | x | | x | x |
| Noise emission | x | | | | |
| Heat generation | | | | x | |
| Pollutant emission | | | | x | |
| Greenhouse gas effect emission | x | | | | |
| Dust generation | | x | | | |
| Generation of solid waste | x | | | x | |
| Digging | | | | x | |
| Vibration | x | | | | |

From analysis performed in line with the environmental aspects and the pressures on worker's health and surrounding populations, several health risks were verified, including: physical, chemical, biological, mechanical, and ergonomic. Santos (2008) states that physical risks are generated by machinery, equipment, and physical characteristics of the workplace, which can cause damage to the worker's health and surrounding populations. Chemical risks are represented by the chemicals found in the liquid, solid, and gaseous states. Biological risks are caused by microorganisms invisible to the naked eye, such as bacteria, fungi, and viruses. Mechanical risks occur according to the physical conditions of the work environment and inappropriate technologies, able to endanger the physical integrity of the worker and surrounding population. Finally, the ergonomic risks are contrary to the techniques of ergonomics that propose working environments adapted to humans, providing physical and psychological well-being.

In the face of adverse scenarios, regarding the rock blasting, the implementation of cleaner production tool in Minerações e Construções Ltda has become necessary in order to minimize the environmental impact of great magnitude. After the implementation of cleaner production, the mining company increased its productivity, ensuring a more efficient use of raw material, the promotion of a better environmental performance - motivating and reducing vibration in the blasting, the emission of dust, digging, noise, and reduction of negative environmental impacts and the resulting waste in the blasting with explosive substances.

## CONCLUSIONS

The study on the contribution of the cleaner production implementation in rock blasting activity in Minerações e Construções Ltda, located in Macaíba/RN, concluded that mining activity causes impacts at all project stages, such as: research, implementation, operation and deactivation of the pits. It was observed that the rock blasting with explosives modifies and degrades the environment, since it promotes the change of the physical, chemical, and biological properties of the medium where the mining is being performed.

Therefore, it is clear the importance of applying an environmental management model in rock blasting activity, with the aim of improving the conditions of the environment, health, and safety for the worker and surrounding populations, allowing thus obtain indicators of noise emision, heat generation, pollutant generation, dust generation, digging and vibration, making the process more efficient, anticipating problems and providing solutions.

To achieve the objectives of this study, an analysis of the pressure on worker's health and surrounding populations was performed from the environmental aspects, besides an exploratory research that pointed out its positive and negative impacts, as well as the results achieved by its implementation, through the analysis of the company Minerações e Construções Ltda.

On the foregoing, the application of cleaner production is of paramount importance to minimize environmental impacts and sensitize society to better take advantage from the natural resources, because it aims to reduce operational costs, as well as seek economically viable solutions for the reduction of waste generation, or even the non-generation of "leftovers" in the steps along the way (HENRIQUES and QUELHAS, 2007).

Therefore, the application of this tool of environmental management has contributed to the creation of an integrated and participatory on this economic activity, contributing to the improvement of the environmental performance of mining company and, therefore, for the worker's health and the surrounding populations.

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# ASSESSMENT AND CONTROL OF SOIL EROSION FROM HILLTOP IRON ORE MINES: A CASE STUDY

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# ASSESSMENT AND CONTROL OF SOIL EROSION FROM HILLTOP IRON ORE MINES: A CASE STUDY

## ABSTRACT

Accelerated soil erosion from surface mining areas is an environmental problem for the post-mining mine sites. Raw materials supply for sustaining the human requirements makes mining operation indispensable; however, many of these operations bring the physical disintegration of the earth's surface. Erosions and silt migration from the overburden dumps and exposed surfaces of hilltop mines are quite common. The waste dump materials are normally loose and unconsolidated. This makes it susceptible to water erosion during the rainy season. As a result, the watersheds surrounding of mining areas are highly affected by siltation. The excessive siltation of the drainage network causes deterioration of water quality and reduces the storage capacity of the river basin.

The paper presents the application of erosion estimation for mine site management, particularly for protecting the river basin from the effects of erosion from the post-mining landforms. A case study at Gua Iron Ore Mines, Jharkhand, India situated at the Karo and the Koina river basins have been reported. Revised Universal Soil Loss Equation (RUSLE) model has been tried for hilly terrain to predict the soil erosion and GIS (Geographic information system) tools have been used for spatial analysis. Based on the estimated erosion the mine-leasehold area is divided into three erosion-risk classes: low, moderate and high which are <5, 5-56 and >56 t/ha/yr (tons/hectare/year) respectively. To protect the watersheds near the mining areas, different types of erosion control structures and their silt removal plan is recommended.

## KEYWORDS

Soil erosion, hilltop mining, RUSLE, GIS, erosion control structures, silt removal plan

## INTRODUCTION

Hilltop surface mining area contributes to the recognized environmental problem of soil erosion across the world (Fu et al., 2006). Geological soil erosion takes place when natural erosive agents like the wind, water, gravity, etc transport soil from one place to another over a distance and deposits it at a depression zone where the erosive power gets reduced (Lal, 2003). Anthropogenic activities are often liable to cause accelerated erosion (Webb et al., 2014). Such activities include agriculture, mining, construction, etc. that modify the Earth's land surface converting them to be more erosion prone(Mohammadi & Nikkami, 2008). Amongst these, mining activity is often criticized as the most noticeable cause of erosion problem.

Mining is associated with generating a various form of waste materials of different particle sizes (Bott, 2014). Mining unit operations, e.g. removal of vegetation, drilling and blasting, excavation and loading, transportation and waste dump formation are liable to bring topographical changes in the mine site. Such changes make the site susceptible to erosion, subsidence, flash flood and other environmental hazards (Mossa and James 2013). Number of locations at active mines or closed mines have fragmented or unconsolidated materials, which are susceptible to erode leading to transport of fine particles and silt by surface runoff during the rainy season. It is common to have mudflow, mass wasting, landslide, and gravity movement of land mass in the mining fields. These provide siltation to the water courses in the downstream areas. Sometimes, the material deposited at the post-mining sites may also contain toxic substances. Acidified surface runoff is well known for causing contamination of both surface water and groundwater (Cragg et al., 1995). A part of mining sustainability, hilltop mining needs an appropriate catchment area treatment plan to prevent the risk and destructive effects of accelerated erosion from mine sites. The major issues to be addressed in the catchment area management near hilltop mining areas: water pollution, flash flooding, reducing channel capacity, sedimentation in river banks, shifting river banks, eutrophication, and many other ecological imbalances. While accelerated erosion from mines cannot be completely curtailed, excessive erosion must be reduced to a manageable or tolerable level to minimize the adverse effects as an obligation of social interest (Toy et al., 1999). Numbers of models have been developed to estimate the soil erosion for developing environmental protection measures. However, the selection of most appropriate model for a particular site is often very difficult due to the geotechnical and geographical differences (Angima et al., 2003). Recently, erosion modelling has been increasingly integrated into the geospatial form in geographic information system (GIS) particularly at large catchment and regional scale (R.P.C Morgan, 2009). GIS has emerged as the more convenient and user-friendly tool for erosion studies.

The satellite remote sensing data covers a large region with a regular revisit capacity. Thus, it helps to identify the changes in the land use and land covers in the mining area, which in turn greatly contribute to the assessment of soil erosion and its control. The RUSLE is the most popular erosion prediction model which applied worldwide in conservation planning (Lu et al., 2004). The model was mainly developed for the agricultural field to predict the average annual soil losses in surface runoff (Wischmeier et al., 1978). RUSLE is applied in management of forest land, rangeland, and disturbed lands and has been recently adopted in many construction and mining sites (Renard et al., 1997).

This paper reports an RUSLE and RS-GIS (Remote sensing-Geographic information system) integrated approach applied for the first time in Indian iron ore mining at Gua Iron Ore Mines, the State of Jharkhand, India, for assessment and control of soil erosion to protect the adjacent Karo and Koina river basins. The factors of RUSLE model were calculated in the form of raster layers using RS-GIS, which is quicker and cost effective technique compared to the conventional methods. According to the result of this study, the mine-leasehold area is divided into three erosion-risk classes: low, moderate and high which are <5, 5-56 and >56 tons/hectare/year respectively. The spatial analysis has been used for determining locations for different types of erosion control measures like check dam, boulder retaining wall, sediment trap, diversion channel, and Vetiver plantation.

## STUDY AREA

Gua iron ore mine is a well-developed mechanized hilltop iron ore mine, which is situated in the Saranda forest, West Singhbhum district of Jharkhand State, India (Figure 1). Its geographical coordinate, approximate center at 22° 12’ 56.47” N 85° 21’ 32.95” E with an average elevation of 730m above the mean sea level (MSL). The average temperature in winter remains 16° C. The temperature goes up to $43^0$ C in summer, but the average temperature is recorded to be 33° C. Saranda forest is the Asia’s largest Sal forest enriched with a variety of flora and fauna. It is also well known for high-grade iron ore deposits. Topographically the study area varies in elevations and the terrain is predominantly undulating in nature. It has reserves of about 182 million tons (MTe) of high-grade iron ore, mostly hematite. The annual production capacity of the mine is planned to be expanded from its current 2.5MTe to 10MTe. The ore excavation is carried out by the conventional cyclic mining method deploying excavators and dumpers. The mining sites, stockyards and overburden dump on the hilly terrain are sources of sediments that are migrated to the natural drainage systems around the mine.

To restrict the sediment migration, it is conventional to construct the erosion control structures like check dams, toe wall or retention walls, trap ponds, etc. Though immediately there is no serious austere effect on the catchment area, expansion of the mine boundary may arise environmental issues. As a post-mining precautionary measure, the study attempts to develop a simple and cost-effective methodology for catchment area treatment for the mines.

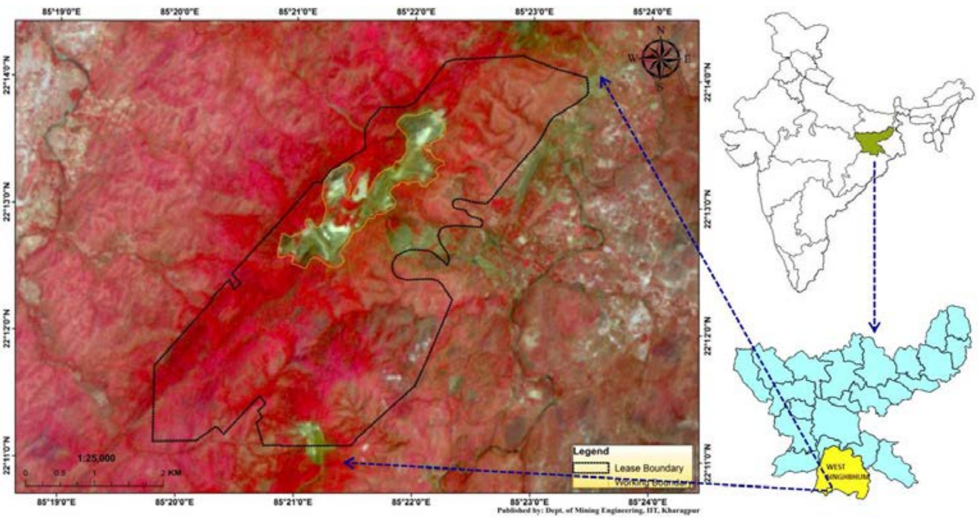



Figure 1 - Location of the study area

## DATA USED

Satellite Image of IRS-P6 LISS-III (acquired on 2014) and Cartoset-1 (acquired on 2009) from National Remote Sensing Centre (NRSC), Hyderabad, India., Survey of India toposheet (1:50,000 scale), 30 years, rainfall data from Indian Meteorological Department (IMD), Pune, India., Soil maps from National Bureau of Soil Survey and Land use Planning (NBSS & LUP), Kolkata, India.

## METHODOLOGY

The overall methodology involved the use of RUSLE in a GIS environment (using ArcGIS software). The RUSLE is the most widely used prediction model to estimate the average annual soil loss from the field. It incorporates the six major erosion factors (Eq. 1), according to land use and land cover their values can be expressed numerically.In this study, GIS is used in preparing thematic layers and estimating soil erosion. RUSLE model integrated with GIS further soil erosion is predicted on a cell-by-cell basis (Millward et al., 1999). Thus, the entire study area has been divided into a 10m × 10m grid. All essential input parameters of the model were prepared in GIS environment using satellite imageries and ancillary data. The average annual soil loss (A) in tons per hectare per year was quantified using RUSLE, expressed by the following equation (K. G. Renard et al., 1997).

$$A = R \times K \times LS \times C \times P \quad (1)$$

where, A is average annual soil loss rate (t/ha/yr), R is the rainfall erosivity factor, K is the soil erodibility factor, LS is the slope length and steepness factor. Generally, both factors are considered as a united form. C is a vegetation factor P is the conservation support practice factor. All these governing factors are essential to quantify the soil erosion. In the present study, the average annual soil loss was estimated on the10m×10m cells by overlaying the five digital thematic layers (R, K, LS, C, P) in raster format using ArcGIS software.

### Development of Model Database for RUSLE

Using the established methodology, the factors of RUSLE were determined over the study area and represented spatially as shown in the Figures 2-6.

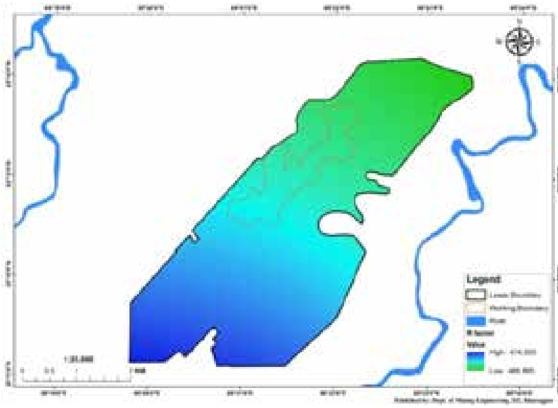


Figure 2 - Rainfall-runoff erosivity (R) factor

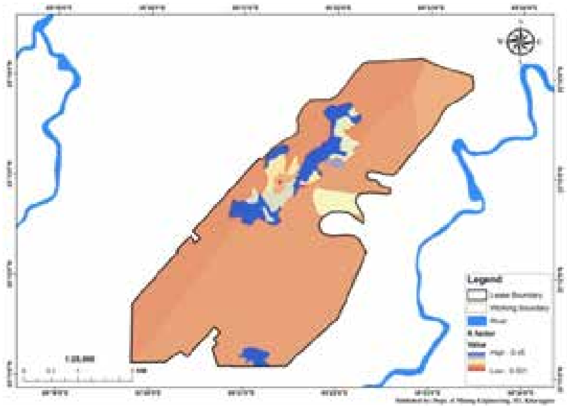


Figure 3 - Soil erodibility (K) factor

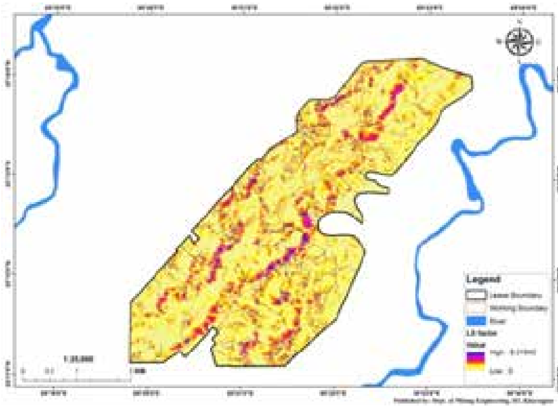


Figure 4 - Slope length and slope steepness (LS) factor

Figure 5 - land use and land cover management (C) factor

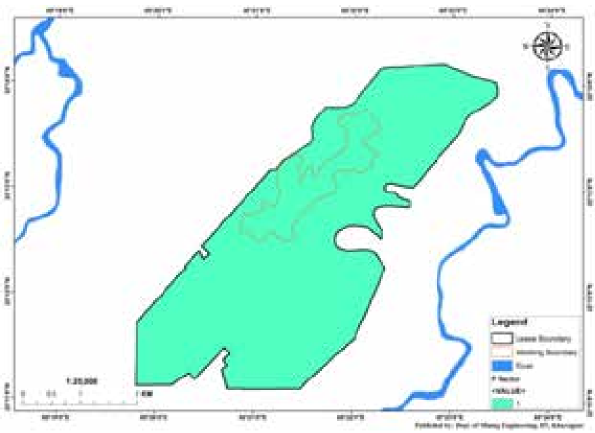


Figure 6 - Conservation practice (P) factor

## RESULTS AND DISCUSSION

### Average Annual Soil Loss

The results of soil loss estimation as per the RUSLE reveal that erosion-risk wise the entire leasehold area can be classified into three categories: low, moderate and high, which are >5 t/ha/yr, 5-56 t/ha/yr, and <56 t/ha/yr, respectively. The area with vegetation cover lie within the low erosion risk zone,whereas, working boundary and mineral stockyard areas are in moderate to high erosion risk zone (Figure 7).

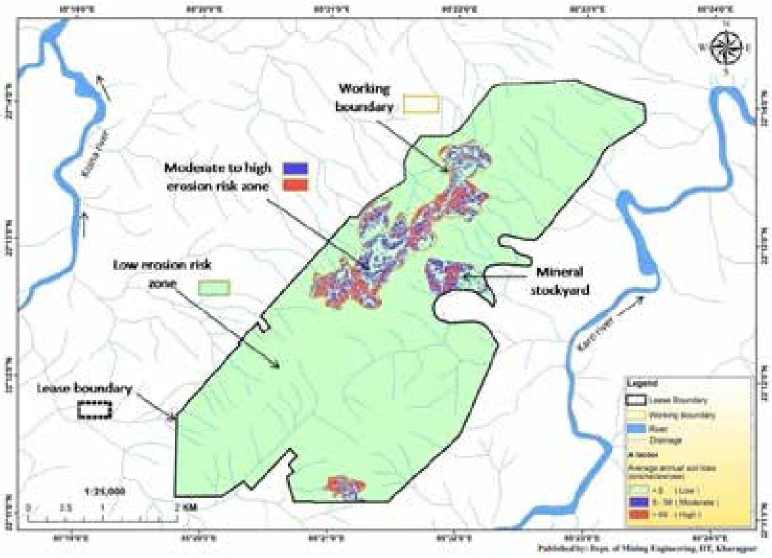



Figure 7 - Soil erosion map

Though working boundary shows moderate to high erosion risk zone, every part of the boundary is not vulnerable to erosion and sediment transportation.This is because mining is a sequential process, land gets excavated bench by bench with a periodicity of site degrading operations.The permanent loose and unconsolidated rock mass like waste dump (Ranichua, Bai hill, & OT hill waste dump) and mineral stockyard are more sensitive for accelerated erosion and sediment transportation (Figure 8).


Figure 8 - Erosion and silt migration sensitive areas of Gua mine (source: Google earth)

In the rainy season, rills and gullies formed on the waste dump and mineral stockyard carry the huge amount of silt and eventually deposited in the bank of Karo and Koina river. Therefore, construction of erosion control structures are necessary across the major streams which feed silt from mine to adjacent river. However, the location of such construction is to be done with careful consideration of the site topography.

**Silt migration through micro-watersheds**

It is observed that Karo and Koina rivers are flowing northward direction from the Saranda forest. To identify the silt migration paths, micro-watershed classification is done using Strahler stream ordering method (1952). Study area shows $1^{st}$ to $6^{th}$ order drainages, indicating a dendritic drainage pattern with a high drainage density, which liable to migrate a huge amount of silt. It was revealed that there are 11 micro watersheds which occupied 8282 hectares of land which are directly or indirectly connected (through drainage network) to the mine and carry the silt towards the rivers (Figure 9).

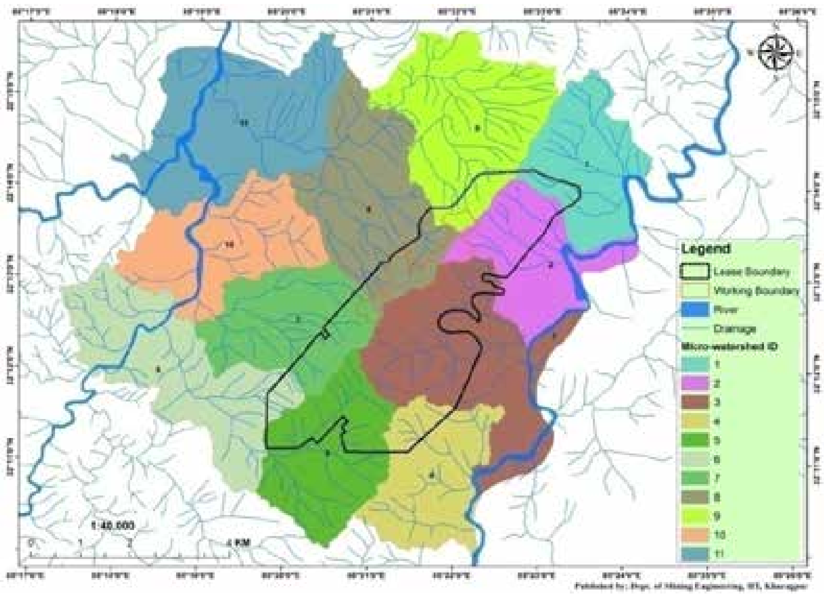



Figure 9 – Micro-watersheds connected to the Gua mine

**Recommended Erosion Control Structures**

On the basis of surface hydrology, GIS-RUSLE outputs, and field survey during 2014-15, suitable erosion control structures and locations were determined. A mineral stockyard covering 16ha of land and three active waste dumps (Ranichua, Bai hill, and OT hill covering8ha, 2ha, and 4ha of land respectively Gua mine-sites) are the prime sources of silt migration towards the rivers. Suitable and sustainable erosion control planning is required for protection of adjacent watersheds. Table1 shows the control measures and recommended structures, site justification and example of implementation of the same.

There are 12 erosion control structures were recommended at Gua mines. Out of 12, one check dam and five traps have already been constructed (Figure 10). However, work is progressive and remaining structures will be constructed in the coming years.

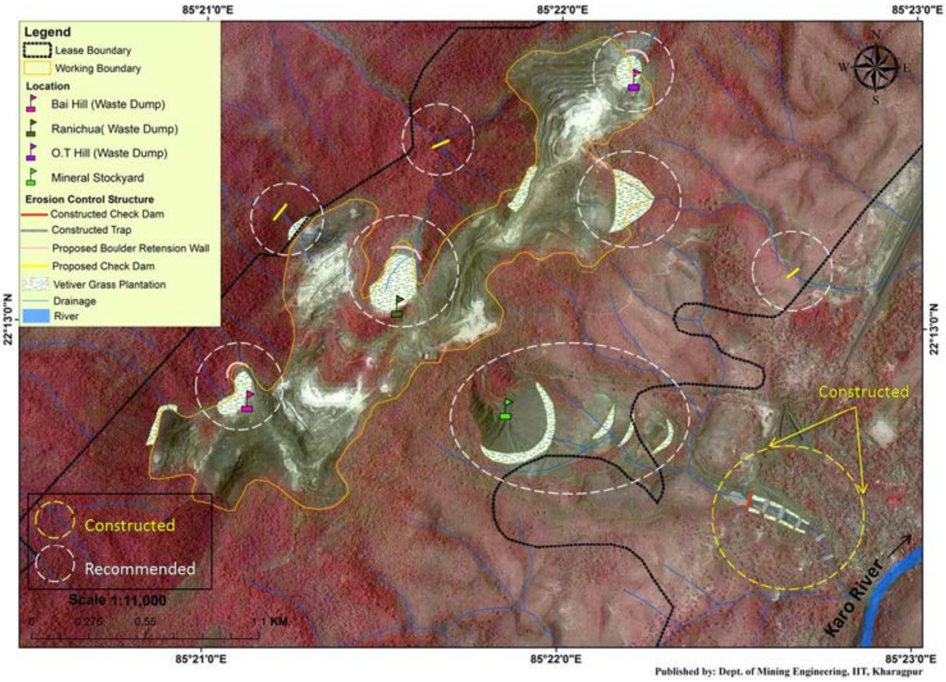
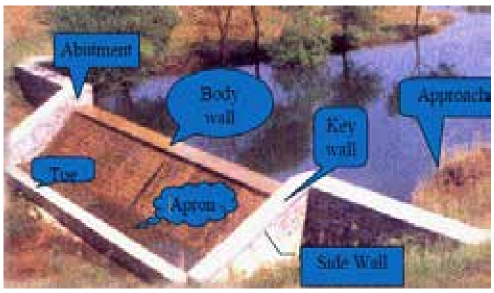



Figure 10 – Recommendederosion control structures at Gua mine

**Table 1**–Recommended structure and site justification

| Sr. No. | Recommended erosion control structure | Site justification & description of the structure | Example |
|---|---|---|---|
| 1 | Check Dam | **Justification:** For those sites covered a large catchment area with a high drainage density and high runoff. Catchment area lies in moderate to high erosion risk zone. Mining is progressive on the top hill. Recommended on second order and higher order drainages where the slope is gradually decreasing towards the downstream. Suggested, wherever the high siltation rate and required enough storage capacity with good strength. **Description:** A small temporary or permanent dam constructed across the small channel in order to break the runoff and promote the sedimentation. Recommended dam construction material: boulders, bricks, iron rod and cement-concrete makes the structure more sustainable. |   |

2 Boulder Retention Wall

**Justification:** Recommended on waste dumps. It is normally constructed at the bottom of a waste dump. Considered to be a type of retaining wall to restrict the soil, mass movement or any kind of gravitational movement of the dump material.

**Description:**A structure designed to restrain loose and unconsolidated soil to unatural slopes. Retention wall holds the soil behind it. Recommended construction material: Boulders and cement-concrete. Sometimes it also built up by the loose boulders with iron-wire-net fencing for strengthening.

3 Trap pond

**Justification:** Recommended at just after the constructed check dam (example 1) where flow velocity gets decreased at downstream. Suggested more than 2 or 3 structures back to back with a regular interval that reduces flow velocity. To collect the suspended fine particles from overflow spill.

**Description:**Sediment trap or trap pond is shallow excavated pit to collect the sediments from the low-velocity runoff. In some types, overflow spills out through a pipe or small drainage ditch. Suspended particles get to settle down through this way.

4 Vetiver Grass plantation

**Justification:** Vetiver plantation recommended at waste dump locations, plant tolerates with heavy metals such as arsenic, cadmium, copper, chromium, lead, mercury, nickel, selenium and zinc. Plantation controls the erosion and increases the slope stability at the waste dumps. Plantation suggested in parts of exposed bare soil and barren land. Channel side plantation reduces the channel erosion and retains the sudden mass movement.

**Description:** Vetiver grass is a dense, bundle-type grass with rigid stem and extremely strong root system which penetrates up to 4.6 m deep in sub-surface and grows to the height of over 2 m above the surface. It has a tremendous ability to sustain and grow in all continents in the tropical and subtropical regions, bears a high range of soil pH and low fertility.

**Expected Quantity of Silt Capture**

A silt capture capacity of the control structure depends on the design capacity of the structure (volume in $m^3$), a hydrological catchment area of the structure (which feed the silt), soil erosion(t/ha/yr) due to rainfall (in/yr) and runoff ($m^3$/yr).

The catchment areas served by the erosion control structures were derived from the micro-watershed map and referred to as sub-micro-watersheds (Figure 11). The sub-micro-watersheds were overlaid on the erosion map and GIS tool was used to determine their intersection. In this way, erosion within sub-micro-watershed was extracted and calculated separately.

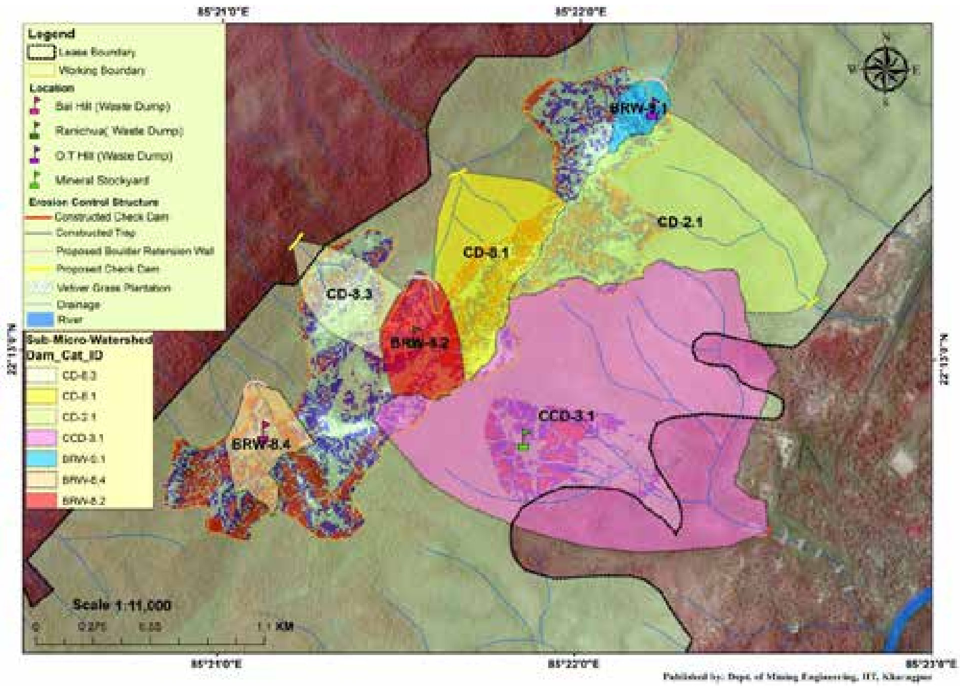



Figure 11 – Sub-micro-watershed map

A study area receives average 1200mm (47 in) of rainfall per year, rainy season lies between June to September. To calculate the average runoff volume of sub-micro-watersheds, 30 years daily rainfall data collected from Indian Meteorological Department, Pune, India. Furthermore, using "Natural Resources

Conservation Service" (NRCS), curve number method (Equation 4), calculated daily runoff of each sub-micro-watersheds.

$$Q = \frac{(P-0.2\,S)^2}{(P+0.8\,S)} \quad (4)$$

where, Q is a runoff, P is rainfall, S is the potential of maximum retention of the soil. It is the most widely used technique for estimating surface runoff volume for a given amount of rainfall from small catchments.Generally, it expressed in acre-feet. Essential soil parameters were also measured in the laboratory (permeability, bulk density, organic matter etc.), a bulk density of the soil is 1.5 g/cm$^3$.

Though sub-micro-watersheds are considered water erosion, the total eroded soil from this area can not reach the check dam. The main reason is a certain amount of soil deposits within transportation pathways on the terrain. Also, some part of eroded soil gets dissolved and suspended in water flow. An assumption is made that 30% of eroded soil does not reach the check dam (basis of 2009 to 2013, available siltation data of the constructed check dam, Gua mine). On the basis of above information, an expected quantity of silt migration from each sub-micro-watershed is given in Table 2. A check dam capacity was recommended for three years sedimentation period because the future mining activity will disturb the hectares of land and generate a huge waste dump that affects the siltation rate.

**Table 2**– Expected quantity of silt capture from Sub-micro-watersheds

| Sr. No. | Sub-micro-watershed ID | Sub-micro-watershed Area (ha) | Runoff (acre-feet) | Average runoff volume (m$^3$/yr) | Total soil erosion (t/yr) | Expected quantity of silt capture (m$^3$/yr) | Capacity of check dam / Retention wall (m$^3$) | Remark |
|---|---|---|---|---|---|---|---|---|
| 1 | CCD-3.1 | 183 | 414.343 | 511083 | 116 | 54 | 1500 | Constructed |
| 2 | CD-8.3 | 17 | 38.491 | 47478 | 61 | 28 | 500 | Recommended |
| 3 | CD-8.1 | 36 | 81.510 | 100541 | 165 | 77 | 500 | Recommended |
| 4 | CD-2.1 | 78 | 176.605 | 217839 | 132 | 62 | 500 | Recommended |
| 5 | BRW-9.1 | 6 | 13.585 | 16757 | 43 | 20 | 200 | Recommended |
| 6 | BRW-8.4 | 15 | 33.963 | 41892 | 54 | 25 | 200 | Recommended |
| 7 | BRW-8.2 | 18 | 40.755 | 50270 | 80 | 37 | 200 | Recommended |

**Silt Removal Planning**

As per the expected quantity of siltation, an appropriate silt removal plan is suggested. Also suggested, site supervision and maintenance (if required) should be done before the monsoon (every year). If construction will be completed in the same year (up to Dec-2016), a silt removal plan suggested in Table 3. If any delay, then silt removal planning will be altered (silt removal, consider after three years from the construction of the check dam / retention wall).

**Table 3** – Suggested silt removal planning (If structures will be installed before Dec. 2016)

| Sr. No. | Location | Micro-watershed ID | Sub-micro-watershed ID | Recommended erosion control structures | Silt removal period (Before monsoon) |
|---|---|---|---|---|---|
| 1 | Bai hill waste dump | 7 | BRW-8.4 | Boulder Retention Wall | In between April to May 2020 |
| 2 | Ranichua waste dump | 8 | BRW-8.2 | Boulder Retention Wall | In between April to May 2020 |
| 3 | Ranichua waste dump | 8 | CD-8.3 | Check Dam | In between March to May 2020 |
| 4 | Ranichua waste dump | 8 | CD-8.1 | Check Dam | In between March to May 2020 |
| 5 | OT waste dump | 1 | BRW-9.1 | Boulder Retention Wall | April-May 2020 |
| 6 | OT waste dump | 2 | CD-2.1 | Check Dam | In between March to May 2020 |
| 7 | Mineral stockyard | 3 | CCD-3.1 | Check Dam (Constructed in 2008) | In between March to May 2020 |
| 8 | Mineral stockyard | 3 | CCD-3.1 | Trap (Constructed in 2010) | In between April to May 2020 |
| 9 | Mineral stockyard | 3 | CCD-3.1 | Trap (Constructed in 2010) | In between April to May 2020 |
| 10 | Mineral stockyard | 3 | CCD-3.1 | Trap (Constructed in 2010) | In between April to May 2020 |
| 11 | Mineral stockyard | 3 | CCD-3.1 | Trap (Constructed in 2010) | In between April to May 2020 |
| 12 | Mineral stockyard | 3 | CCD-3.1 | Trap (Constructed in 2010) | In between April to May 2020 |
| 13 | Bai hill, Ranichua, and OT hill west dump, Bottom of mineral stockyard | 2, 3, 7, 8, 9 | DC-8.4, CD-8.1, CD-2.1, CCD-3.1, BRW-8.2, BRW-9.1 | Vetiver Grass plantation<br>A suitable period for plantation is rainy season or spring (June to Dec.) | — |

## CONCLUSION

A scientific basis for determination of locations of erosion control structures like check dam, retention wall etc. and estimation of their required sizes were developed in this study. The established methodology of spatial analysis of terrain and RUSLE that are used in agricultural fields were adopted for hilly mining terrain to develop a practical approach for catchment area treatment near hilltop mining. The proposed method (GIS integrated RUSLE model) was used for assessment of soil erosion from a hilltop iron ore mines in India.The methodology described above could assess the soil erosion, identify the most erosion prone areas and prescribe appropriate measures to protect the adjacent rivers. The study established the strong relationship between mining activity, vegetation cover, and erosion. A vegetated land indicated low erosion risk. Whereas, excavated land, mineral stockyard and waste dumps are under high to moderate erosion risk zone. Thus, it is recommended that systematic vegetation planning and development must be practiced to control the accelerated erosion from mining region as a part of environmental sustainability.

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# BIOFACTORY, THE NEW RESOURCE TECNOLOGY FOR THE PRESERVATION OF THE FLORA BIODIVERSITY IN IRON MINING

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# BIOFACTORY FOR PRESERVATION OF THE FLORA BIODIVERSITY IN IRON MINING AREAS

## ABSTRACT

The plants formations the formation of plants are associated with the most important iron mining areas of Brazil, in many situations, are presented as unique communities because of geoecology peculiarities, resulting in high endemism, rarity and specificity. The licensing of mining enterprises depends on the technical efficiency proven to mitigate impacts of this flora. In 2015 the Vale implemented the first biofactory of the world, focused exclusively in the preservation of flora biodiversity in iron mining. Using biotechnology to obtain native species of flora on a large scale under a significantly reduced cost, especially those that are endangered and who have difficulty propagation by traditional means. In the first year it was possible to obtain plants of 550,000, comprising 88 different species of 21 botanicals families. One of the highlighted species is the *Hoffmannseggella milleri*, a native orchid in superficial iron crusts, once considered extinct in the wild by the scientific community as a result of iron mining. And from individuals rediscovered in 2014 in preserved areas of the company were obtained 15,000 seedlings with high genetic diversity through seed germination *in vitro*, collected from mother plants in the field. In contrast to the conventional method was used, which is the division of clumps, as well as obtaining only a few dozen new plants, also the collection of these plants would be necessary in their habitats, the total cost would be changed of 2.5 times by plant. The production of native flora plants in biofactories opens up new perspectives, such as the ability of reproduction of species never before propagated by conventional means, the significant increase in the production capacity of the production units of plants, reducing costs, and, especially, increase chance of future generations have access to plants genetics resources.

## KEYWORDS

Biofactory of native plants, licensing of mining enterprises, mitigate impacts of this flora, reducing costs, mining sustainability

## INTRODUCTION

The Iron Quadrangle, in Brazil, is one of the main extractors regions of iron ore of the world (Rosière & Chemale, 2000), and is also known for its importance in gold, topaz and emerald (Roeser & Roeser, 2013).

It occupies an area of about 7,000 km$^2$ (Dorr, 1969), and is in transition between two brazilian biomes, and hotspots, the Cerrado (Brazilian Savanna) and Atlantic Forest.

It integrates diverse backgrounds vegetables, such as fields rocks, savannas and forests, consisting also one of the main regions of high floristic diversity of South America (Giulietti et al, 1997), notable for its high degree of endemism (~ 30 %), threatened, rare, and of potential ornamental and medicinal uses (Jacobi & Carmo, 2008).

In this scenario, the pressure to impact as little as possible and mitigate the impacts of the best way, has been the technical impositions licensing of mining projects in the region. Another point is the need to reduce costs scenario that the industry has been seeking.

Thus arose the Biofactory of Native Seedling Production Center Vale S/A, founded in 2015 is the first in the world focused solely on conservation of flora biodiversity impacted by mining.

## METHODS

Work on biofactory is all developed *in vitro* environment by using techniques of plant micropropagation.

**Stages of work in Biofactory Production Center Seedlings of the Vale S/A:**

1) Obtaining propagules: propagules to be inoculated *in vitro* environment are in seeds, or any kind of organs fragments, such as leaves and cotyledons. The species are chosen according to some specialty feature, such as demand for production of large quantities of seedlings, rarity and difficulty of multiplication by conventional routes;

2) Preparation of culture medium: usually species little studied because of its low value economic, thereby are tested various formulations of culture media contend different concentrations of salts and hormones, in order to arrive at a streamlined protocol for each species;

3) Sterilization of the culture medium: can be done either in at high pressure and temperature (121 °C, 1 atm, 20 minutes), or by chemical way (NaOCl) or gaseous (NaOCl + HCl);

4) Inoculation (or establishment) of propagules *in vitro* environment: the seedlings are disinfected, or have all their microbials, internal and external load, eliminated by means of disinfectants solutions and consequent are applied on the culture media;

5) Growth of seedlings: occurs in light intensity, photoperiod and temperature controlled room environment;

6) Seedlings acclimatization *ex vitro* environment: the final stage, the seedlings are transferred to trays with unit cells, and appropriate substrates, with strict humidity control to not wilt stresses.

## RESULTS

In 10 months of driving biofactory, they were inoculated and are developing around 1,056,023 seedlings, some of them already in the final stage *in vitro* development and elsewhere in *ex vitro* acclimatization.

These seedlings are distributed in 21 different botanical families, and 88 species and are presented in Table 1.

The estimated cost of seedling production in biofactory is about 2.5 times lower compared to conventional methods.

## DISCUSSION

It is noteworthy that many of the species worked so far are threatened with extinction, and still little studied in terms of the development micropropagation protocols, and yet the plant micropropagation in biofactory has proven feasible for mass production species affected by mining.

The technology opens up a new perspective of sustainability, it brings with it quande production capacity quantity of seedlings in a short space of time, at a very low cost, about 40 % of the final cost of the changes obtained by conventional routes (internal datas the company) and, especially, increasing the chances of future generations to have access to these genetic materials.

A good example is the orchid *Hoffmannseggella milleri*, which was already considered extinct by the scientific community because of mining activity (Mota et al., 2012), but was recently rediscovered in preserved areas of the company, and has been micropropagated in biofactory taking an estimated yield of 20 thousand seedlings between the years 2015 and 2016. Some of these seedlings are already in vitro acclimation outside the environment, a stage prior to reintroduction habitats.

The next challenges consist in increasing the number of species to be multiplied by means of new protocols, and refinement of protocols for in vitro multiplication of some species, in addition to the acclimatization of seedlings and management until the reintroduction and the establishment in the field.

**Table 1- Species and botanicals family in work in biofábrica Vale S/A.**

| Specie | Family |
|---|---|
| *Caryocar brasiliense* | *Caryocaraceae* |
| *Schinus terebinthifolius* | *Anacardiaceae* |
| *Guatteria nigrescens* | *Annonaceae* |
| *Anthurium scandens* | *Araceae* |
| *Baccharis dracunculifolia* | *Asteraceae* |
| *Eremanthus erythropappus* | *Asteraceae* |
| *Eremanthus incanus* | *Asteraceae* |
| *Helichrysum bracteatum* | *Asteraceae* |
| *Lychnophora pinaster* | *Asteraceae* |
| *Aechemea bromelifolia* | *Bromeliaceae* |
| *Billbergia elegans* | *Bromeliaceae* |
| *Billbergia porteana* | *Bromeliaceae* |
| *Aechemea sp.* | *Bromeliaceae* |
| *Arthrocereus glaziovii* | *Cactaceae* |
| *Clusea sp.* | *Clusaceae* |
| *Stephanopodium engleri* | *Dichapetalaceae* |
| *Pepalantus sp.* | *Eriocaulaceae* |
| *Dalbergia nigra* | *Fabaceae* |
| *Mimosa calodendron* | *Fabaceae* |
| *Sinningia sp.* | *Gesneriaceae* |
| *Ocotea sp.* | *Lauraceae* |
| *Ocotea odorifera* | *Lauraceae* |
| *Marattia cicutifolia* | *Marattiaceae* |
| *Clidemia hirta (Pixirica)* | *Melastomataceae* |
| *Miconia sp. (pixiricão)* | *Melastomataceae* |
| *Myrciaria cauliflora* | *Mirtaceae* |
| *Eugenia uniflora* | *Myrtaceae* |
| *Acianthera prolifera* | *Orchidaceae* |
| *Acianthera teres* | *Orchidaceae* |
| *Alatioglossum cf. ciliatum* | *Orchidaceae* |
| *Anacheilium cf. allemanii* | *Orchidaceae* |
| *Anathallis aff. sclerophylla* | *Orchidaceae* |
| *Bifrenaria harrisoniae* | *Orchidaceae* |
| *Brasilidium crispum* | *Orchidaceae* |
| *Brasilidium marshalianum* | *Orchidaceae* |
| *Bulbophyllum weddellii* | *Orchidaceae* |
| *Capanemia theresiae* | *Orchidaceae* |
| *Carenidium gracile* | *Orchidaceae* |
| *Catasetum cf. hookeri* | *Orchidaceae* |
| *Cattleya bicolor* | *Orchidaceae* |
| *Cattleya loddigesii* | *Orchidaceae* |
| *Cattleya walkeriana Gardner* | *Orchidaceae* |
| *Christensonella acicularis* | *Orchidaceae* |
| *Cleistes machrantha* | *Orchidaceae* |
| *Coppensia blanchetti* | *Orchidaceae* |
| *Coppensia warmingii* | *Orchidaceae* |
| *Cyrtopodium eugenii* | *Orchidaceae* |
| *Encyclia patens* | *Orchidaceae* |
| *Epidendrum campestre* | *Orchidaceae* |
| *Epidendrum valenteanum* | *Orchidaceae* |
| *Epidendrum floribundum* | *Orchidaceae* |
| *Epidendrum saxatile* | *Orchidaceae* |
| *Epidendrum secundum* | *Orchidaceae* |
| *Epidendrum sp.* | *Orchidaceae* |
| *Galeandra cf. montana* | *Orchidaceae* |
| *Gomesa crispa* | *Orchidaceae* |
| *Grobya cf. amherstiae* | *Orchidaceae* |
| *Hadrolaelia pumila* | *Orchidaceae* |
| *Heterotaxis brasiliensis* | *Orchidaceae* |
| *Hoffmannseggella caulescens* | *Orchidaceae* |
| *Hoffmannseggella crispata* | *Orchidaceae* |
| *Hoffmannseggella liliputana* | *Orchidaceae* |
| *Hoffmannseggella milleri* | *Orchidaceae* |
| *Hoffmannseggella kleberii* | *Orchidaceae* |
| *Hoffmannseggella regentii* | *Orchidaceae* |
| *Hoffmannseggella rupestris* | *Orchidaceae* |
| *Hoffmannseggella sanguiloba* | *Orchidaceae* |
| *Ionopsis utricularioides* | *Orchidaceae* |
| *Lophiaris pumila* | *Orchidaceae* |
| *Polystachya concreta* | *Orchidaceae* |
| *Prosthechea pochysepala* | *Orchidaceae* |
| *Pseudolaelia vellozicola* | *Orchidaceae* |
| *Schomburgkia crispa* | *Orchidaceae* |
| *Sophronitis cernua* | *Orchidaceae* |
| *Stanhopea lietzei* | *Orchidaceae* |
| *Zycopetalum cf. maculatum* | *Orchidaceae* |
| *Peperomia cf. hoffmannii* | *Piperaceae* |
| *Andropogon bicornis* | *Poaceae* |
| *Andropogon cf.lateralis* | *Poaceae* |
| *Andropogon cf.leucostachyus* | *Poaceae* |
| *Aristida recurvata* | *Poaceae* |
| *Echinolaena inflexa* | *Poaceae* |
| *Paspalum carinatum* | *Poaceae* |
| *Setaria parviflora* | *Poaceae* |
| *Pilocarpus microphyllus* | *Rutaceae* |
| *Vellozia compacta* | *Velloziaceae* |
| *Vellozia sp.2* | *Velloziaceae* |
| *Vellozia sp.3* | *Velloziaceae* |
| **88** | **21** |

## CONCLUSIONS

The micropropagation is technically and economically important and viable for preservation of the biodiversity of flora, contributing to the sustainable development of mining activities.

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# BRAZILIAN, AUSTRALIAN AND CANADIAN MINING AND ENVIRONMENTAL LEGISLATION AND APPROVALS PROCESSES – A HIGH-LEVEL REVIEW FOR IRON ORE MINING OPERATIONS

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# BRAZILIAN, AUSTRALIAN AND CANADIAN MINING AND ENVIRONMENTAL LEGISLATION AND APPROVALS PROCESSES – A HIGH-LEVEL REVIEW FOR IRON ORE MINING OPERATIONS


## ABSTRACT

This paper presents an overview of the main federal, state and provincial mineral and environmental current legislation and licensing, in Western Australia and Canada, relevant to the iron ore industry, making up a comparative analysis with Brazil. It was developed as a high-level schematic 'road map' to identify the main steps required to apply for and obtain approval to construct, operate and close an iron ore mining operation. Part of this includes identification of the main regulatory authorities; major stages involved throughout the approvals processes; main licenses / permits / approvals to be obtained; mandatory stakeholder engagement requirements and the statutory time frames incurred at each main step. Workflows were developed for the three main phases of the whole entrepreneurship life-cycle (prospecting and exploration, mine development and operations and mine closure). These analogous regulatory models are intended to provide a tool for systematic comparison between the Brazilian, Australian and Canadian regulatory framework. The expected benefit from this is to identify opportunities for streamlining the existing approvals process through the provision of an alternate approach to policy development and regulation, providing transparent expectations of and for industry with definitive timeframes which, it is believed would in turn encourage economic investment in the country.



## KEYWORDS

Environmental legislation, Mining approval processes and Iron ore.


## INTRODUCTION

Brazilian mining and environmental policy is complex, often conflicting among the various interfaces and often slow in license approval procedures, which discourages mineral projects in Brazil.

Australia and Canada have similar mineral vocation and environmental challenges to Brazil, and are internationally recognized for their more integrated social and environmental legislative environment and relative efficiency in their approval of mining projects processes.

This study is a technical review of minerals and environmental legislation, including Australia, Canada and Brazil, with emphasis on iron ore projects.

In Australia, 95% of iron ore is located in Western Australia with the majority of iron ore production coming from the Pilbara region, although a number of active mines are located in the mid-west, Kimberley and Wheatbelt.

In Canada iron ore mining is centered in the two provinces of Québec and Newfoundland & Labrador in the prolific Labrador Trough mineral belt. There are currently numerous iron ore projects in various states of advanced exploration, engineering and development in the Labrador trough. Also there is one new iron ore project underdevelopment on Baffin Island in the Territory of Nunavut but at present the only producing provinces are Québec and Newfoundland & Labrador.

In Brazil these resources are sourced predominantly from Serra dos Carajás, Espinhaço Ridge and the State of Bahia.

**OBJECTIVE**

An overview of the main federal, state (Australia) and provincial (Canada) legislation relevant to the mining and environmental licensing of iron ore mining with a comparative analysis with Brazil.

In order to facilitate the study of the approval processes, a workflow was developed for the three main phases of a mining project: (I) Prospecting and exploration; (II) Mining development and operations and (III) Mine closure.

**AUSTRALIA (WESTERN AUSTRALIA)**

Australian laws, in general, are complex due to the interplay between the federal government and the states. The *Environmental Protection Act* is administered by the Western Australian Department of Environment and Conservation (DEC) and the Office of the Environmental Protection Authority (EPA), while the *Mining Act* is administered by the Department of Mines and Petroleum (DMP).

In addition to the assessment of proposed activities under state legislation, should the proposed works impact on matters of national environmental significance, the mining proposal would also require assessment under the federal Environmental Protection Biodiversity Conservation (EPBC) through a bilateral agreement between the state and the Federal Government.

Additional approvals may also be required under other environmental, planning, heritage and water legislation. A common feature of the environmental approvals processes is that proponent is required to consulted all relevant stakeholders for the project and demonstrate this through the maintenance of a stakeholder register.

There is recognition in the Western Australian mining industry that the environmental approvals process although comprehensive, can be improved. The intent of the ongoing reform is to reduce the cost and complexity and length of the assessment process.

**Phase I – Prospecting and Exploration**

The Western Australian *Mining Act* provides several types of tenures that may be applied for prospecting, exploration, retention and miscellaneous leases, and mining and general purpose leases. Authorisation from the Minister for Mines and Petroleum is required for iron ore (and numerous other commodities) exploration activities.

Prospecting is considered to be a short term, transient activity which should not result in a lasting impact to the environment. The maximum area for a prospecting license is 200 hectares and there is no limit to the number of prospecting licenses that a company may hold. The term of the license is four years with the provision to extend for another four years.

Exploration licenses are granted for a period of five years. This period can be extended by DMP in prescribed circumstances. While there is no limit to the number of exploration licenses a proponent can hold, a financial security (bond) is required for each license, and rental is payable for each license.

After securing a license but before undertaking any ground disturbing activities on a tenement, the *Mining Act* requires that a Programme of Work (POW) be submitted and approved by the Minister (or a prescribed official).

The Programme of Work on its approval (for prospecting or exploration) then becomes a legally binding document and is often imposed as a lease condition. This approval is valid for a period of 12 months unless an extension is granted.

To ensure the continuity of the assessment process a Memorandum of Understanding (MOU) exists between the two agencies (EPA and DMP) that are responsible for criteria that trigger referral of the Programme of Works for assessment under the *Environmental Protection Act.* If none of the criteria are relevant to the proposed activity, assessment will continue solely under the *Mining Act*.

In an effort to reduce duplication of assessment processes, the Australian Government has established bilateral agreements with all state and territory governments. This allows some proposals containing impacts on matters of national significance to be assessed by the relevant state/territory on behalf of the Commonwealth, with the proponent subsequently receiving approval from both state/territory and Australian government ministers.

Considering the accumulate timing for approvals processes to prospecting and exploration, minimum timeline is estimated in 6,5 months, with maximum timeline of 8,5 months (Figure 1).

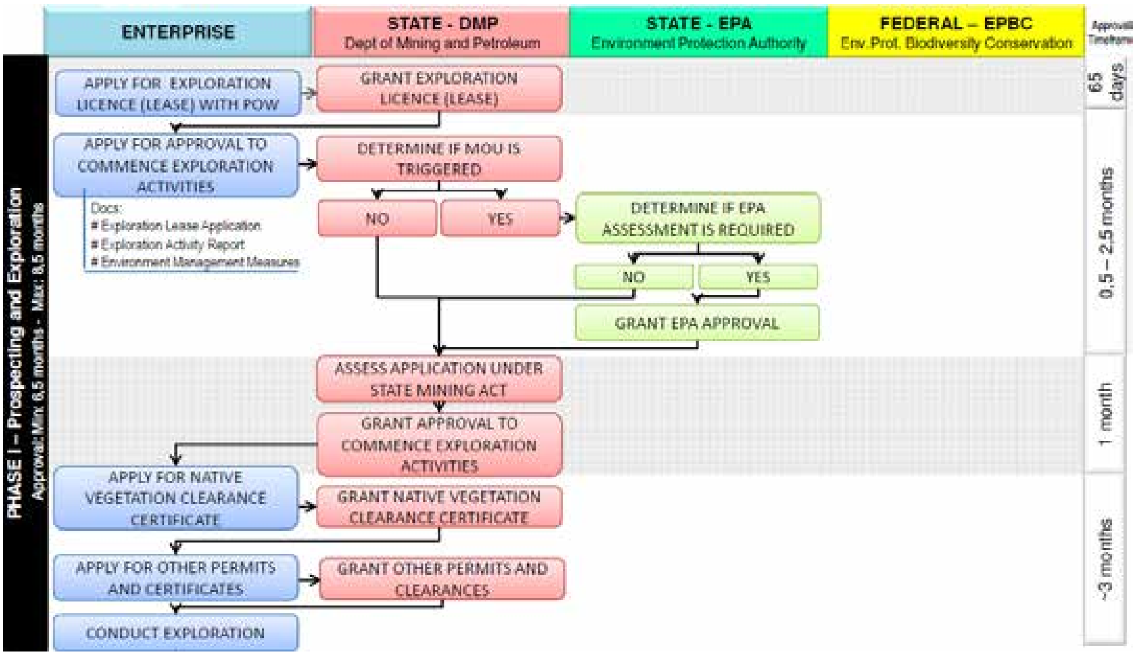


Figure 1 – Approval processes with deadlines and agencies involved in the prospection and exploration phase in Western Australia

**Phase II - Mine Development and Operations**

The Western Australian state *Mining Act* gives the holder of an exploration tenement an automatic right to apply for, and have granted, a mining lease, or mining leases, within the area of that exploration tenement. The term of a mining lease is 21 years, and it may be renewed for further terms.

An application for a mining lease to DMP, accompanied by a Mining Proposal and Mineralization Report is lodged with the Mining Register and the application details are advertised publicly. Prior to granting it must also be advertised in accordance with the federal *Native Title Act 1993.* There is no limit to the number of mining leases that a proponent can hold, and a rental is payable for the lease.

The nature of the tenure type may influence the approval process. These have be broadly classified into three groups: Public land belongs to the Crown; Private land can be freehold land or Crown leasehold land, and Aboriginal land may be freehold, leasehold or Crown reserve.

If activities are likely to impact on sites and/or objects of significance to persons of Aboriginal descent, the consent of the Minister for Indigenous Affairs is required to disturb the site.

It is required financial surety in the form of an environmental performance bond on mining tenements to ensure adequate financial provision is made for rehabilitation of the lease at the end of mining. These bonds are routinely applied when a Mining Proposal is considered for a mining lease.

The Mining Proposal must also include a Mine Closure Plan that has been prepared in accordance with *Guidelines for Preparing Mine Closure Plans* issued by the state.

If the Mining Proposal triggers any of the criteria under the Memorandum of Understanding (MOU) formal assessment is required under the Environmental Protection Act. Where assessment is required, it will occur at one of three levels: An Assessment on Proponent Information (API); A Public Environmental Review (PER); A Strategic Proposal. APIs and PERs are the most common assessment processes for an iron ore mine.

In order to operate on the site there are a number of other environmental approvals or permits. Two key approvals include the requirement to obtain a native vegetation clearing permit and works approvals for prescribed premises before any construction commences. An operating license is also required before the prescribed premises can legally have production on it.

Common prescribed premises on mining sites include processing plants, de-watering discharges, tailing facilities, process ponds, crushing and screening facilities, waste water treatment plants and landfills associated with accommodation camps, and other aspects of the mining operation with the potential to pollute. The works approval application can be submitted after ground disturbance (pre-stripping) has commenced.

The *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) is the Australian Government's central piece of environmental legislation State Agreement Acts have been used in Western Australia for large projects involving one (or more) iron ore mines, related processing, construction and operation of a railway to transport the ore and/or construction and operation of a port.

Agreements have two broad phases of approval: the first is the negotiation and execution of the agreement and its ratification by parliament, and the second is the approval of development proposals, around which the agreement is written.

The Minister cannot approve proposals until all primary approvals have been finalized, such as environmental approval, native title agreements and heritage clearances.

Considering the accumulate timing for approvals processes to mining development and operations, specifically for mining development minimum timeline is estimated in 9 months, with maximum timeline of 39 months. Specifically for the operations (mine and mill), minimum of 13 months and maximum timeline of 42 months (Figure 2).

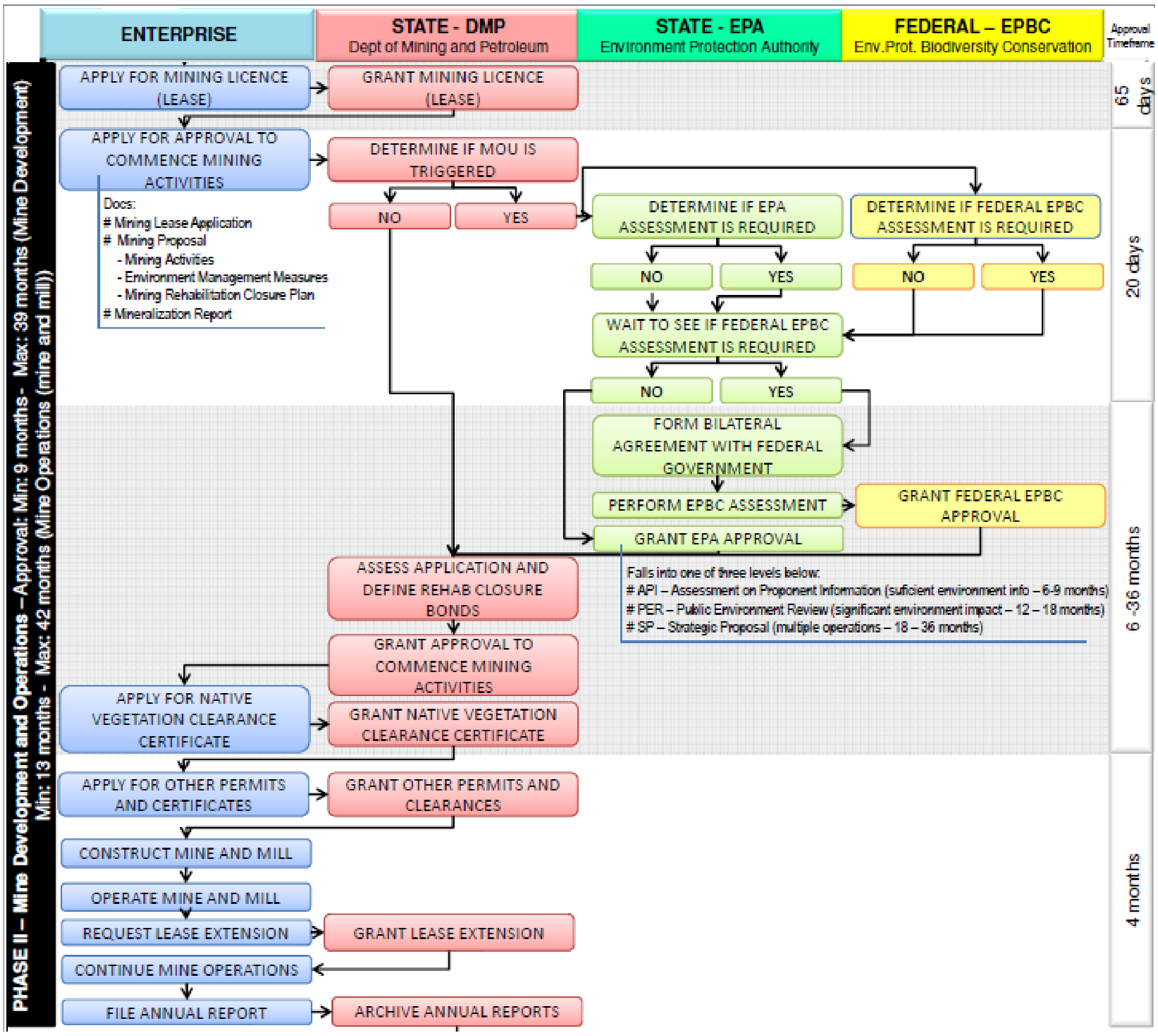


Figure 2 – Approval processes with deadlines and agencies involved in the mine development and operations phase in Western Australia

**Phase III - Mine Closure**

The mine operator is required to submit a Mine Closure Plan to the state DPM for approval with each new Mining Proposal application or when changes are made to an existing approved Mining Proposal. Over the life of the mining project the operator is required to demonstrate that the Mine Closure Plan is being implemented.

The approved mine closure plan must be reviewed regularly over the life of a mine and is required to be submitted for approval every three years (or a time specified by the Minister).

In the event of unexpected closure, there is a requirement for the closure process to be accelerated. The Mine Closure Plan will be immediate revised to include a detailed Decommissioning Plan within three months of notification to the DMP or at a time a specified a by the department.

If a temporary closure is imminent, a detailed Care and Maintenance Plan must be prepared, based on the existing Mine Closure Plan, and submitted within three months of its notification to the Department of Mines and Petroleum or at a time a specified a by the department. The Care and Maintenance Plan must demonstrate that on-going environmental obligations will be met during this period.

The tenement holder may retain liability for environmental impacts caused by the project after the tenement has been relinquished. Appropriate investigations has to be carried out to identify, assess and manage any contamination issue.

A 'Closure Notice' may be issued to require monitoring, reporting and active management of a decommissioned facility after a license has ceased to have effect.

The Western Australian Government, through the DMP, requires the payment of environmental bonds for various activities that may be undertaken during exploration and mining activities. Such bond are payable before the approval of Programmes of Works or Mining Proposals.

Bonds will only be retired when the rehabilitation has met all completion criteria and standards set out in approval documents, annual environmental reports and decommissioning plans. Bonds will not be retired until the DMP is satisfied that the rehabilitated area is safe, stable, erosion is comparable to the surrounding areas and that the biological system is sustainable under a range of seasonal conditions representative of that climate. In some circumstances it may take up to 10 years or more to fully retire a bond (Figure 3).


Figure 3 – Approval processes with deadlines and agencies involved in the mining closure phase in Western Australia

## CANADÁ (NEWFOUNDLAND & LABRADOR AND QUÉBEC)

Mining projects are only allowed to proceed after receiving approval from respective main government agencies (Provincial – Ministry of Natural Resources and Wildlife – MNRW and Ministry of sustainable Development Environment and Parks – MDDEP and Federal – Canadian Environmental Assessment Agency – CEA) which approval is only forthcoming after project proponents have met defined requirements and proven to have had the appropriate levels of public and aboriginal (First Nations) notice, hearings, negotiation and agreement.

While the process and the elements required to be addressed by project proponents is well defined, the length of time to complete the process of securing a government authorized license to mine is not. The process at the provincial and federal levels is clearly set out but many authorizations have no defined timetable. Legislation simply states that authorization will be provided "...upon the satisfaction of the Minister." Whilst such policy might be interpreted as a lack of transparency from government for the permitting process, it is necessary to ensure that projects only proceed once governmental approval has been provided. The system depends on well-prepared, professional submissions by project proponents, an experienced and competent civil service and well-educated, reasonable opponents.

Experience has shown that a well-planned and prepared permitting effort by a project proponent will significantly reduce the amount of time to secure the necessary permits. Regular interaction with government officials maintains momentum and ensures that each file progresses through government processes whilst providing an immediate conduit for questions from government representatives to be addressed by the proponent without delay.

Knowledge of Canadian First Nations (Aboriginal) groups and their requirements, legal rights and moral suasion is absolutely critical to avoid First Nations society upheaval, project resistance, legal challenges and even physical blockades to a property. All projects in Canada are required to consult with the nearest First Nations group on behalf of the Crown (Government of Canada) and reach an accommodation exemplified by an Agreement in Principle and legally framed in a negotiated Impact Benefit Agreement. An IBA is not legally required before a mining license is issued but mining licenses are not issued by the provincial governments without proof that an IBA, or multiple IBAs, have been executed.

Considering the similarity of general procedures and time frame, Newfoundland and Labrador processes will be described together with Québec.

**Phase I – Prospecting and Exploration**

Upon completion of claim staking, an Exploration Program with a detailed description of the activity must be submitted to the provincial government prior to the commencement of activities. A mineral license of five years duration is issued allowing exclusive right to explore for minerals in, on or under the claim area and it may be renewed and held for a maximum of twenty years (provided the required annual assessment work is completed, reported and accepted by the province). If the exploration program may result in major ground disturbance or disruption to wildlife or wildlife habitat, the proponent must submit an application for exploration approval to the provincial Ministry of Natural Resources accompanied by a notice of planned mineral exploration work detailing the expected activities to be undertaken. It is required that the rights and interests of Aboriginal groups be addressed and proponents must consult with these groups regarding the accommodation of their requirements.
Considering the accumulate timing for approvals processes to prospecting and exploration, minimum timeline is estimated in 4 months, with maximum timeline of 9 months (Figure 4).

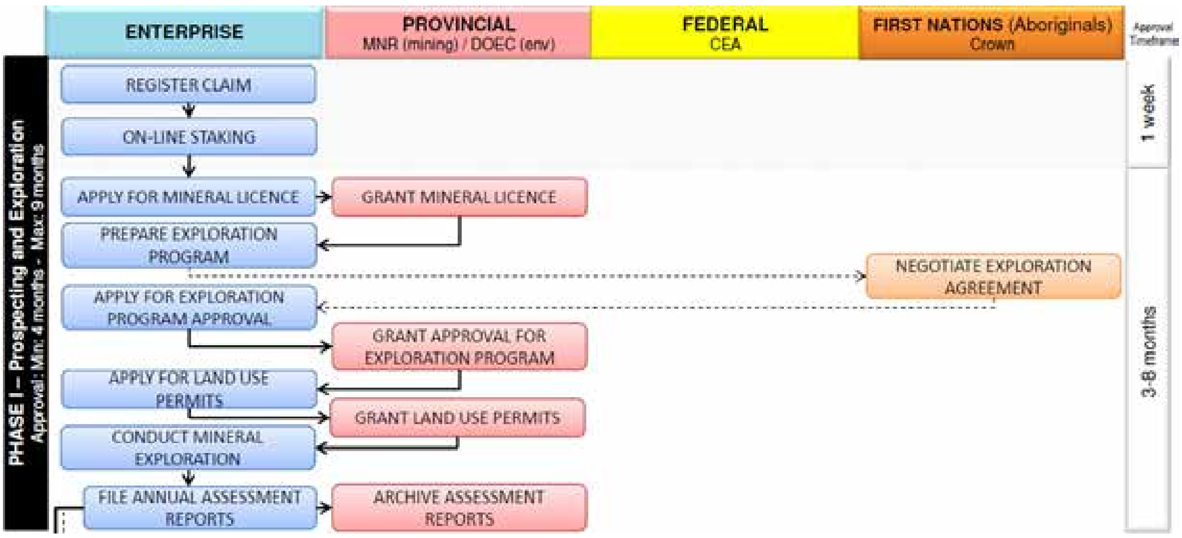


Figure 4 – Approval processes with deadlines and agencies involved in the prospection and exploration phase in Newfoundland & Labrador and Québec

**Phase II - Mine Development and Operations**

A holder of a mining license has the right to be issued a mining lease provided that all terms, provisions and conditions of or pertaining to the license have been complied with. Once a project has reached the mine development phase, several milestones must be achieved: Land Tenure requirements, Obtaining a mill (processing) license (if required); Approval of the environmental assessment; Various environmental permit approvals; Submission of development and rehabilitation and closure plans and positive acceptance and provision of financial assurance for the mine closure plan.

The project will first enter the Environmental Assessment process via a Project Registration report with the provincial Department of Environment and Conservation (DOEC). Proponents must demonstrate how the best practicable technology and methods will be used to minimize harmful effects. The registration will also be examined by all interested government departments and reviewed by the Federal Government in accordance with the Canadian Environmental Assessment Act (CEAA) in an effort to informally harmonize the provincial and federal review process in an effective and timely manner. As stated in the exploration phase, specific details to consulting with and accommodating Aboriginal groups and communities as a whole with the province are limited. The proponent may not develop a subsurface resource in Labrador Inuit Lands until the proponent enters into an Inuit Impact and Benefit Agreement (IBA) with the Aboriginal government.

Considering the accumulate timing for approvals processes to mining development and operations, specifically for mining development minimum timeline is estimated in 30 months, with maximum timeline of 66 months. Specifically for the operations (mine and mill), minimum of 36 months and maximum timeline of 72 months (Figure 5).

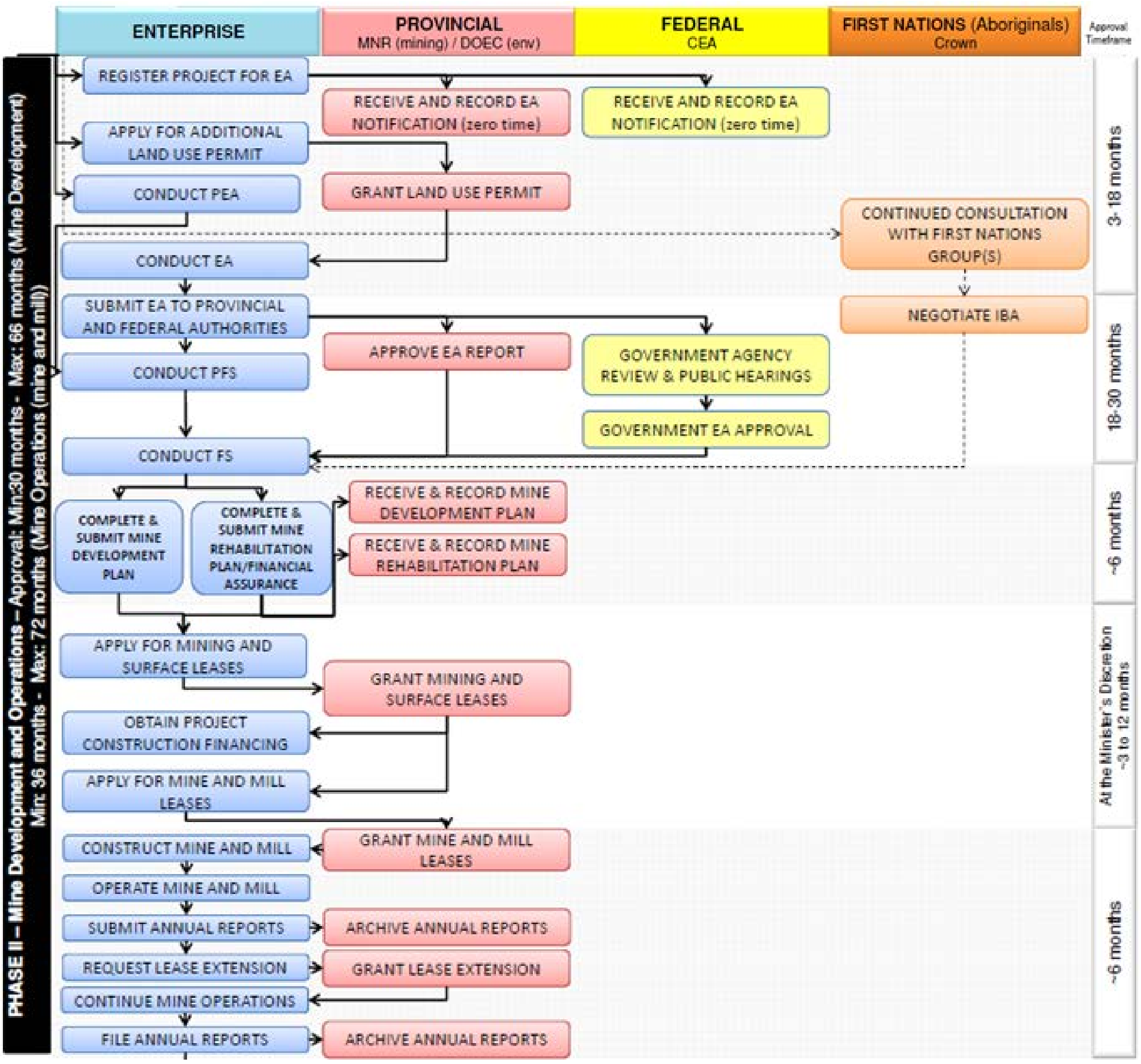

Figure 5 – Approval processes with deadlines and agencies involved in the mine development and operations phase in Newfoundland & Labrador and Québec

**Phase III - Mine Closure**

Before commencing mine development, the proponent must file a Rehabilitation and Closure Plan and provide financial assurance for rehabilitation and closure, all to the satisfaction of the provincial Ministry of Natural Resources. These are required under the provincial *Mining Act* and/or the provincial Mining Regulation under the *Mining Act*. The plan should set out all measures the proponent proposes to take to progressively rehabilitate a site during mine development and operations and rehabilitate a site upon closure of a project. The lessee shall provide financial assurance as part of a rehabilitation and closure plan. Details of assurance type, amounts and timing of payment shall be approved by the ministry (Figure 6).

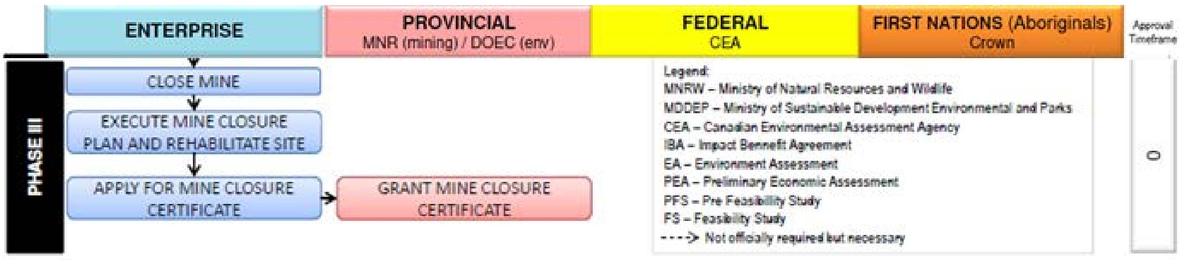


Figure 6 – Approval processes with deadlines and agencies involved in the mining closure phase in Newfoundland & Labrador and Québec

**COMPARATIVE ANALYSIS**

In this item a brief integrated comparative analysis is presented, bringing the general figures described above for Australia and Canada mineral and environmental legislation approval processes, including Brazil.

Figure 7 shows the number of macro activities necessary for the progress of the approval flows, the number of interface bodies involved, and the time limits established by law for the completion of the procedures for the three countries under study.

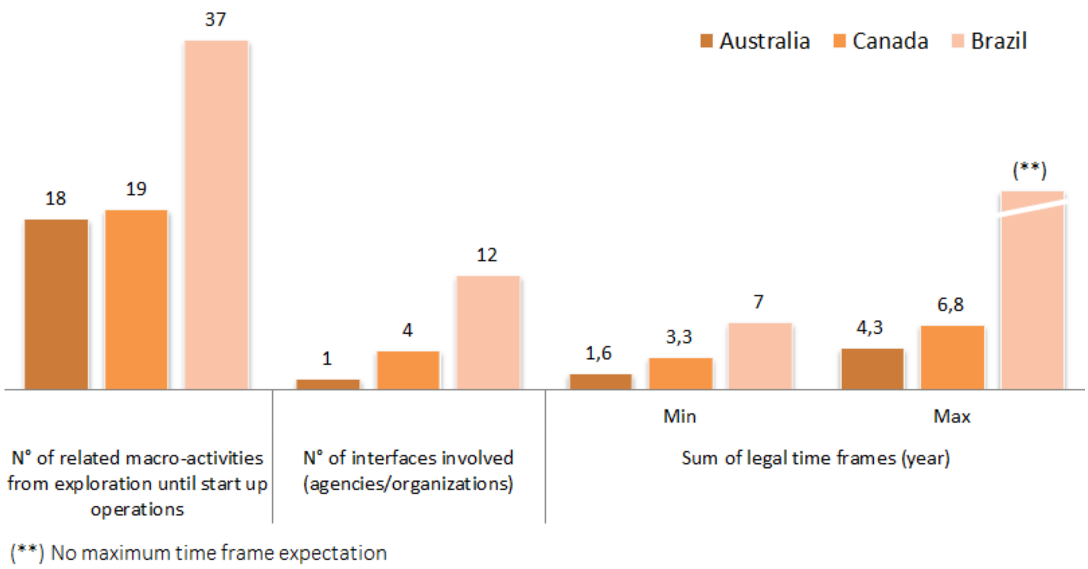


Figure 7 – General figures for Australia, Canada and Brazil mineral and environmental legislation approval processes for iron ore projects

Figure 8 details the legal time frames from exploration until a pre-operational phase for iron ore projects.

| Detailed legal time frames for authorizations | | | | |
|---|---|---|---|---|
| Country | Exploration (month) | Pre-installation (month) | Pre-operation (month) | Total (year) |
| Australia | 6,5 to 8,5 | 13 to 43 | unnecessary | 1,6 to 4,3 |
| Canada | 4 to 9 | 36 to 72 | unnecessary | 3,3 to 6,8 |
| Brazil | 30 | 30 | 24 | 7 (minimum ) |
| (Obs1) Time frame don't include the engineering time as preparation of studies, project design, survey and implementation. | | | | |
| (Obs2) For exploration, Brazilian agency has no legal deadline to reply. Thus the period presented are estimated. | | | | |
| (Obs3) Pre-installation authorizations include approvals of studies and varieties of licenses such as the Provisional License (LP) and the Installation License (LI). The pre-operation licenses include Operating License (LO) and Mining Permit. In | | | | |

Figure 8 – Legal time frames in Australia, Canada and Brazil for mineral and environmental legislation approval processes until a pre-operational phase in iron ore projects

## CONCLUSIONS

**Western Australia and Canada**

Mineral and federal environmental laws and the states and provinces / territories are aligned by the use of bilateral agreements ( "memoranda of understanding") and it promotes clarity of responsibilities and deadlines in the legal procedures for the development and implementation of mining projects;

Federal law prevails, but the power of approval and evaluation is often transferred to the states or provinces / territories, except when the impact of the project is important for the nation;

In Australia the interface is performed only with the mineral state agency who is responsible to call others if necessary;

The Operational License (LO) is not required in Australia and Canada. At the end of the installation phase the companies can start operation.

**Brazil**

The mining and environmental legal approval processes in Brazil (from exploration to mine operation) is complex, bureaucratic and slow when compared to Australia and Canada.

In Brazil we note an excessive number of agencies/organizations involved and macro activities required for licensing, considering that all procedures are of the entrepreneurial responsibility;

The Provisional (LP) and Operating (LO) licenses are specific requirements of Brazilian law and result in longer terms in environmental licensing processes;

In Brazil, the lack of predictability of time to obtain licenses penalizes the project implementation. Steps that could be performed in parallel, such as mobilization for work, are only carried out after the issue of licenses.

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# CAN INVESTOR DISCLOSURE HELP MITIGATE WATER-RELATED RISKS? A LOOK AT THE IMPACT OF BOTH VOLUNTARY AND MANDATORY REPORTING IN THE EXTRACTIVE INDUSTRY AND A CALL FOR BROADER REQUIREMENTS

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## ABSTRACT

The mining industry faces increasing water-related risks, whether it be from extreme weather events resulting from global warming, water scarcity combined with increased water demand, heightened environmental regulation in mining-heavy jurisdictions, or growing political awareness and organization from communities that rely on the same water sources used and polluted by mining operations. Many stakeholders, including institutional investors in the mining industry, are calling for greater transparency and disclosure about miner's environmental, social, and corporate governance (ESG) practices, including their long-term water management plans. This paper examines the growing trend around water risk disclosure and discusses whether increased transparency leads to both better investment decisions and more environmentally sustainable mining practices. Thus far, most disclosure around water risk has been vague, voluntary, and unverified. In the United States, the Securities and Exchange Commission (SEC) has proposed increasing its requirements for mandatory reporting of environmental risk at the project-level. The position of this paper is that each of the existing reporting schemes are valuable in its own way and that increased transparency is beneficial for all stakeholders. However, the most effective schemes are mandatory, focused at the mine-asset level, require third-party certification, and take into account not just scarcity but also regulatory risk and extreme weather events. For this reason, financial regulatory agencies should broaden the environmental risk reporting requirements for mining operations.

## KEYWORDS

Disclosure, water, risk, mining, securities litigation

## INTRODUCTION

The mining industry faces increasing water-related risks. More frequent incidents of drought, leading to water scarcity, and flooding, leading to operation shutdowns, are the predicted results of climate change in many mining regions around the world. Water demands are increasing as miners turn to processing poorer grades of ore. Many countries where large mining operations take place are strengthening their environmental legislation and implementing stricter enforcement of environmental permits. Greater attention is being paid to the potential negative impacts on the communities that rely on the same water sources used and polluted by mining operations.

Investors have an obvious interest in understanding a mine's exposure to water risk. Calls for assessment and public disclosure of this risk have been growing. The disclosure can come in several forms. It can be voluntary, through a framework such the Global Reporting Initiative (GRI); or mandatory, as part of the mining company's required risk disclosure in its financial reporting to a government regulator like the United States Securities Exchange Commission (SEC). Tools have been developed to help investors assess water risk at the project level, like Bloomberg's Water Risk Valuation Tool, which maps mine assets against geographic water scarcity indicators. (Bloomberg, 2015). The position of this paper is that each of these reporting tools can be valuable in its own way and that increased transparency is beneficial for all stakeholders. However, the most effective schemes are mandatory, focused at the mine-asset level, require third-party certification, and take into account not just scarcity but also regulatory risk and extreme weather events. For this reason, financial regulatory agencies should broaden the environmental risk reporting requirements for mining operations.

## DISCLOSURE OF WATER RISK

There are many motivations for developing disclosure schemes for environmental risk. Policy makers, investors, third party stakeholders, and corporations themselves seek different, but often overlapping, goals from disclosure programs. Disclosure of risk through financial reporting requirements is meant to help investors make informed decisions about where to put their money. Schneider and Ingram (1990) describe disclosure programs as "capacity building tools" that enable stakeholders to take action through different means. Armed with data, stakeholders can effect corporate change through the market (divestment, for example, or shareholder action), government (through lobbying, or lawsuits), and civil society (through mobilizing protests, or creating media exposure). (Stephan, 2002). Naysnerski and Tietenberg (1992) document how citizen suit enforcements of the Clean Water Act were made possible because of publicly available compliance records. Fung and O'Rourke (2000) point out that disclosure programs allow for comparison between corporations, enabling advocates to "spend maximum energy targeting the minimum, or worst, environmental performers." Schuster and O'Connell (2006) document the growing trend of voluntary corporate disclosures. They argue that while some companies attract investors seeking to reduce risk through higher levels of transparency and credibility, these reporting practices come at the increased cost of information gathering, auditing, and verification.

## VOLUNTARY DISCLOSURE

The World Resources Institute conducted a survey of voluntary water disclosure practices in the mining industry and concluded that one drawback of programs like the GRI is that water usage data is typically reported at the aggregate corporate level. (Miranda & Sauer, 2010). This data is thus relatively useless for an investor that wishes to make a risk assessment of a particular mining project. In addition, while many mining companies report on their exposure to water scarcity there is much less of an emphasis on reporting water *quality* data. Effluent quality and general waste management plans are "either not reported or not detailed enough to understand risk." The impact of the mines' water use on the surrounding community is "rarely reported."

These deficiencies can translate directly into an investor not fully appreciating the material risks associated with a mining operation. Water contamination risks, and conflicts with communities threatening company's social license to operate, are among the most the significant liabilities for a mining operation. Voluntary reporting schemes similarly often do not require companies to report on their exposure to natural disasters and extreme climate events at the mine-asset level.

Many voluntary reporting instruments lack performance metrics to monitor compliance and are not accompanied by third party certification requirements. The World Economic Forum (WEF) conducted a survey of all the voluntary initiatives employed by the mining industry and concluded that "they are applied inconsistently, the landscape is confusing, and there is a lack of accountability and measurement." (D'Esposito & Banks, 2016). The WEF report also warned of "initiative fatigue." With the proliferation of reporting schemes it can be difficult for a company to pick and choose which programs to participate in and for an investor to decide which programs are worth paying attention to.

The creators of the Bloomberg Water Risk Valuation Tool additionally report that while mining companies may report on water scarcity as a risk to existing operations they typically do not undertake an analysis of how the changing climate may impact future access to water. This especially matters in the mining industry where a significant percentage of a company's total value can be based on the availability to exploit untapped mineral reserves. (Bloomberg, 2015). In South Africa, for example, there are many mines that have been unable to progress to the production phase of operation due to lack of sufficient access to water. (Naidoo, 2015). This tool can be useful to investors interested in assessing water scarcity risk at the mine asset level. The user may additionally manually input predicted regulatory changes, such as a loss of water rights. While this feature could be useful if the interested investor or other stakeholder understands the political landscape of the region where the mine asset exists, it is less helpful without an idea of the likelihood of such regulation. For this reason, requiring a mining company to assess and disclose its own exposure to regulatory risk is a more optimal approach to ascertaining future water availability.

**Do Voluntary Initiatives Have a Measureable Impact on Environmental Performance?**

One recurrent criticism of voluntary disclosure initiatives is that they are merely "greenwashing" tools, serving only to assist in public relations and branding for companies without changing corporate behavior. Schiavi and Solomon (2006) point out that these programs often attract companies that are already industry leaders in environmental performance and sustainability metrics. These are often the large multinational corporations that can devote significant resources to sustainability programming and desire to use voluntary initiatives to highlight their already good performance. As a result, smaller companies, or those with particularly poor environmental records, opt-out of participation in the voluntary initiative.

In a paper titled, "How Credible are Mining Companies Sustainability Reports?" Fonseca (2010) examines the ICMM's Sustainable Development Framework and its attempt to "lessen the gulf between rhetoric and reality" through its requirement of an external audit. Fonseca points out several criticisms of the assurance process, including the lack of guarantee that the assuror is independent from the mining company being assessed and "low levels of stakeholder engagement in the assurance process." Tsang et al. (2009) write that, in complying with the GRI, many companies disclose their own management behavior and programs "rather than what changes, damages, or benefits impact communities."

To test whether voluntary initiatives really have an effect on corporate behavior, researchers at the Columbia Water Center compared scores that mining companies had received from the Mining Association of Canada's Towards Sustainable Mining (TSM) program with water quality data obtained from the Canadian government. (Parthasarathy & Condon, 2016) TSM has been implemented since 2005, and requires companies to report and assess the performance of their Canadian-based mines. Companies receive scores on their mines' performance in tailings management, biodiversity conservation management, and other areas on a scale from C to AAA. The quantitative analysis suggests that TSM participation has a statistically significant relationship with relatively positive environmental performance. It is not certain, however, that TSM participation is the cause of this positive performance. The mines that participate in TSM are generally from globally operating, high revenue-accruing companies. Their excellent environmental performance may be symptomatic of this status rather than TSM participation.

## MANDATORY DISCLOSURE

Most large U.S.-listed mining companies already report, to some degree, on water-related risk as part of their required climate change risk disclosure to the SEC. Under its 2010 guidance, the SEC requires companies to disclose "significant physical effects of climate change, such as effects on the severity of weather (for example, floods or hurricanes), sea levels, the arability of farmland, and water availability and quality." (SEC, 2010). Companies are additionally required to report on how any predicted changes in environmental legislation will affect their operations. The amount of detail reported by companies, however, varies greatly. Newmont's 2016 filing, for example, goes into great detail for some of its mining locations, reporting on "power shortages in Ghana resulting primarily from drought, insufficient rainfall … and insufficient hydroelectric" power. (Newmont, 2016) Southern Copper Corporation's filing, in contrast. reports its exposure to climate change related risk rather vaguely: "The potential physical impacts of climate change on our operations are highly uncertain, and would be particular to the geographic location of our facilities. These may include changes in rainfall patterns, water shortages, changing sea levels, changing storm patterns and intensities, and changing temperatures." (Southern Copper Corporation, 2016). Pressure is mounting from investors and environmental advocates alike for the SEC (and the financial regulatory agencies of other countries) to require more specific disclosure on these issues.

**Disclosure Pressure from Shareholder Litigation**

In the United States, the Securities Exchange Act gives shareholders the right to sue to recover economic loss sustained as a result of fraud related to the trading of their investments in stocks or bonds. This fraud can come in many forms, including insider trading, price fixing, or corporate misrepresentations to its investors. This last type of fraud has seen increased attention (primarily at the U.S. state level) from those interested in corporate statements regarding future environmental liabilities, including climate change impacts. (Gillis & Krauss, 2015).

In the past year, lawsuits against three different foreign-owned mining companies operating in South America were brought in U.S. courts regarding mismanagement and lack of disclosure of water-related risk. The Canadian mining company Barrick Gold announced in May that it had reached a preliminary agreement to pay $140 million to settle claims brought by shareholders regarding its failure to comply with environmental regulations at its mining operation on the Chile-Argentina border. And both Vale and BHP Billiton are on the receiving end of multiple shareholder lawsuits stemming from the tragic collapse of a tailings dam operated by its Brazilian joint venture, Samarco.

Barrick acquired the proposed site for its Pascua-Lama mine in 1994: a gold ore deposit at 15,000 feet in the Andes mountains, buried under, and surrounded by, fragile glaciers. Due to doubts over water quality from the nearby community, and national concern over destruction of the glaciers, it was difficult for Barrick to obtain the necessary permits to begin construction of the mine. It finally gained approval after agreeing to 400 separate environmental conditions imposed by the Chilean government. Barrick was required to implement dust-control mechanisms to prevent particulate matter from reaching the glaciers, and to construct an elaborate water management and treatment system. However, during the initial phase of construction, Barrick realized that there was not enough water available at the site to perform adequate dust control on its roads, yet declined to purchase chemical alternatives to prevent the dust from reaching the glaciers. Barrick also modified the water management plan without seeking approval from Chilean regulators.

In April 2013, when a Chilean appeals court issued an injunction against further construction of the Pascua-Lama mine and indicated that Barrick was potentially liable for $10.2 million in fines for failure to comply with environmental regulations, Barrick's stock price fell 8.4%. On May 24, 2013, the Chilean government suspended the project, citing 23 violations of an environmental permit, and imposed a fine of $16 million. Barrick halted trading of its stock for several hours following the news, but its stock price nevertheless dropped approximately 2%. Prior to these events, Barrick made repeated statements to its shareholders that it was in compliance with all permits and environmental legislation. In March of this year, the U.S. judge overseeing the securities litigation ruled that Barrick's misstatements regarding its environmental compliance meant that investors could not accurately weigh their investment risk. Following this ruling, the parties reached a preliminary settlement agreement for $140 million, currently awaiting court approval.

Last November, an iron ore tailings dam collapsed in Brazil, releasing around 60 million cubic meters of mining waste into the Doce River Basin, and destroying the village of Bento Rodrigues. (Phillips, 2015). Seventeen people were killed, hundreds were displaced, and the tailings waste containing mercury and arsenic flowed more than 300 miles downstream to the Atlantic Ocean. Vale and BHP Billiton jointly owned the corporate operator of the dam, Samarco. Following the tragedy it additionally came to light that Vale regularly deposited waste from its own mining operations into the faulty tailings dam. Several shareholder class actions have been filed against Vale and BHP Billiton alleging that the corporate parents had information indicating that the dam had structural weaknesses and yet did not take steps to mitigate the disaster. An additional group of shareholders that purchased Vale stock after the disaster occurred are suing on the basis of alleged misstatements regarding the contents of the spill. Following the spill, Samarco and BHP made repeated statements that the tailings waste released into the river basin was not harmful to human health. However, both the United Nations and a local Brazilian research institute reported that levels of lead, copper, and chromium were many times higher than the legal maximum. (Kiernan, 2015). All of the cases filed against Vale and BHP are awaiting class certification and consolidation.

Brazilian independent prosecutors have likened the Samarco disaster to the Gulf Oil Spill, saying "[u]nless one wishes to suppose that the environment of Brazil is worth less than that of the U.S., it's inadmissible that the valuation of the environmental damage caused by the defendant companies falls below, at first glance, the $43.8 billion acknowledged by the party responsible for the tragedy in the Gulf of Mexico." (Kiernan, 2016). The BP oil spill disaster similarly spawned many shareholder class actions and the success and failure of these lawsuits may shed light on the future of the Samarco securities litigation.

In June, oil giant BP agreed to pay $175 million to settle a shareholder class-action lawsuit over statements it made regarding the 2010 oil spill in the Gulf of Mexico. (Reuters, 2016). The shareholders in this class, all of whom had purchased BP stock after the spill had occurred, accused BP of making misleading statements regarding the severity of the spill and its ability to clean up the disaster. The shareholders in the action argued that they would not have chosen to invest their money in BP if they had known just how much oil was being released into the Gulf. This settlement is in addition to the 2012 agreement reached between the SEC and BP for $525 million, the third largest penalty obtained in Commission history. In both cases the underlying complaint of fraud was that BP had made repeated statements to investors that oil was leaking from the Macondo well at the rate of 5,000 barrels of oil per day despite knowing that the actual rate was more than 50,000 barrels per day.

A second class of shareholders, those who had purchased stock before the spill occurred, were blocked from proceeding with their complaint alleging that BP had deliberately overstated its ability to manage potential disasters and had created an "impression that the risk of catastrophic risk was lower than it actually was." The court declined to certify the pre-spill class, explaining that even if BP had misrepresented the risk, they lacked a "clear causal link between the misrepresentation and the economic loss." The court hypothesized with an example, that if BP had reported the risk of the blowout at around 0.5%, while the actual risk was in fact 2%, there were certainly some high-risk investors in the class who would have continued to purchase BP stock, although at a reduced price. The court reasoned that it was not able to separate out this class of investors and therefore any securities fraud claims regarding pre-spill misrepresentation of risk management had to be brought as individual actions rather than as part of a class. Based on the types of claims that were allowed to proceed against BP, it is reasonable to conclude that shareholders could have a more successful claim against Vale for alleged misstatements regarding the toxicity of the material released into the Boce River rather than more generalized allegations of misrepresentations of Samarco's ability to manage risk.

Canada has similar disclosure laws meant to ensure that shareholders are sufficiently informed of their investment risk. Following a massive tailings pond breach at the Mount Polley mine in Ontario a shareholder class action was filed against the mine's owner, Imperial Metals. After the disaster, Imperial Metals' stock lost 42% of its value. The filing alleges that Imperial Metals failed to inform shareholders that engineers and inspectors had warned of problems with tailings management at the mine. (Uechi, 2014).

Shareholder litigation of the type discussed here may serve as one additional incentive to companies to avoid environmental mismanagement. These lawsuits may police undisclosed environmental risks, promote transparency, and in the long term encourage better internal corporate risk management policies. Unlike direct tort litigation over the disaster itself, however, the payments awarded in these types of cases can serve only a punitive function. None of the money paid out by the company makes it into the hands of the community impacted by the disaster or goes toward remediating the environmental damage. In the case of the Samarco disaster, the settlement reached with the Brazilian authorities requires a total minimum payout of $1.1 billion. (Williams-Grut, 2016). (This amount was deemed insufficient by independent prosecutors who announced in May they would be seeking $44 billion in damages in a civil suit and accused the government of "selling out.") (Pearson, 2016). Given that shareholders of BHP and Vale stock could potentially recover hundreds of millions of dollars in a securities class action, the punitive effect of this payout relative to the total amount required by the official settlement is significant.

**U.S. Proposals for Increased Environmental Risk Disclosure**

The SEC recently proposed changes to its disclosure requirements for mining companies that could increase the liability potential of companies that fail to accurately disclose environmentally related risks to its investors. Under the proposed rules, mining companies must submit a "technical report summary" for each mineral resource or reserve that is significant enough of an asset to be considered material. (SEC, 2016). The SEC outlined specific requirements for the contents of the technical reports, including, most relevantly: "the final identification and detailed analysis of environmental compliance and permitting requirements, including the finalized interests of agencies, NGOs, communities and other stakeholders, together with the completion of baseline studies and finalized plans for tailings disposal, reclamation and mitigation." If finalized, this rule would require companies, such as Barrick Gold, to be upfront about their compliance with environmental regulations protecting glaciers. It may also require companies like Southern Copper to provide an honest analysis of the concerns of the community living near the mine and provide predictions of stakeholder opposition. Southern Copper's Tia Maria mine project has been on hold for more than a year following massive protests over its potential impact on groundwater. (Quigley & Willis, 2016).

These technical reports must be prepared by a "qualified person," who may be an employee of the reporting company, but must meet certain qualification requirements as outlined by the SEC. This "qualified person" would likely be liable as an expert under the Securities Exchange Act for any material misstatements made in the report. This creates a genuine risk of litigation were an expert to inaccurately describe a mining company's ability to legally secure enough water for its operation, or its ability to comply with the host country's environmental laws. The proposed rules specifically outline that the "qualified person must examine the regulatory regime of the host jurisdiction to establish that the registrant can comply (fully and economically) with all laws and regulations (e.g., mining, environmental, reclamation and permitting regulations) that are relevant to operating a mineral project using existing technology."

Even if these rules are finalized they are simply requirements regarding disclosure of information regarding environmental risk, they don't necessarily guarantee better environmental performance. However, there is evidence suggesting that these types of reporting requirements do have a genuine impact on the behavior of the company doing the reporting. In April 2010, an explosion at the Upper Big Branch coal mine in West Virginia resulted in the deaths of 29 miners. The mine had received more than 600 citations for safety violations in the 18 months prior to the explosion. In reaction to this disaster, a senator from West Virginia added a provision to the working draft of the Dodd Frank Act, requiring that mining companies disclose their safety records in their earnings reports and make a filing with the SEC each time a mine received a safety warning.

In a recent paper, researchers from the University of Chicago and Rice University compared mine safety records of publicly traded mining companies subject to this Dodd Frank provision with those that were privately held and under no disclosure obligations. (Christensen, Floyd, Liu, & Maffett, 2016). They found that the decrease in safety citations at the disclosing mines was 11 percent greater than those that did not disclose. The publicly traded mining companies also experienced a 13 percent greater decrease in worker injuries. The mine safety violations reported to the SEC were already publicly available through the Mine Safety and Health Administration's website. Interestingly, this same study found that the same violations, once they were submitted to the SEC, resulted in mutual fund ownership of the disclosing company declining twice as much than if the violation had only been reported through the MSHA.

Similarly, stock prices fell significantly more when the safety violations were reported through the SEC.

These findings suggest that when evidence of socially undesirable behavior is made readily available to investors, investors choose to penalize the misbehaving company with their wallets. The authors of the study noted that the decline in mutual fund ownership was, not surprisingly, “most pronounced for funds with explicitly stated preferences for ‘socially responsible investment.’”

## CONCLUSION

In addition to the proposed changes in disclosure requirements for mining operations, the SEC has also made a call for public comment on whether it should require broader disclosure on environmental, social, and governance (ESG) factors across all industries. In a comment letter organized by the nonprofit Ceres, many institutional investors wrote: “[W]e believe it is critical for the SEC to improve reporting of material sustainability risks . . . because we need it to make informed investment and proxy voting decisions.” (Ceres, 2016). These investors recognize the failings of relying solely on voluntary reporting mechanisms – the programs on their own do not sufficiently inform investors about companies’ environmental risk exposure. Not all are in support of this trend toward mandatory disclosure. In its own comment letter, the U.S. Chamber of Commerce asserted that these disclosure rules would “contribute to an environment that makes it more difficult for businesses to innovate, compete and grow" and that “investors [would] become inundated with information that is not useful.” (U.S. Chamber of Commerce, 2016). The American Petroleum Institute argued that the cost of compliance with the proposed disclosure rules would put an undue financial burden on its member companies.

The above survey is meant to describe the growing trend around water risk disclosure and ask whether increased transparency leads to both better investment decisions and more environmentally sustainable mining practices. While most disclosure around water risk has been vague, voluntary, and unverified there have been moves more recently toward requiring assurance and specific data disclosure. The most effective disclosure schemes are mandatory, focused at the mine-asset level, require third-party certification, and take into account not just scarcity but also regulatory risk and extreme weather events. For this reason, financial regulatory agencies should broaden the environmental risk reporting requirements for mining operations.

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# COLLABORATIVE GOVERNANCE FOR SUSTAINABILITY: A MULTI-STAKEHOLDER APPROACH TO DRIVE LAND USE, CONSERVATION AND SOCIAL AGENDA IN MINING AREAS

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# COLLABORATIVE GOVERNANCE FOR SUSTAINABILITY: A MULTI-STAKEHOLDER APPROACH TO DRIVE LAND USE, CONSERVATION AND SOCIAL AGENDA IN MINING AREAS

## ABSTRACT

Large mining projects affect the territory economically, environmentally and socially. Those projects are viewed with mistrust by communities and local leaders, despite the great expectations they generate. Companies, in turn, establish strategies to address such concerns and act more connected to local development. This is the basis of the design of Alcoa Juruti Mine at the banks of the Amazon River. Once the company got the licenses to start bauxite mining operations in 2006, the Sustainable Juruti model was proposed to promote an agenda of sustainability at Juruti municipality. The region historically has been struggling to reverse its level of poverty, to implement basic services and infra-structure and to enhance community level of involvement in live improvement and environmental issues.

The model based on a public-private-social partnership is formed by a tripod: 1) The Sustainable Juruti Council, a permanent forum for dialog and collective action among the parties, considering a long-term agenda; 2) the Sustainability Indicators (more than 80 items in the human, social, environmental and economic fields) monitoring the development of Juruti and providing the Council with qualified information; and 3) the Sustainable Juruti Fund, which finances activities prioritized by the Council and mobilizes resources to generate an endowment fund for present and future generations. Over the years this structure has matured and improved. Recently is ongoing creation of the Juruti School of Sustainability, the model's fourth leg. But keep the challenge: a multi-stakeholder approach to promote local development based on sustainability and cooperation in the midst of intense conflict of interests.

As results through the Sustainable Juruti Council it was possible to start a dialogue process resulting in common goals, based on the SDG (UN), and for seeking joint solutions. The indicators qualify the multi-stakeholder dialogue, seeking to balance different views and interests with technical information. The Fund seeks to demonstrate the feasibility or catalyse new ways to produce (fish, vegetables, forestry), to preserve nature (lake management agreements), and to develop the society (environmental education, care for adolescents at risk).

## KEYWORDS

Amazon, Council, Development, Fund, Indicators, Multi-stakeholder, Sustainability

## INTRODUCTION

Setting up a large mining project normally affects the territory economically, environmentally and socially. It has been widely understood the impact and externalities of mining in remote areas, as well as its potential for development. However, the practice of incorporate such impact assessment by mining companies is often largely lacking, which has contributed to severe social and environment impacts on communities, as well as economic frustration, especially in the developing nations of the world.

One of the most well-known mining history of social and environmental liabilities in the Brazilian Amazon was the collapse of the Serra do Navio manganese project. After a period of 45 years of economic boom and welfare resulting from the mining, collapsed. This case became a symbol of unsustainability for large-size mining projects (TOSTES, 2007). Such enterprises are challenged to be overcome.

Under the impact of new development paradigms, mining is challenged by two new factors: 1) the social license is a key element for its sustainability, and 2) the developments, in the long run, cannot sustain themselves as an ‘island of prosperity’ in an environment of poverty and institutional instability. Therefore, it is necessary for mining projects to generate multiple benefits (ENRIQUEZ, 2007).

The Alcoa company faced that challenge when started to build its bauxite mine project in Juruti, at banks of the Amazon River, in the Pará State (Brazil). Up until 2006 this city had a population of 33,000 inhabitants, 60 per cent living in the rural area (IBGE, 2010) with low incomes and with no access to basic social services (health and education) — the tenth worst Human Development Index score in Pará State (UNDP, 2000).

In addition, there is the vulnerability of the Amazon environment, both for the fragility of forest ecosystems and the absence of the government. With the development of the Juruti Mine, these social and institutional weaknesses have become largely explicit. The company, in turn, was not adequately prepared to deal with the social and environmental conflicts that erupted under the leadership of communities and public agencies, even jeopardizing the issuance of the installation and operation license.

The economy was growing along with urban and environmental problems arising from the mine, and critics wondered what to do with the mineral income from installing the mine. How could that income be invested in strategic sectors of local development and how would it benefit the local communities? Will they dig out the bauxite, leave a hole and go away? What would be the sustainability of Juruti with the mine — what legacy would be left for future generations? These questions had poor or incomplete answers and there lacked room for dialogue among the stakeholders on local development, as well as ‘critical mass’ to give direction to what was coming up.

At that moment, Alcoa has proposed the Sustainable Juruti model aiming generate positive social and economic effects in the local community and enhancing environmental conditions.

In 2011, I have described such model that would raise the bar of how mining projects can operate in Amazonia without creating new waves of deforestation in the region, as well as its first results (ABDALA, 2011). In this article, review the initial results and add elements that updated the sustainability model, which remains active under construction.

**The proposed model**

In brief, the Sustainable Juruti model (SJ) envisions promoting governance capacity through a comprehensive sustainability agenda, a monitoring system and the means of implementation by forming a tripod structure. 1) an inter-sectorial Council, assembling stakeholders; 2) a platform of Indicators, for providing qualified information to the Council; and 3) a Fund, which finances activities prioritized by the Council and mobilizes resources to generate an endowment structure for present and future generations. Based in multi-institutional partnerships to provide mutual benefits for companies, communities and local government.

This model was designed base on three assumptions to guide the construction of a local development agenda (MONZONI, 2008): 1) the concept of social coordination spaces, thus allowing for broad and democratic participation of the community in building the agenda towards a common future; 2) focus on local territory, which considers the host city as a generator of development in the region; 3) dialogue with reality, which shapes the agenda in view of the local demands, regional public policies, and contextualizes the agenda within global and business initiatives focused on sustainability.

Those assumptions give the background to a tripod of interventions that promotes multi-institutional partnerships (public authorities, communities, civil organizations, enterprises), whose components and purposes are as showed in the Figure 1.

The Sustainable Juruti Council is a permanent forum for dialogue and collective action between society, government and businesses to discuss the common and future public interest. It prioritizes actions and formulates a long-term agenda.

Sustainability Indicators provide the tools for monitoring the development of Juruti and its surroundings and feed the council with qualified information for the decision-making process.

The Sustainable Juruti Fund complements local funding for development actions based on council-prioritized indicators, and mobilizes resources to generate financial wealth for present and future generations.

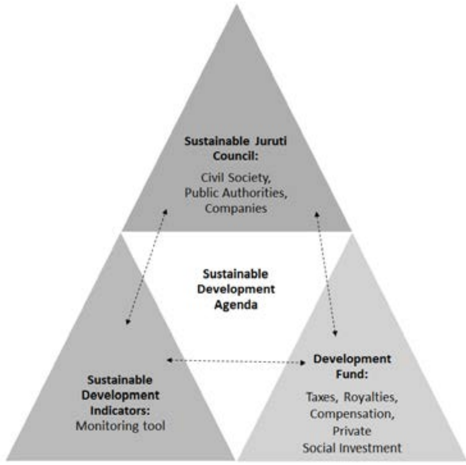


Figure 1 - Sustainable Juruti Model

This model was conceived and designed from the core challenge that presents itself in Juruti: "the installation of a large enterprise in a region of high biodiversity, social organization and public authority unprepared to face a horizon of large and rapid changes, as well as the lack of financial resources to meet the demands of the population. According to this scenario, such insertion carries potentially significant, long-term implications on a wide range of players, with huge social, economic, political and historical differences, as well as on the environment" (Monzoni, 2008, p. 8).

**Participation and Social Control**

The governance approach is based upon a partnership among civil society organizations, communities, businesses and government representatives, for which the Sustainable Juruti Council (CONJUS) is privileged institutional forum. Created in 2008, this is a permanent forum for dialogue and collective action among partners oriented for the sustainable development of Juruti.

The Council is plural and have a diversity of participants. Nowadays its Board of Directors have the 15 member, as following:

| | |
|---|---|
| 9 from Civic organisations | SINTICOLPEMJ, ABONS, AMTJU, Tribo Muirapinima, Prelazia de Óbidos, Projeto Resgatando Vidas, ACMBSR, ASSIMJUR, SINPROEJ, Jará Publicidade, RCJ, ACA, ACEJ, AMONJ, PAE-Balaio, ACCJ, e Colônia Z42. |
| 3 from Public authorities | SEMPRO, SEMPLAG, UFOPA, SEMMA, Conselho de Saúde e AUB. |
| 3 from Companies | ALCOA, Hotel Pequiá, Terra Amazônica |

Table 1 – CONJUS Board of Directors

Based on the diagnostic generated in the first results of the sustainability indicators, the CONJUS is in the process of preparing the Sustainable Developments Goals (SDG) of Juruti, a comprehensive blueprint of action to be taken locally by public and private organizations aiming sustainable development. Nowadays it is organized into five red flags: 1) biodiversity conservation; 2) integrated waste management; 3) capacity building and education; 4) youth culture; and 5) local forest economy.

**Monitoring and funding**

The Juruti Indicators, which started in 2007, is a development monitoring system for Juruti and the surrounding areas, which is included as a long-term public tool in the Sustainable Juruti initiative. The objectives behind collectively monitoring the local transformations are:

- To encourage collective reflection on the dynamics of local development;
- To promote a learning environment that favors human and social empowerment;
- To provide the instruments necessary for the strategic planning process of the Council, Fund and public and private institutions for formulating a sustainable development agenda for the Juruti municipality and the region.

The indicators (more than 80 items in the human, social, environmental and economic fields) qualify the dialogue among companies, communities and government, seeking to balance the social and institutional interests with technical information. For such outcomes to be achieved, technical workshops, community meetings, internet research and public hearings were held, which mobilized more than 600 participants from 115 communities and 71 institutions, with 90 contributions through online survey the internet. In this process the most important factors that arose were: 1) health, education and safety; 2) water, agriculture, financing, technical assistance and land tenure; 3) transportation, communication, energy and waste.

The first outcomes are already published in a book so that the indicators can be understood in a didactic way. The information system is also 100% available for viewing on the Internet. It keeps records Juruti's baseline indicators as well as the recent changes, creating a 'thermometer' tool for municipality management.

The monitoring that is carried out using participative methodologies means that the tool is recognized by the town's residents as a way of understanding how the town is evolving and this results in the formulation of proposals for improving the quality of their life.

The results are presented to the players involved and the general public in various ways: reading and conversation groups, talks promoted by Conjus and workshops with the community and local leaders.

Activities are aimed at town residents and focus on discussing the evolution of the economic, environmental and social data of the municipality and identifying ways of using these data in such a way as to bring about improvements in the quality of local and regional life.

The indicators have been appropriated in different ways: they are used as a learning aid in the municipal school syllabus; the goals of the Juruti Education Pact use the indicators for monitoring the performance of the municipality in this sector; they helped retrieve local identity, based on an historic survey of the social and environmental characteristics of the town; they allowed Conjus to define indicators for monitoring its "Sustainable Development Targets"; they help with decisions for allocating the social investments of the Juruti Mine; and they have also been a monitoring benchmark model for major undertakings in Brazil.

The development monitoring culture is just beginning in Juruti, as in most other Brazilian municipalities, and the Indicators must be made for use in the decision process of public policies, for allocating private investment and for the actions of civil and specialist organizations.

The sustainability indicators allow for CONJUS to guide the lines of action for the Sustainable Juruti Fund (FUNJUS), which also represents a partnership amongst the city administration, local civic organizations, Alcoa (first sponsor) and the Bank of Pará, with the technical support from the Brazilian Biodiversity Fund (Funbio).

FUNJUS is a long-term financing tool oriented for the sustainable development of the territory by encouraging the creation of value in the four sustainability pillars or, or types of capital: human, social, environmental and economic. FUNJUS is a promoter and catalyst, a lever for local development.

It adds to but does not replace the government as a financial backer of public policies. Given the recent transformations in the city, it considers the impacts, imbalances and perspectives for the stability of Juruti (FUNBIO, 2010).

Since 2009, it was financing 21 community projects, mobilizing R$ 200 thousand from an overall amount of US$ 1 million (IJUS, 2015).

**Reinvention**

In 2015 the Sustainable Juruti Institute (IJUS) was founded to set up the Sustainable Juruti Council (Conjus) and the Sustainable Juruti Fund (Funjus) under the same institutional 'umbrella'.

In the last three years there was a capacity building process which resulted to transferring the Funjus management and resources from the Funbio to the IJUS.

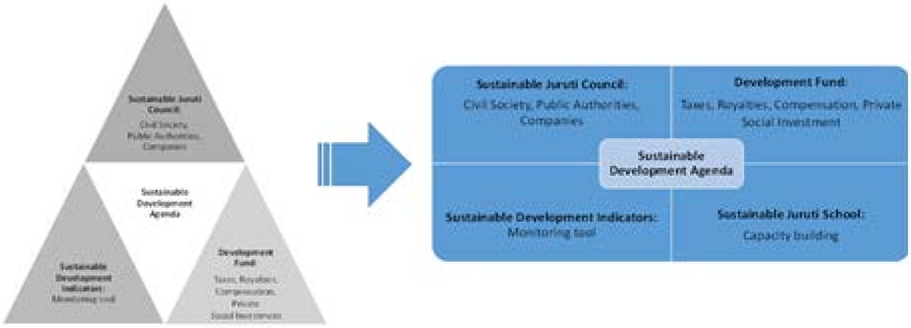


Figure 2 – From tripod to tetragon model of interaction.

The same is being planned to occur with the Indicators. Initially this system was implemented jointly with Alcoa, the City Administration and local civic organizations, with the technical support from the GV Foundation (FGV). In 2013, an agreement between the parties enabled the Municipal Department of Planning and Management (PMJ) to internalize the governance of the Juruti Indicators. Recently, CONJUS and the city agreed to focus on the local Sustainable Development Goal Indicators (ODS) and simplify the process. To do so the Amazonia Social Progress Indicators (Amazonia IPS) will be used (http://www.ipsamazonia.org.br/) for monitoring the municipality and adding economic information.

Using Amazonia IPS enables an alignment at the regional level, because the index will also be adopted by Faro, Oriximiná and Terra Santa municipalities, as part of the *Sustainable Territories* initiative (http://agendapublica.org.br/programa-territorios-sustentaveis-e-lancado-no-para/), as well as by the Pará government, which adopted the IPS as the basis for directing its investments in the social area (http://www.ipsamazonia.org.br/ips-para).

Finally, the IJUS decide to found the *Juruti School of Sustainability* in order to qualify the local leaders and their organizations, social and government, and thus strengthen the capacity to designing the agenda and collective actions.

As a result, the SJ model is reinventing itself in form and content, recognizing the key role of capacity building and changing your tripod format to a tetragon model of interaction, as Figure 2.

**Conclusion**

The governance of sustainability policies tends to follow more a pluralistic praxis of the political process, where the decision-making system is permeated by a broader set of actors and interest groups. In the long term, organizing and coordinating differences among political actors is necessary to involve more directly the forces that shape social conflict and cooperation, incorporating different interests, identities, institutions and values.

The Sustainable Juruti model is demanding in terms of: 1) qualifying leaderships for dialogue using appropriate social technologies, 2) dedicated staff and resources, and 3) mining operations that can be adapted to social and institutional demands.

Benefits may be internal and external to the enterprise. Examples of internal benefits include anticipation, management and (consequently) the reduction of risks arising from social and institutional conflicts generated by the project; strengthening of the license to operate; employee satisfaction for being part of a company recognized positively by the society and its peers in the market; and the company's strengthened brand and reputation in the market. The external benefits include private social investment and corporate responsibility in line with the development goals set by the local society and government, creating convergence and economies of scale; a space for direct, transparent dialog between the stakeholders and the company without patronage; and creation of a financial and institutional legacy generated by the mineral income that stretches beyond the closing of the mine.

The impacts and benefits of this type of corporate approach, jointly with communities and governments, can be observed in the short term, but will be more consistent and durable in the medium and long term. Short -term results include reduction of conflicts and, increased trust amongst businesses, society and government, and a mechanism for dispute settlement; promotion of joint initiatives and mobilizing partnerships (public and private, local, regional and national) to promote local sustainability; the increase of corporate social responsibility and private social investment; increase in public transparency on private investments, budget and use of public resources; and forwarding of social demands for public services to government agencies, thus allowing for directing private social investment in a complementary and strategic manner.

In the medium and long term, the highlights include participatory governance of the territory; increased living quality and levels of institutional and social development; increased presence of the state through increased control, supervision and services; gradual withdrawal of investments from the mining project in providing public services which are typical of the state); social and economic inclusion of communities; development of local value chains (agribusiness, forestry and services) with greater local autonomy in relation to the mineral chain; establishing conservation units of full protection and sustainable use; endowment fund for investments in local development; mine closure without causing a collapse in local society.

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# CURRENT MINING AND ITS SUSTAINABLE DEVELOPMENT IN THE SLOVAK REPUBLIC

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# CURRENT MINING AND ITS SUSTAINABLE DEVELOPMENT IN THE SLOVAK REPUBLIC


## ABSTRACT

Underground mining activities in the Slovak Ore Mountains, the part of the Western Carpatians Mountain in the territory of Slovakia /the Slovak Republic/, have a long history. Mining techniques have developed rapidly in the last centuries. This paper deals not only with mining history, but also with underground brown coal mining, magnesite mining and other mining activities at present and the sustainable developments of the mining industry in the Slovak Republic. This paper looks forward in the context of mineral raw materials and especially from the aspect of the new Energy Union in Europe.



## KEYWORDS

Mining sustainable development in Slovakia, Coal and Magnesite, Domestic consumption of coal and Energy interests.


## INTRODUCTION

The mining activities in the territory of Slovakia have a long history. The mining minerals northeast of the Danube River has been long know. Charlemagne (Emperor of the Romans) extended his influence to these areas, because he received the rich silver and gold deposits of Schemnitz (at present, the city Banská Štiavnica, the Slovak Republic) and Kremnitz (at present, the city Kremnica, the Slovak Rep.). After that time the reopening of old mines was the starting signal for new prosperity during renaissance.

Current data on the Slovakian mining industry are based on underground brown coal mainly, and magnesite mining, as well as on surface mining of construction rocks, e.g. bentonite, clay, ecological raw materials (Vasková, Hrubovčáková 2012 and 2014; Vasková 2009). Brown coal is mainly extracted by the company Hornonitrianske bane Prievidza, a.s. in the territory of the Upper Nitra Coal Basin. The magnesite raw material is one of the most essential natural resouces in Slovakia. Magnesite plant in Jelšava, biggest mining and processing magnesite plant in the Slovak Republic and also one of the biggest dead-burnt magnesia "DBM" producers in the world belongs now to Slovak magnesite work, joint-stock company of Jelšava (Certificate of Approval, 1994). ). Both of these mine such as other mining companies are connected to production of energy or as a big consumers of energy, therefore the policy of energy is the key of economic prosperity.

Energy policy and energy security issues are highly topical theme in the world, at EU level as well as within the Slovak Republic framework. For the purposes of the presented contribution it is necessary to indicate the three basic forms of energy security:

- external security (or energy supply security) – means „*ensuring that the imported energy products meet the needs of the consumers in time and quantity*",
- internal security – means „*ensuring that the national production, transmission and distribution system are able to provide final customers with the energy they need*" and
- energy consumption – which „*has a significant impact on energy security by means of its volume and quality*" (Genova, 2007, p. 29).

Energy policy and energy security issues are part of the strategic documents setting out the direction of the energy sector in the European Union. In January 2007 the European Commission published Communication "An Energy policy for Europe". This Communication, while respecting the sovereignty of individual EU countries in setting out their energy mix, established three basic pillars of the EU's energy policy up to 2020: **energy security, competitiveness, and sustainability.**

The European Council in March 2007 adopted the EU's new energy and environment policy which established „*a forward-looking political agenda to achieve the Community's core energy objectives of sustainability, competitiveness and security of supply*" (European Commission, 2008, p. 2). This document became the basis for the development of the legislative framework in the next period.

The main principles and objectives in the field of energy by the year 2020 are based on the strategy Europe 2020 and are further elaborated in European Commission (2010): "Energy 2020: A strategy for competitive, sustainable and secure energy". According to this document the new energy strategy focuses on five priorities:

- „*achieving an energy efficient Europe,*
- *building a truly pan-European integrated energy market,*
- *empowering consumers and achieving the highest level of safety and security,*
- *extending Europe's leadership in energy technology and innovation,*
- *strengthening the external dimension of the EU energy market*" (European Commission, 2010, p. 5-6).

In December 2012 the European Commission released Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions – "Energy Roadmap 2050". This document established a framework for long-term measures in the field of energy and in other related sectors. „*The EU is committed to reducing greenhouse gas emissions to 80-95% below 1990 levels by 2050*" (European Commission, 2011, p. 2).

"Energy policy of the Slovak Republic" is in accordance with the EU energy policy. This document indicates the future direction of the energy sector of the Slovak Republic in the long term. Its task is to ensure a well-functioning energy market with a transparent competitive environment and optimal conditions for investments in the energy sector. Above mentioned document also defines four pillars of the energy policy of the Slovak Republic (MH SR, 2014): energy security, energy efficiency, competitiveness, and sustainable energy.

Energy security issue of the Slovak Republic is elaborated in complex and detail way until 2030 in the strategic material "The proposal of Energy Security Strategy of the Slovak Republic" approved on 19th October 2008 by the Resolution of the Government of the Slovak Republic No. 732/2008. This document sets out the priorities and proposes a series of measures to increase the energy security of the Slovak Republic. Issues of energy policy and energy security should be understood in relation to sustainable development. By the careful assessment of measures in these areas, national governments can help to maintain healthier environment for future generations. Responsible approach to the extraction of non-renewable energy sources also allows preserving part of their volume for the future.

Issue of sustainable development started to be discussed at the turn of 60s and 70s of the 20th century. In this period the knowledge extended, that unlimited or uncontrolled growth of any type (population, production, consumption and so on) is not sustainable in an environment of really existing scarce resources. It is therefore necessary to replace them by more durable and fair development concept – concept of sustainable development (Rusko, 2011).

As defined in the article "Evaluation of Sustainable Development in the Member States of the European Union", published in the journal Problemy Ekorozwoju, „in 1990 sustainable development became a political principle in the European Union. In 2001 in Gothenburg, the European Council established a sustainable development strategy which was renewed in 2006 and aimed to meet the needs of the present without compromising the ability of future generations to meet their needs" (Haraś et al., 2015).

This idea was also incorporated in the strategy Europe 2020 and in many other Community documents and initiatives.

In the Slovak Republic sustainable development is defined in § 6 of Act No. 17/1992 Coll. on the environment as amended as the development that maintains the opportunity to satisfy basic needs of current and future generations, while it does not reduce the diversity of nature and preserves the natural functions of ecosystems.

In relation to achieving sustainable development, the United Nations Conference on Climate Change was held in Paris in 2015. It resulted in agreement that individual countries would adopt national targets to reduce emissions.

## MINERAL FUELS IN THE SLOVAK REPUBLIC

Mineral fuels account for approximately 7% of overall reserves of mineral resources in the Slovak Republic (Energy, 2010). Their importance for the Slovak Republic is unchored in Act No. 44/1988 Coll., on the protection and use of mineral resources as amended. According to this Act, mineral fuels, specifically radioactive minerals, all types of coal, oil and flammable gas and bituminous rock, suitable for energy usage are among the reserved minerals (Act No. 44/1988 Coll.). Reserves of these minerals are given in Table 1.

Table 1 - Mineral fuels reserves in the Slovak Republic on January 1st 2012
(Source: own elaboration based on Baláž, Kúšik [2012])

| Energy source | Economic reserves | Potentially economic reserves |
|---|---|---|
| **Brown coal and lignite (in kt)** | 440.520 | 644.629 |
| **Natural gas (in mil. $m^3$)** | 8.793 | 15.752 |
| **Mineral oil (in kt)** | 1.922 | 8.248 |
| **Uranium (in t U)** | 6.561 | 3.488 |

The Slovak Republic has at its disposal small amount of reserves of oil and natural gas; more important are stocks of brown coal and lignite. The Slovak Republic is highly dependent on import of energy raw materials – it imports 90% of primary energy sources such as nuclear fuel (100%), natural gas (98%), crude oil (99%) and coal (68%) (MH SR, 2008; Jarábek, Lunkin 2014). Regarding to the gross inland energy consumption, the Slovak Republic has balanced energy mix. In 2012 natural gas and nuclear energy were among the key energy sources in Slovakia (see Figure 1). It is anticipated that this trend will be maintained in the future.

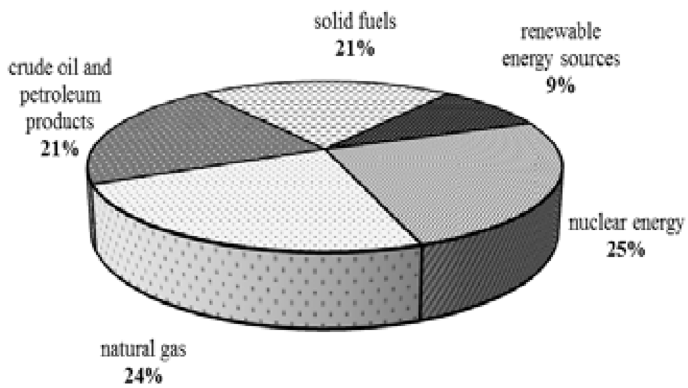



Figure 1 - Gross inland energy consumption in the Slovak Republic in 2014 (in %)
(Source: own elaboration based on the data from Eurostat)

The Slovak Republic also has the opportunity to develop its own energy sources, especially extraction of brown coal, hydropower potential and renewable energy sources. Concerning brown coal extraction, cca 2,300 kt of domestic coal supplied to the thermal power plant Nováky, represents important contribution to the state energy security (ÚV SR, 2011; MH SR, 2014).

## POSITION OF COAL IN THE ENERGY SECURITY OF THE SLOVAK REPUBLIC

The importance and the position of coal are evaluated within the current conceptual materials of the Slovak Republic, specifically in the Raw Material Policy, the Energy Policy and also in the Energy Security Strategy until 2030. The updated Raw material policy of the Slovak Republic (Resolution of the Government of the Slovak Republic No. 722/2004 as of 14 July 2004) states, that brown coal and lignite will remain the significant fuel and energy raw material in future with the principle of the rational use of opened deposits (MH SR, 2004).

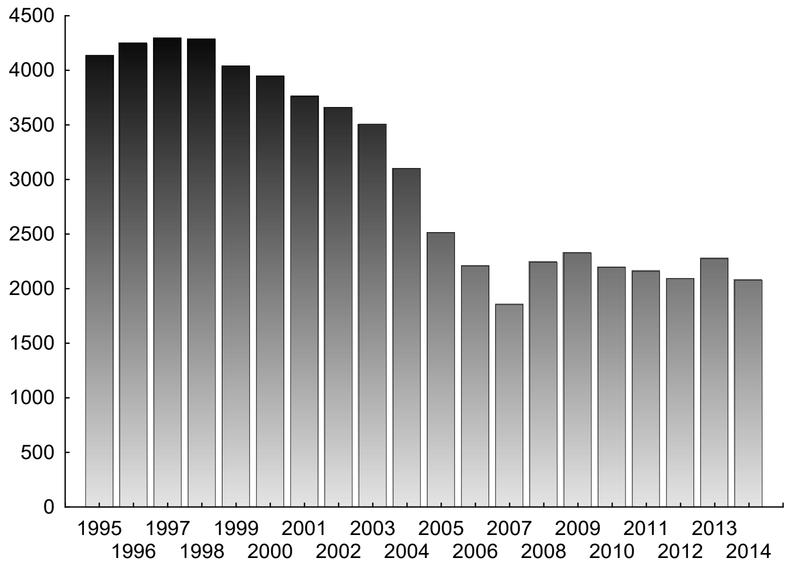
The Energy Policy of the Slovak Republic (approved by the Resolution of the Government of the Slovak Republic No. 548/2014 as of 5 November 2014), as a starting point for the development of power engineering, thermal energy, gas industry, mining, processing and transportation of oil, coal-mining and use of renewable energy sources has defined two goals of coal mining in the Slovak Republic (MH SR, 2014):

- to ensure enough domestic coal to produce electricity for the population and industry until 2035,
- to gradually replace the conventional mining methods by underground coal gasification after 2020 and thereby to ensure a synthesis gas for production of electricity and heat, resp. for chemical use.

The Energy Security Strategy of the Slovak Republic was approved by the Resolution of the Government of the Slovak Republic No. 732/2008 as of 15 October 2008. According to mentioned document exploitation of brown coal deposits contributes to the security of energy supply, particularly electricity, provides partial domestic energy self-sufficiency, leads to the stabilization of the national economy and reduces the high import dependence on precious energy resources (MH SR, 2008).

To the date of January 1, 2011 the Slovak Republic disposed of 454,051 kt of economic coal reserves and 650,831 kt of potentially economic ones. Not all of these stores are recoverable because the extraction takes place under the difficult conditions. In 2014 solid fuels accounted for 21% of gross inland energy consumption in the Slovak Republic. In the same year 3.9 million tons of hard coal and 2.5 million tons of brown coal were consumed. Domestic extraction of brown coal in 2014 amounted to 2,188 kt (see Figure 2 -), the residue was imported mainly from the Czech Republic (66 %) (ŠÚ SR, 2016). Extraction of domestic brown coal is intended firstly for the electricity and heat generation in thermal power plant Nováky, therefore extraction development is closely related to the operation of the mentioned power plant. The thermal power plant Nováky will be influenced by the new Directive of European Parliament and Council 2010/75/ES on industrial emissions, which will be applied after the year 2015. So the further progress of the coal extraction will be after the year 2015 closely influenced by the electricity and heat generation mainly in the thermal power plant Nováky.

Price of the steam coal extracted in the Slovak Republic is influenced by the incurred costs for the underground mining. Domestic steam coal is characterized by the high content of sulfur and ash, calling for the implementation of the flue gas desulfurization and fly ash collection facilities when exploited in the power plant in accordance with requirements for the implementation of emission limits set by the law. Storage of the ash causes also the increase in the operating costs. Price of electricity generated from the domestic coal is influenced by these factors too.




* the years 2006 and 2007 were adversely affected by the accident in the mine Nováky

Figure 2 - Extraction of brown coal and lignite in the Slovak Republic in the period 1995-2014 [in kt]
(Source: own elaboration based on the data from HBÚ)

Hard coal is not extracted in Slovakia. Its consumption was in the year 2014 entirely covered by import, mainly from the Czech Republic (29 %), Russia (22 %), Poland, the USA and Ukraine (ŠÚ SR, 2016). It is primarily intended for the steel industry and electricity generation in the thermal power plant Vojany (EVO). Hard coal consumption follows a downward trend. Decline in imports of hard coal in recent years is connected with economic crisis, gasification implementation and with decreased electricity generation in the thermal power plant Vojany in the Slovak Republic.

In the last decade, coal mining in Slovakia has reported a decreasing trend, which is considered to continue into the future (see Table 2 -). The largest share of the lignite mining in Slovakia has Hornonitrianske bane Prievidza, a. s. Prievidza. "*Exploitation was again restored in the mine Čáry, a.s. Čáry. In the mine Dolina, a.s. Veľký Krtíš liquidating exploitation of residual reserves is in the progress*" (Petrovič, 2010).

Table 2 -Anticipated development of brown coal and lignite mining in Slovakia [in kt]
(Source: MH SR [2014])

| | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2025 | 2030 |
|---|---|---|---|---|---|---|---|---|---|
| **HBP, a.s.** | 1 975 | 1 825 | 1 600 | 1 550 | 1 450 | 1 400 | 1 350 | 1 300 | 1 300 |
| **BČ, a.s. and BD., a.s.*** | 250 | 250 | 200 | 250 | 350 | 400 | 450 | 500 | 500 |
| **Together** | **2 225** | **2 075** | **1 800** | **1 800** | **1 800** | **1 800** | **1 800** | **1 800** | **1 800** |

*BČ, a.s. = Baňa Čáry, a.s.; BD, a.s. = Baňa Dolina, a.s.

## ANALYSIS OF THE DEVELOPMENT OF GROSS INLAND CONSUMPTION OF COAL IN SLOVAKIA

For the purposes of this paper the future development of gross inland consumption of solid fuels in Slovakia was predicted. Data from the period 1994-2014 (see Figure 3) were used applying method of regression analysis. The analysis was implemented on the basis of historical data under the "ceteris paribus" condition - all the other factors affecting the gross domestic consumption of solid fuels in the SR were considered constant. The aim was to make prognosis of the development of the gross domestic consumption of solid fuels until 2018. When modeling time series in order to forecast future values, we used quadratic equation. Estimation of the parameters of a polynomial equation was carried out in Microsoft Excel on the basis of the values of time series using the method of least squares. We visualized regression curve on the Figure 3.

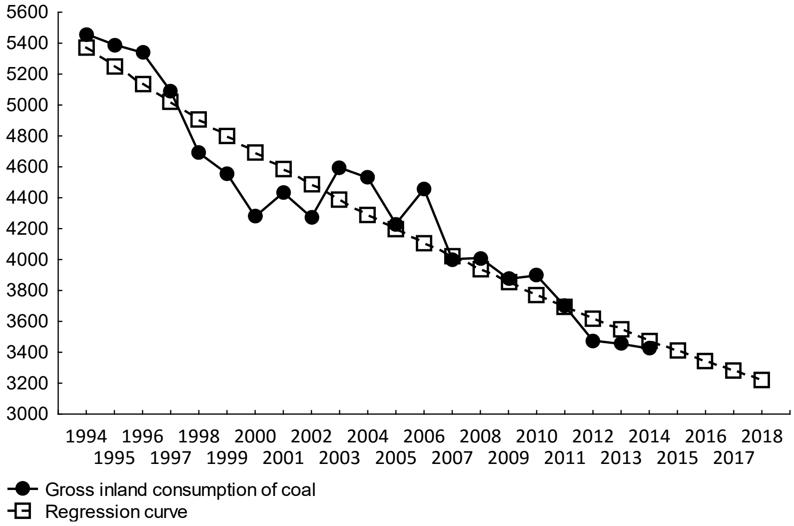



Figure 3 -Gross inland consumption of solid fuels in Slovakia in the period 1994-2014 and prognosis until 2018 (in Mtoe) [Source: own elaboration based on the data for the period 1994-2014 from Eurostat]

## ANALYSIS OF PRODUCTION OF ELECTRICITY FROM DOMESTIC COAL

Since the year 2005 the so-called general economic interest is applied for the production of electricity from the domestic coal in Slovakia. The main reason for its use is the security of electricity supply and technical safety of the power system of the Slovak Republic, where the source for electricity generation in the thermal power plant Nováky plays important role not only in covering the demand in the basic regime, but also in provision of the ancillary services, regulatory electricity supplies and hereby covering the peak consumption and system deviation in the electricity supply grid.

Based on the Resolutions of the Government of the Slovak Republic No. 356/2005 as of 4 May 2005 and No. 639/2006 as of 19 July 2006 the domestic coal use for the electricity generation was adjusted in the general economic interest (see Table 3 -). On 19th January 2010 the Resolution of the Government of the Slovak Republic No. 47 was adopted. This resolution extended the General economic interest in the production and supply of electricity from domestic coal until 2020 with a view to 2035 (ÚV SR, 2011). Optimization of production of electricity from domestic coal until 2030 was carried out after evaluating mining capabilities of our mines as part of resolution of the Government of the Slovak republic no 381 from 10th January 2013.

Table 3 - General economic interest in the production of electricity from domestic coal in the period 2005 – 2010 [source: MH SR (2014)]

| SE, a. s. – ENO* | | Approved general economic interest (2005-2010) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 |
| Electricity production | GWh | 1.651 | 1.603 | 1.603 | 1.957 | 1.881 | 1.890 |
| Electricity supply | GWh | 1.411 | 1.375 | 1.375 | 1.717 | 1.651 | 1.659 |
| Heat supply | TJ | 1.759 | 1.748 | 1.738 | 1.733 | 1.711 | 1.707 |
| Coal consumption for electricity | Kt | 2.031 | 1.936 | 1.936 | 2.179 | 2.097 | 2.102 |

**ENO* – Power plant Nováky

Based on the above mentioned resolutions of the Government of the Slovak Republic and relevant legislation (The Act No. 656/2004 Coll. on energy as amended and Act No. 276/2001 Coll. on regulation in network industries as amended) the Ministry of Economy annually issues decisions, in which it determines the obligations for generation, transmission and distribution of electricity. In relation to these decisions the Regulatory Office for Network Industries annually issues the price obligations, to predict a tariff as supplementary charge for each MWh of electricity supplied to the system that was evidently produced from the domestic coal in a thermal power plant (ÚRSO, 2012).

In the following period it is necessary to monitor the cost development in the field of electricity generation from the domestic coal to optimize the supplement to electricity price. 100% of allowances for electricity sector have to be bought at the auction from 2013. For this reason the Slovak Government imposed the Minister of Economy in collaboration with the Minister of Environment to submit proposal of measures to streamline functioning of the mining support in response to new carbon dioxide emission trading scheme in 2013 as regards the extension of the Novaky plant lifetime in 2015 until the end of March 2012 (Petrovič, Mokrišová, Ďurove, 2011).

On 5$^{th}$ September 2012 the Government of the Slovak Republic adopted Resolution No. 449/2012, which brought into force material The update of the analysis of the operation of state aid for mining industry. This Material analysis the domestic coal use current status and simultaneously proposes measures to streamline functioning of the mining support in the response to new carbon dioxide emission trading scheme after the year 2013. In paragraph B.1 of the above mentioned Resolution, the Slovak Government imposed to the Minister of Environment in collaboration with the Minister of Economy to prepare a state aid scheme for the use of revenues generated from auctioning allowances. These revenues will be used to support energy facilities for electricity and heat generation operated in general economic interest.

The aim of this task leads to the environmental measures, in particular to reducing the production of pollutants. This could be achieved by improving the technology of electricity generation with an expected reduction in the greenhouse gas emissions after 2015, with a reduction of negative environmental impact. In the case of Nováky plant, there is no way for the support of the combustion of coal under current conditions. The revenues generated from auctioning allowances will not be used on tariffs for the operation of the system but only for the reconstruction and modernization of the combustion plants which will have to demonstrate compliance with the strict environmental conditions.

## POSSIBILITIES FOR THE FUTURE USE OF COAL

Perspective for the further use of brown coal and lignite lies in its co-incineration with biomass and waste. According to Petrovič (2010) in this respect it is necessary to think of gradual increase in the use of biomass and waste, resp. gradual replacement or replenishments of the certain volumes of coal. Another possible usage of coal in the longer term is the technology of underground coal gasification. This technology was successfully tested in the Slovak Republic in 2010 by HBP, a.s. company in cooperation with the experts from Faculty of Mining, Ecology, Process Control and Geotechnology of Technical university in Košice. In that way it will be possible to achieve energy from those coal reserves, which cannot be extracted by the conventional methods of mining.

According to Energy Security Strategy of the Slovak Republic underground gasification of coal deposits under the Slovak coal mining conditions would have the following advantages (MH SR, 2008):

- would be used economically unfavorable brown coal seams in the thickness of 1.5-4 m, occurring in the peripheral sections of the coal basins, or possibly the layers from the economically disadvantageously extracting depths being not excavating-able applying the classical extraction methods;

- would be used until now not excavated pillars from the older depleted layers. Exploiting of these, until present not excavating able stores applying the classical methods, energy potential of coal deposits could be increased by up to 50%;
- the positive impact on the environment – there would be no problem with the transportation of coal and disposal of coal cash.

In the future it is also possible to apply the method of carbon capture and storage, utilization of which in Slovakia defines the Act No. 258/2011 Coll. on the permanent storage of carbon dioxide in the geological environment as amended. With regard to the carbon capture and storage the study of geological potential is being processed in the Slovak Republic (IEA, 2012). Increased interest of organizations dealing with the extraction of hydrocarbons and fossil fuels in the application of this technology has not been shown yet. Its use is expected in the longer term (IEA, 2012).

## CONCLUSION

In this contribution the domestic coal was analyzed from the various points of view and its position in ensuring energy security of the Slovak Republic was evaluated. Within the development of the technologies, the clean coal technologies, which are used in generation of electricity and heat, were designed. These technologies mitigate the pollution problems to a large extent mitigate pollution problems by considerable reducing of $SO_2$ and $No_x$ emissions and dust particles from the coal-fired power plants. They also contribute to the increase in the energy efficiency of converting coal into electricity; however there are still reserves to enhance the energy efficiency of the large coal-fired power plants through ongoing development of these technologies.

By ensuring the commercial utilization of carbon capture and storage in generation of electricity on the basis of coal there will be created a presumption for its use in the combustion processes by utilization of other fossil fuels, particularly natural gas. This allows the transition to sustainable use of the fossil fuels for energy production. In the future it will be necessary to focus on the development and industrial application of the integrated technology solutions that will joint utilization of clean coal technologies and technology of carbon capture and storage appropriately in order to achieve the electricity and heat production while minimizing $CO_2$ emissions.

Because of improvement of the clean coal technologies, thermal power plants efficiency, successful large demonstrative projects and appropriate regulatory framework for carbon capture and storage, the sustainable use of coal could form the utilizable business model for generation of electricity and heat on the basis of coal after the year 2020.

It is necessary to keep in mind that additional equipment used by the new technologies beyond 2020 will require also significant additional investments, which are difficult to estimate currently. They will depend particularly upon the level of technological development, as well as on results of research and development. For this reason also the incentives for the further use of fossil fuels in the energy sector can be justified. Their aim is to promote sustainable technologies originating in various EU mechanisms.

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# DESIGNING AND OPERATING A TAILINGS SAFETY MANAGEMENT SYSTEM: THE KEY SUCCESS ASPECTS

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# DESIGNING AND OPERATING A TAILINGS SAFETY MANAGEMENT SYSTEM: THE KEY SUCCESS ASPECTS.


## ABSTRACT

The Tailings Storage Facilities (TSF´s), particularly the tailings dams should be considered as one of the main business operational risks for all mining companies that have this structure in their process. The failure of a tailings dam brings a range of consequences to the business, ranging from operational disruption, fines and billions in repair costs to the permanent closure of the company. On the other hand, the probability of a tailings dam failure, based on available statistics is high, being in the order of 2 major accidents per year. This likelihood together with the high consequences reminds the need of adopting high-level mitigation systems in order to control and maintain the risks at acceptable levels to the sustainability of the business. In this scenario, the adoption of tailings safety and risk management systems is no longer an option to be a necessity, either for managing a single deposit, whether in the corporate management of multiple units and several mining dams.

A safety management system is composed of tools and processes to ensure that the tailings storage facility operates within satisfactory safety conditions reducing to a minimum the risks of failure. This paper aims to discuss in practical terms the organization and operation of these safety management systems, detailing the model of operation and the critical elements to ensure the effectiveness required. Among the critical elements of success for a safety management system we can highlight: Organization Chart and resource allocation, integration between technical and executive areas, preparation of standards and procedures, communication matrix, definition of key performance indicators for each TSF, reporting and follow-up, use of independent and unfiltered internal and external reviews and finally training and good relationship environment. In this paper every key aspect presented will be discussed establishing a practical connection in the design and operation of a tailings safety management system.



## KEYWORDS

Tailings Storage Facilities, Risks, Tailings Dam, Safety Management System.


## INTRODUCTION

A safety management system and risk management in tailings deposits or simply a tailings management system it is a set of procedures, tools and best practices that help to control risks involving tailings storage facilities (TSF's ) (Vick, 1990). In this paper the focus will be geotechnical risks and the tailings dams, which are particular type of TSF that involves the major risks mainly because the water storage.

Despite the primary focus on the tailings dams the concepts discussed herein apply to any type of tailings deposits such as filtered, thickened or dry-stacking. Moreover, it can also be applied to a single structure in a single mine or even several structures in various mines and even in several countries within a corporate management system. On the other hand the tools can range from simple spreadsheets and procedures to complex models using software, and georeferenced systems (GIS) and probabilistic risk analysis. The most important is not the complexity of the tools, but how they are organized and structured correctly within the company business. The figure 1 illustrates the main items in makeup of a tailings management system.


Figure 1 – Tailings management system basic components.

When dealing the implementation of tailings management systems we are directly dealing with the establishment of governance standards. It is recognized that poor governance can be associated of a series of failures or breaks of tailings deposits throughout history (Robertson, 2012).

In this context, the present work aims to provide practical recommendations for formatting, organization and operation of a tailings management system, covering and highlighting the key points that should be considered in the system preparation. Figure 2 illustrates these various successful interfaces in the preparation of a tailings management system.

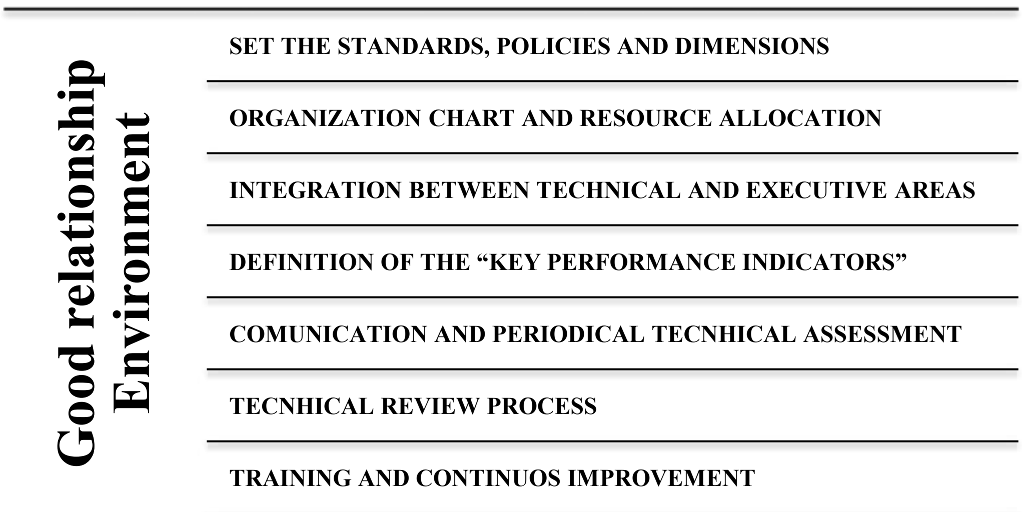


Figure 2 – Key Success Aspects for a tailings management system

The paper is structured in the form of observations and recommendations mainly based on the author's experience in functions and activities related to operation and risk management in tailings facilities. The paper aims to share with the industry these experiences and concepts and how they can be applied. It is important to mention that this work is not intended to replace the various guides and publications already available on the subject, but complementary through a practical view, updated and integrated the various interfaces that permeate governance within a management system, for example the references from ANCOLD, CDA, ICOLD and MAC guidelines, presented in the references of this paper.

The following will be discussed each of the items of the figure 2 and how they relate to each other, always focusing on preparation, formatting and practical operation of the tailings management system. The order of the items presented also is related to the logic sequence of implementation and operation.

## ESTABLISHING STANDARDS, POLICIES, TARGETS, COVERAGE AND DIMENSIONS

The first step in preparing a tailings management system is to define the objectives and system dimensions, i.e., set goals and the levels at which the issue will be dealt with in the organization. As a rule it is recommended that the tailings risk be regarded as among the top three business risks of any mining company. Usually should be the second or third, behind the own risks inherent to the ore or metal price. In a simplified way the establishment of the risk of rupture dimensions of a tailings structure can be done by answering the following question: What is the impact of a tailings break to my business? For the answer it is important to analyze the various historical cases and the overall context in which the project is inserted.

The second step in the definition of the dimensions is to assume that the responsibility upon the dam safety is the company itself. This type of risk cannot be transferred or outsourced. Currently there are companies in the market that make various services related to risk management and safety management for tailings dams, including companies that provide implementation of safety management systems services. Even in such cases, regardless of the use of specialized consultants or engineering companies, it is crucial to understand that the dam safety is an internal affair and should be "signed" by the senior management of mining companies.

After established the risk level acceptance and being fully aware at all company levels (shareholders, key executives and operations team/production) the next step is the preparation of the policy and corporate commitments related to dam safety. This policy should establish key goals and how these should be achieved and items that must be respected. An important item of any policy regarding tailings is to set the goal of zero major failure in a TSF. The policies and goals should be SMART (Specific, Measurable, Attainable, Realist, Timely) and should be prepared together with everyone involved in the safety management process.

The next step and already in line with the next item to be discussed, is the preparation and drafting of the internal procedures regarding tailings management. The procedures should describe the main processes to be applied and defining the assignments and responsibilities that permeate the system. The following will be better discussed the organizational structure of the management system and the importance of clear definition of roles and responsibilities at all levels. An extremely important item right now is the endorsement of policy and procedures by top executives.

As already mentioned this paper works on the preparation of the safety management system for the operational stage that is, assuming that the TSF has been designed and built. But it is worth mentioning the importance of defining processes and standards for design and construction of this TSF itself. It is fact that the safety management should start even in selecting the disposal technology, the site selection, the engineering firm selection, quality of the geotechnical investigations, construction supervision and quality control. For a good tailings management the company standards must consider all aspects and best available practices for design, construction, operation and closure.

Defined and understood throughout the organization as a high business risk the subsequent steps are related to the establishment of the requirements related to the risk control. In general it is not possible or is very difficult to work on the consequences of a dam break already built and in operation. So, to control these risks there is the need for actions on the probabilities as the risk is a direct relationship between probabilities and consequenquencias. To reduce the likelihood must act primarily in the organization of the management system, exactly what will be treated in subsequent items. So within this current topic the main points should be considered and highlighted:

- The failure of a tailings deposit must be considered and formalized as one of the main business risk of a mining company.
- Given the scale of the problem, it should be treated with the highest levels of the organization and with high rigor.
- The tailings safety management should be guided by policies and procedures that must be formal and endorsed by the high level of the organization.
- The formalization, dissemination and approval are essential in any tailings safety management system.
- Safety management is something extensive, ranging from the design, site selection, technology selection, construction, operation by the closure. It is a process that permeates the entire life cycle of the project.

## ORGANIZATION CHART AND RESOURCE ALLOCATION

As noted previously, the establishment of standards is essential in the format of a management system. Within the preparation of these standards is essential to incorporate the definition of the roles and responsibility of all involved in the safety management, ranging from the TSF operator to the chief executive officer. Normally mining companies are composed of lines of operation and management or executive lines. When it comes to organizational structure each company has its specific features and functions, it is not possible to generalize about an ideal organization chart or more suited to a tailing safety management system. But in general it is essential to define in the organization an "owner" for the TSF.

In the most of the mining companies the TSF is managed by the plant team. In other cases, where the deposit is of great relevance and/or large, there is the need for a separate and dedicated team to be directly responsible for the TSF management. When the plant is the responsible, like in the first case, it is essential to define someone in the team to be the key responsible for the TSF, which preferably do not share functions with production, where there could be a conflict of interest.

Within the context of the proposed management model it is recommended to establish the role of “tailings coordinator." As noted earlier, this figure may be linked to production manager or plant manager or even be directly linked to the general manager (or highest level in the production line) in the case when the TSF is of great importance and demand its own structure. The tailings coordinator is one of the most important figures within the management system. It must be the responsible for all operational and safety controls of the TSF, to generate and control this information and passing on to the other levels of the organization. Important to note that this paper is not intended to describe the roles and responsibilities of each function, but it is up to this professional to lead the process of generating information on the TSF within the management system.

Given the suggested management model the tailings coordinator will act within a matrix, being supervised managerially by the plant manager or general manager (depending on the relevance of the deposit, as previously mentioned) and technically by another professional with recognized experience in operation and safety management of TSF. This other professional, here called "Tailings management accountable" or "tailings management office (TMO)” must be positioned at a level above the highest level of production team and acting independently. In some cases this professional may be replaced by a specialized company or even be represented by own coordinator tailings, in the case of smaller companies.

Sometimes this function can be confused with the engineer of record (EOR). In fact the position of TMO is “independent” to the operation and the EOR is part of operation. Within the management model suggested the engineer of records can be the own tailings coordinator, which in itself contains the typical duties of this role. In other hand, given the high turnover of professionals registered in recent years in the mining market it is recommended that the engineer of records function has been engaged by the designer of the TSF, where possible, being the coordinator tailings only the supervision.

The important thing here is not the function itself, but the concept of the organizational structure. In this concept the TSF safety management function must take place in a "box" with specified skills to do so and be independent of production on a decision level where production targets and the mining company's cash generation does not overlap the safety goals. In this case it is important that there is a strategic "link" between the area of operations and the executive area, done by a professional with required skills and where routinely risks regarding the tailings dams are interpreted and communicated to "senior management level". The next item will discuss in more detail about the functioning and importance of this "link" between the technical and the operational area for the success of the system. Figure 3 is intended to illustrate the generic organizational chart proposed that waste safety management model.

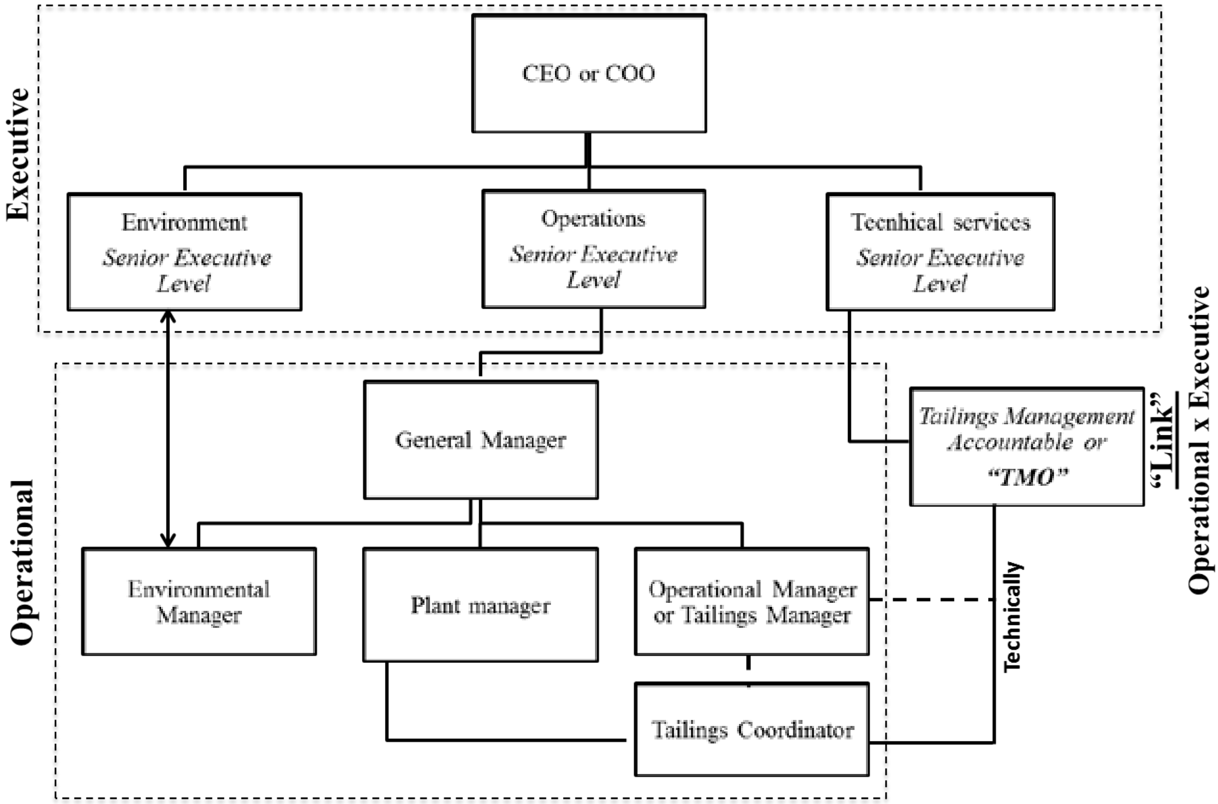


Figure 3 – Generic organization chart

It is important to be clear that each company has its peculiarities. Perhaps the only big news in this model is the definition of TMO as a specialized oversight channel. This area that supervises, analyzes and routinely reports the risks related to tailings dams should be independent of the operation and should report to an equivalent level to the highest level on the area of production. In the case of this example of Figure 3 the risks related to tailings dams are treated at senior management level where there is equivalence of forces and powers between the level of supervision and the level of operation, so there is a reduction in the occurrence of risks of conflict of interest.

Another key point when it comes to organizational structure is set directly responsible ("owner") for the dam safety. In this case the owner is the one that has authority over the budget. It is usually linked to the general manager at the production level and senior operations executive at the senior management level. In this way an important action for the success of a management system is the preparation of assignments and responsibilities for each level and incorporating the budget validation by the technical (TMO) and operational areas. In this case there must be a strategic alignment between those responsible for the management system at the operational level in conjunction with those responsible at the senior management level. So within this current topic the main points can be highlighted:

- The preparation of an organizational chart with clear role definitions and responsibilities for all organizational levels and battery limits is essential for a tailings management system.
- It is important to define the "owner" of the TSF and also those responsible for the safety management. The "owner" of the TSF should be one that has authority over the budget.
- The budget preparation process should be done by the area of operations and validated together with the TMO (tailings management office);
- There must be an external oversight channel and independent of the operation team, which is not bound to the objectives and production targets. This channel is also responsible for the technical alignment between the operational level and the executive level and for the technical guidance for the operation team.

Indeed, the safety management model suggested in this paper one of the key pieces of success in the governance is the presence of this external oversight channel, which will be more fully discussed in the next item.

## INTEGRATION BETWEEN TECHNICAL AND EXECUTIVE AREAS

As mentioned in the previous item the good governance requires a good organizational structure and a perfect strategic alignment between operational and executive areas of a mining company. In this context the presence of the “external” oversight channel is really important in the assembly of this structure and it´s functioning. This oversight channel was here called TMO, making an analogy with the project management and the Project management offices (PMO). Within the context of mining companies that function can be performed in several ways. It can be done by an employee of the company but "external" TSF operation team (geotechnical engineer), by a group of specialist engineers, the local coordinator of tailings or even by an external company. Again the format setting will depend on the size of the company, the relevance of the TSF and / or also the number of sites or dams. For purposes of this paper the important thing are the concepts.

The presence and TMO operation allows the risks related to the tailings management system are routinely assessed within a platform with the skills and competencies required. Moreover, to be "external" and independent from the operation allows that the evaluations are free of filters and conflicts of interest; and properly interpreted and dimensioned so that there is understanding by the executive level. In this model the flow of information about the TSF and its risks is unfiltered and faster, as well as decision-making, which also begin to occur in the most appropriate levels. Below the TMO main requirements:

- Have character "independent" and external to the operation, even using an employee of the company.
- Have specific goals and linked to dam safety. Not be linked to production targets.
- The TMO must not concentrate administrative functions, focusing mainly on the provision of technical services to the TSF operations. Administrative functions should be concentrated in the operational area.
- It is linked to the senior executive level of the company. Despite being a technical function, should also have the executive profile, always remembering that this matter affects directly the business running activities.
- Having recognized expertise in risk management and tailings safety management.

In addition to all the advantages already presented a very positive point of the TMO operation is the load reduction for the operation team who can give the necessary focus to production knowing that the risks are continuously monitored. In subsequent items will be possible to have a better understanding of TMO functions within the operation of the proposed tailings management system.

## DEFINITION OF THE “KEY PERFORMANCE INDICATORS” FOR EACH TSF

At the tailings management model suggested the geotechnical risks for each TSF are continuously monitored through periodic evaluation of the "Key Performance Indicators" (KPI's) for each TSF.

The KPI's essentially consist of the main set of data from geotechnical monitoring of the TSF and periodic technical field inspections carried out by the operating staff. The monitoring data includes readings from piezometers, surface landmarks, flow drains, water level of the reservoir, length of the beach, etc. The TSF operating data, like tailings production, solids percentage, particle size, compaction control, are also considered a KPI´s. Especially the monitoring of the water balance is a strategic item to be monitored in the TSF, because the amount of water is an issue directly associated with the safety condition. Finally, the safety inspection statements should contain the main field observations related to dam safety, as state of conservation and presence of anomalies.

Although generally be composed of geotechnical monitoring data, operating data and field inspection data, the KPI may vary depending on the tailings deposit characteristics, the type of technology employed and must be established in conjunction with the designer company for each TSF. In general it is recommended that the KPIs are directly aligned with the potential failure mode of each TSF, which must already be identified in the design and construction steps, as well as revised during operation. It is critical to the success of monitoring via KPI`s they are understood by the operating staff and the supervision team (TMO), establishing acceptance limits for each KPI.

It is important to note that the KPI´s should be routinely reviewed based on the characteristics of deposits and its operation. The KPI's review requirements will be detailed again in section dedicated to the review process. The next section will discuss the TSF performance assessment process through the periodic analysis of the KPI's.

## COMUNICATION AND PERIODICAL TECNHICAL ASSESSMENT: REPORTING STRUCTURE

Defined the procedures and policies, the organizational structure, roles and responsibilities and KPI's for each TSF the next step is the performance review process. This process basically consists of technical analysis on a monthly basis of the KPI by the operation team and also by the TMO. The first interpretation gate must be made by the operating team as soon as the data is collected. The second gate of interpretation is done by the TMO as an independent process. Of course the data can be discussed between operation and TMO. This process is called performance analysis and basically consists in the interpretation of the data generated by the TMO and the monthly ranking of TSF based on the risk category. Suggested risk categories are basically satisfactory, satisfactory with restriction and unsatisfactory. Each category has its peculiarities, which are presented in the figure 4. The decryption, actions required, and level of decision should be adjusted for each mining company.

● Satisfactory safety condition ● Satisfactory safety condition with restriction ● Unsatisfactory safety condition

*Note: Small yellow dots means pending actions to be performed or continuous actions; small red dots means delayed actions*

| "TSF" stability Status | Description of the Condition | Action needed | Required decision level |
|---|---|---|---|
| Green | All safety, design and operational requirements are met. | Requires no action, except if there are any outstanding recommendation (see small dots). | Operational management level. |
| Yellow | There are safety, design or operation requirements that are not met. There is no imminent risk of major failure. Or, for three consecutive months a recommendation (small dots) is not met | Condition not acceptable in the system. Requires adequacy actions and constant follow-up by the senior team. Need to increase monitoring and supervision. Immediate visit from Tailings Specialist or Designer/consultant or both. | Senior Management Level |
| Red | There is significant risk of major failure and/or a destabilization process in progress. Requires the immediate attention from the mine, designer company and experts. | Resource mobilization for rapid resolution of the hazardous condition. Communication to the COO and CEO. Crisis committee should be established to coordinate actions. The ERP should be activate. | Senior Management Level including the COO. |

Figura 4 – Suggested Scorecard

Each monthly performance review should generate a short report, which is the formal record of the technical analysis done by the TMO, which includes all the observations and recommendations. This report shall be sent to operation team and the chief executive responsible for that operation. An important success factor is just the formalization of the monthly review process by the TMO. Since the submission of the data, their discussion, validation, analysis and report preparation is done in accordance with a formal standard (see preparation of standard item), with clear deadlines and responsibility lines.

As seen in Figure 4, significant risks should always be communicated to senior management level, which then must take responsibility for the rapid resolution of the problem to reach to the minimum safety requirements set out in the company policy. Within the tailings management model proposed the TMO also generate a monthly summary report that is sent to the senior management level and containing the key findings and key recommendations of each TSF. The idea is always keep the senior level aware of the risks related to the TSF. Here it is important to highlight that the policy should state that conditions such as yellow (satisfactory with restriction) and red (unsatisfactory) should not be accepted by the organization. This is indeed a success key aspect.

**TECNHICAL REVIEW PROCESS**

As discussed previously, within the proposed management system model, TSF's operational risks are continuously reviewed on a monthly basis by the TMO, which makes the analysis of KPI's and routinely evaluates the TSF safety condition. As already mentioned the TMO must be an element of the company and even if it has "independent character" needs to be crosschecked. In this context the technical review process in this model of tailings management considers two types of review. The annual review and a complete review in audit level every two years, like a peer-review panel.

The annual review is a rather simple process and basically consists of contracting an external reviewer (a company or independent professional) that will make a technical visit of the TSF and examine all data geotechnical monitoring and performance of the structure. All generated monthly reports will be available, as well as all the information generated during the year. Who coordinates this process is the TMO together with the EOR and the local tailings coordinator. This annual review can be made by local companies, but preferably with prior knowledge of the TSF. The final report is destined to the local operation.

The other type of review, more detailed, is called independent external audit. This audit must have totally independent character of the designer, construction or operation and is expected to be held every two years. This audit is rated the dam project, developed studies and operation, as well as the whole process of safety management and operation. In this audit the focus is to evaluate in depth the performance of the TSF in comparison to the original design, evaluating the history and applied management processes. It is in this audit are reviewed potential failure mechanisms of TSF in conjunction with the review and restatement of KPIs used for the monthly analysis of performance. The report generated by the external audit should be presented to the senior management team, including CEO of the company. This is like an audit "certification" of the management system and should include an updated "risk analysis" of the TSF.

Within the review topic is important to note that a very important item to success is the correct reviewer selection. In addition the minimum requirements for each type of revision must also be clear and also incorporated in the waste management standard. The review requirements should also be aligned with the best international practices.

## TRAINING AND CONTINUOS IMPROVEMENT

For the success of any management system is essential to have a full understanding from all parties involved, from the operation team to the senior executive level of the company. In this context the training program should be coordinated by the TMO and should include specific modules for each level of the organizational structure. The operating staff demands more practical training on safety management and dam operation, focus on identification, dimensioning and communication of risks. As for the highest levels of the organization the training should have the focus of showing how the dam safety affects the business using case studies and institutional aspects. The trainings aim to maintain strategic alignment and engagement of people at all levels of the organization. The training process can be carried out through handouts and presentations, always coordinated by the TMO. It also is recommended conducting periodic workshops of dam safety, which aim to share experiences and reaffirm the alignment across the organization.

From the continuous improvement point of view the review process discussed in the previous section always generates a series of recommendations for the TSF and also for the governance and management system processes. All these recommendations should be centralized and taken as points of improvement being continuously monitored and updated by the operating teams with the TMO.

## GOOD RELATIONSHIP ENVIROMENT: TRUST

Relationship is the drive for success in any management system. Especially when dealing with tailings management (a high risk structures) is essential to have a reliable and transparent environment between the parties involved. It is critical for the success of the management system that there is no "filters" in any of the processes discussed in previous sections. Adverse situations should always be reported and the communication must be clear and based on principles of ethics and responsibility, focusing on the final result that is the minimization of tailings risks. It should always be looked for the relation win-win, avoiding competition and over-charging. Everyone should be aware of their responsibility and importance to the successful in the management system operation and consequently to control the risks involving the tailings deposits.

## SUMMARY

The safety of tailings storage facilities should be understood as a process and therefore must be guided by routines, principles, policies and records, which must be formalized, disseminated and respected. Analyzing historical and recent cases of tailings dam failures is noted that most of them can be associated with any negligence or failure in the governance. The presence of “filters” and the lack of appropriate communication channels are bad elements in the tailings management and are direct proportional to the increase of the risks.

Within this context, this paper provides a practical view of construction and operation of a model of tailings management system highlighting the key concepts of success. This model brings a series of recommendations and formats of organization that aim to "fill" some gap´s normally identified in the management of these complex structures called tailings storage facilities.
This is a set of opinions and concepts that are based on experiences of author over the years in operation and management functions and which must be interpreted in the form of improvement suggestions to the mining industry. Although many recommendations seem obvious it appears that most mining companies still deal with tailings with unappropriated governance standards.

Using this "directives" presented in this paper in the form of guide, the following concepts are “key” in preparing a tailings management system:

- Recognizing the tailings risk as a business risk and set it as one of the main company risks.
- Preparation of standards and the establishment of a tailings management policy that must be formal and endorsed by senior management level of mining companies, including CEO.
- The organization must be a TSF oversight channel that is independent of the operation and is directly connected to the company's top management. This channel has the role to interpret technical risks in business risks, helping decision makers on issues related to tailings management.
- KPI's adoption for each TSF. The KPIs should be full understanding of the operating and oversight teams.
- The adoption of TSF performance assessment in monthly bases. The process should be formal and issuing monthly safety condition report. The adoption of monthly analysis allows deviations are identified early and on time to be fixed.
- “Vertical” communication of the TSF safety condition. Decisions about risks in TSF's should be taken at the appropriate level, preferably at senior level, cannot be limited to the “operating environment”.
- The review process should be understood as a "cross-check" of the entire process of safety management and not just as a "gate" to indicate whether the structure is stable or not.
- The adoption of formal processes, as well as its dissemination and frequent training helps in the elimination of "filters."
- The construction of a tailings management system should seek to create an environment of trust that prevails transparency in all processes and interactions.

Given the high risk associated with tailings dams it can be seen that the tailings management systems, in well organized, provided good tools to control the tailings risks. On the other hand the adoption of appropriate practices of engineering and construction, as well as the correct selection of the disposal method (with the use of technologies that reduce the amount of accumulated water) are complementary elements in reducing the consequences involving the breaking of a tailings dam. This practices and standards with a good tailings management system minimize the risk of these tailings deposits to a minimum and acceptable to the sustainability of the mining business nowadays.

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# DOES MINE LAND REHABILITATION RESTORE ECOSYSTEM SERVICES?

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# DOES MINE LAND REHABILITATION RESTORE ECOSYSTEM SERVICES?

## ABSTRACT

Current best practice in mine rehabilitation usually evaluates outcomes against targets such as vegetation growth, plant diversity or soil parameters. However, ecological gains from rehabilitation do not necessarily restore the social uses of the affected ecosystems. The concept of ecosystem services (ES) provides an integrative approach to gauge to what extent restoring ecosystem functions also improves human well-being. An ecosystem service-based procedure to evaluate land rehabilitation in mining is being developed and is discussed here. International recommendations on good practice for mining rehabilitation and for consideration of ES in decision-making contexts were compiled and structured in a step-wise procedure for assessing land rehabilitation. The procedure is being tested in a bauxite mine in the Amazon region where rehabilitation has been monitored for three years. The case is particularly interesting because rehabilitated areas will be returned to riverside communities highly dependent on local natural resources. Therefore, it is essential that the rehabilitated areas ensure long-term community livelihoods. A land cover map was prepared using remote sensing to support ES analysis. As preliminary results, criteria to prioritize ecosystem services and guidance to include them in rehabilitation actions are presented.

**KEYWORDS:** Bauxite, mining, reclamation, mapping ecosystem service, land cover map

## INTRODUCTION

As mining strongly modifies ecosystems, it affects their capacity to provide essential benefits to society, called ecosystem services. Assessing impacts on ecosystem services has been recommended since 2006 by the Convention of Biological Diversity's "Voluntary Guidelines on Biodiversity-Inclusive Impact" (CDB, 2006) and strengthened after the publication of the International Finance Corporation's Performance Standards on Environmental and Social Sustainability (IFC, 2012). Therefore, ensuring that mine land rehabilitation can result in actual restoration outcomes in terms of both biodiversity and the ability of ecosystem to provide services are critical to secure a social license to operate. The concept of ecosystem services (ES) provides a promising yet underexplored avenue to conceptualize ecological and social impacts of mining (Rosa and Sánchez, 2015) and to frame rehabilitation in order to evaluate its outcomes.

The quality and quantity of services provisioning depend largely of ecosystem functions (Maestre et al., 2012). Restoring ecosystem functions is not an easy task, especially in case of mined sites, because the more degraded is an ecosystem, the less effective is restoration (Bullock et al., 2011). In addition, the effectiveness of restoration programs in increasing biodiversity and ecosystem services has not been properly evaluated. Rey-Benayas et al. (2009) demonstrated through a meta-analysis that ecological restoration increased biodiversity 44% while provision of ecosystem services 25%.

Currently monitoring the progress of rehabilitation is usually based on ecological indicators such as diversity, richness and vegetation cover (Clements et al., 2010), but the achievement of a stable post-mining condition cannot be demonstrated by tracking the trajectory of a selected array of fauna or flora species (Harris e Diggelen, 2010). This kind of indicator is not sufficient to demonstrate the restoration of ecosystem services, because it does capture the social benefits provided by restored ecosystems. In fact, finding long time series monitoring based on biophysical and social indicators is not common (Wortley et al., 2013; Nunez-Mir et al., 2015). Aronson et al. (2010), who reviewed 115 papers published from 2000 to 2008 inquiring if monitoring program considers socioeconomic benefits, found that only 3% of papers presented some social result from monitoring programs. Therefore, one key question in mine land rehabilitation is: How can stakeholders know when a land was rehabilitated?

Preliminary results of an ongoing research aiming at developing a procedure to assess mining land rehabilitation through ecosystem services is presented in this paper. Considering that mining often affects large sites and the frequency require by conventional techniques of land monitoring, it may become costly and impractical (Duzgun and Demirel, 2011). In addition, indicators of land rehabilitation should be easily measurable, adaptive, and sensible to temporal and spatial changes (Harris e Diggelen, 2010). Therefore, remote sensing is a valuable tool to provide data a cost-effective mean, that has being applied to map and quantify ecosystem services supply. The ES concept is an opportunity to demonstrate the social gains of mine rehabilitation processes, due to its integrative nature (Nunez-Mir et al., 2015).

## METHODS

The research was carried out in two phases. Firstly, a concept of how to evaluate land rehabilitation outcomes based on ecosystem services was developed by reviewing best practice of mine rehabilitation and the state of practice of ecosystem services mapping. A procedure for assessing land rehabilitation will result from this phase and will be tested, in the second phase, in a bauxite mine where a regular rehabilitation program is being developed (Figure 1). Literature review showed that the main tool to identify, to map and to assess ecosystem services is a land cover and use map. Hence, land cover and use map of the study area was prepared at the 1:25,000 scale using a RapidEye satellite image of 2014. Ecosystem services provided by each land cover class were identified using the methods proposed by Burkhard et al., (2010). The satellite image was processed using ENVI 5.3 software, through the maximum likelihood algorithm. The map was finalized in Quantum GIS 2.10 software. Field work and GPS control to check land cover classification was conducted from November 8 to 12 2015.

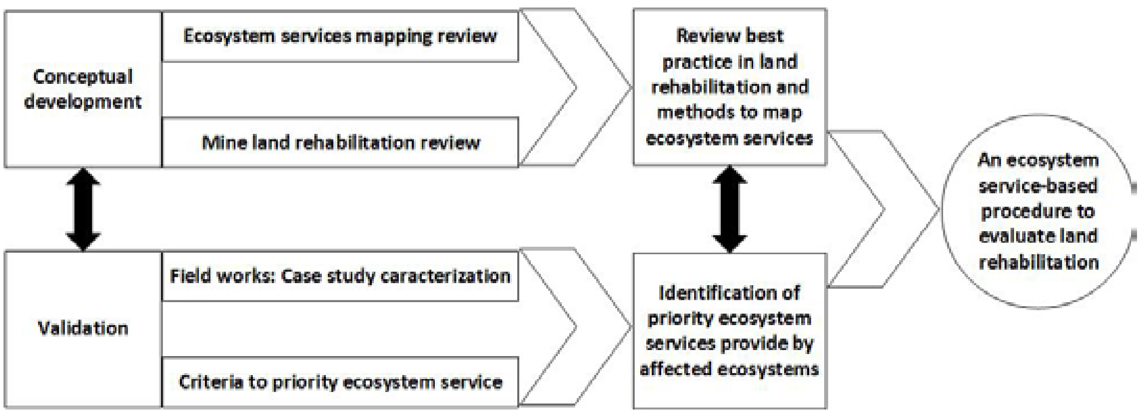


Figure 1 - Research methods.

## A SHORT DESCRIPTION OF THE CASE STUDY

The Juruti Project, located in the western end of Pará State, in the Brazilian Amazon, is composed by a bauxite open pit, a 55 km railway and a river port. The mine is owned by Alcoa, a global company specialized in the aluminum stream. After obtaining government environmental approvals in 2005, Alcoa initiated project construction and started operations in 2009. In addition to the open pit, the mine has a beneficiation plant, three tailings storage facilities, a water pipeline, and ancillary installations. The land rehabilitation program started as soon as construction ended by rehabilitating sand and gravel pits along the railway. In the mine area, rehabilitation trials started after the first area was available, as strip mining allows for progressive rehabilitation. The first pit will have 5,500 hectares at its final extension. Two new pits are already scheduled and additional pits will be established in the future. Current mine output is 3Mt/y.

Vegetation in the mine area is mostly rainforest in very good conservation status despite selective timber harvesting in the past. Nearby riverside communities extract Brazil nuts, acai berries and develops subsistence agriculture and are highly dependent on fishing.

The mine is located in federal lands whose rights of use were granted in 2005 to an association representing 25 communities' claims to a land title became stronger with the announcement of the mining project and the corresponding environmental impact assessment (Lopes, 2012).

A condition of the environmental approval is that rehabilitated land be returned to communities. Therefore, the objective and actual outcomes of the land rehabilitation program is very important to local communities, because when each mining pit is decommissioned, it should be used to the communities to maintain their livelihoods.

**The land rehabilitation program**

Rehabilitation works started in 2012 with the nucleation method, which is a part of an approach called systemic restoration (Reis et al., 2010), that aims at integrating the rehabilitated area within a conserved landscape. The nucleation method employs several techniques to reduce landscape fragmentation in order to facilitate natural restoration. For that reason, the company applied the following techniques: (i) immediate soil translocation; (ii) preparation of artificial perchs; (iii) planting functional native trees; and (iv) artificial shelters. A preliminary analysis (Table 1) of implementing rehabilitation program was performed through a rapid appraisal based on document review, field observation and interviews.

Table1 - Preliminary analysis of the land rehabilitation program developed at the Juruti mine

| Activities of land rehabilitation | Preliminary evidence |
|---|---|
| Immediate translocation of soil, roots and branches | Immediately after vegetation suppression, topsoil is disposed of in rehabilitation areas |
| Improving mining extraction to result in a topographic condition better suited to restoration | Mixed application: in a number of rehabilitation stands, contouring mimics natural landforms, but high walls are visible in other stands |
| Establishing restoration modules according to the nucleation method | Older modules were prepared according to prescribed techniques, but more recent restoration modules do not fully comply with prescribed techniques |
| Creating roughness in modules to control erosion and retain water | This activity was not investigated and will be a focus of the next field campaign |
| Reorganize seedling production, involving local communities | Limited evidence obtained through field work confirmed the application |
| Training Alcoa's team to develop land rehabilitation | This activity was not verified, because it is considered not relevant for the research |

| Activities of land rehabilitation | Preliminary evidence |
|---|---|
| Propagating the result of the land rehabilitation program to stakeholder. | This activity was not verified, because it is considered not relevant for the research |
| Monitoring and annually reporting results to government | All annual reports are being reviewed |
| Elaborating ethnobotany research to identify and characterize key species | This activity was not investigated and will be a focus of the next field campaign |
| Gauging the seedling production developed by communities | Stakeholders from local communities and company tell about the training program that include the standards of seedling production |
| Involving stakeholders in decision-making of future use of rehabilitated land | This activity was not investigated and will be a focus of the next field campaign |
| Using internal haulage roads to tailings storage | At the time of the site visit, decommissioned roads were being prepared for this end |

In 2013 the company suppressed 73 hectares of vegetation and started rehabilitation of 42 hectares approximately. In 2014, 138 hectares were suppressed while rehabilitation was initiated in 72 ha (Figure 2). Estimation of suppression and rehabilitation for the next 3 years are also shown. The balance between the suppressed area and the area under rehabilitation is approximately constant and corresponds to areas used for permanent infrastructure (workshops, beneficiation plant, etc.). In addition, the tailings storage facility has not been recovered because it did not reach its final capacity. Moreover, it requires a different rehabilitation approach due to substratum physical condition (Almeida and Sánchez, 2015).

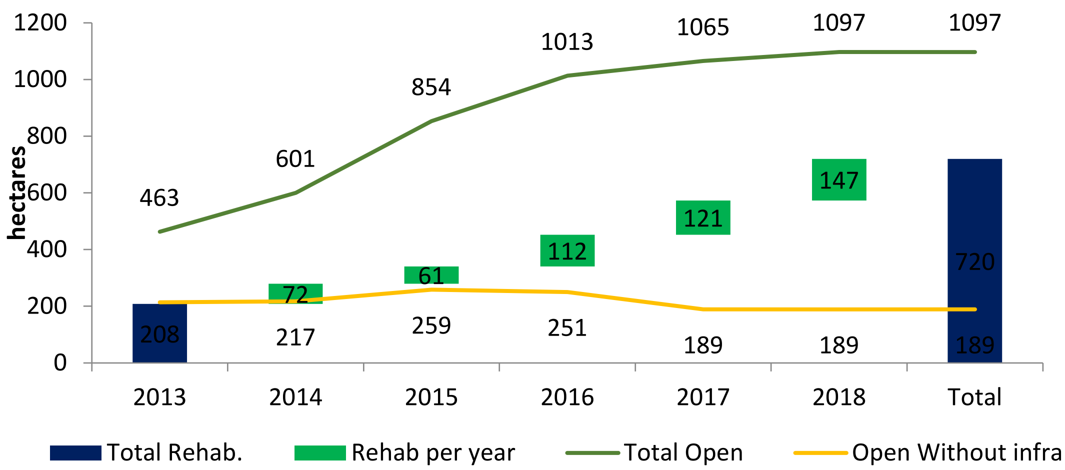


Figure 2 – The development of suppression and rehabilitation in the Juruti mine.
Source – Internal documents of Alcoa (2015).

Monitoring collects data on classical vegetation descriptive parameters, such as diameter at breast height, diameter at soil height, total height and diversity. The monitoring process also collects data about soil erosion, land cover density and fauna attraction, usually collected once a year. In addition, the company carries on other monitoring programs that could be of interest to assess the outcomes of the rehabilitation program, namely fauna monitoring, forest inventory and water quality monitoring.

**RESULTS AND DISCUSSION**

The remote sensing analysis of the study area resulted in a land cover and use map with seven classes (Figure 3). It was possible to separate native vegetation from degraded vegetation and areas featuring recovering vegetation. It was also possible to separate anthropic uses and mineral extraction sites. The confusion matrix showed the classification reached a good level of accuracy, 93% (kappa index 0.89). The main confusion was between degraded and recovering vegetation. Although the classification accuracy was high, the confusion is concentrated in the two most important classes for this research.

The land cover and use map associated to the rapid appraisal are the main tools to develop an initial identification of ecosystem services. Based on previous experiences (Rosa and Sánchez, 2016 submitted) and on recommendations from literature (Burkhard et. al. 2012; Landsberg et al., 2013), we related the land cover and use classes mapped (Figure 4) to a list of ecosystem services.

Figure 4 presents the potential of ecosystem service supply, in accordance of the scale suggested by Burkhard et. al. (2012). We added a column supporting the classification based on information extracted from the Environmental Impact Study of the project, on rapid appraisal performed and on monitoring reports. The project entails two types of drivers of change: (i) change in land cover and use; and (ii) increase of demand for ecosystem services by attracting people or by utilizing natural resources.

The ecosystem service analysis is based on a temporal or spatial analysis (Barbosa et al., 2015), i.e. it aims at understanding environmental changes that influence ecosystem services provisioning. A method to perform this kind of analysis is interpreting a time series of satellite images (Abdullah et al., 2016). A number of software and models have been developed to measure and map ecosystem services (Nemec and Raudsepp-Hearne, 2013). All use a common basic element, a land cover and use map (Ayanu et al., 2012 Barbosa et al., 2015).

Therefore, the precision of ecosystem services quantification is directly related to the accuracy of land cover map classification (Eigenbrod et al., 2010). In addition, spatial resolution and image quality influence the ecosystem services mapping (Baral et al., 2013), the number of classes established (Kandziora et al., 2013), and the technique used to classify (Barbosa et al., 2015). An overestimation of any particular class can result in overestimating the provision of some ecosystem services.

For practical reasons, it is not possible to utilize all ecosystem services supplied as indicators to monitor rehabilitation. Therefore, it is necessary prioritize the ecosystem services more able to inform about the status of land rehabilitation. Five criteria were used to prioritize ecosystem services (Figure 5). The first two criteria aim at selecting only the ecosystem services affected by the project. The remaining criteria select services that can be used as indicator of physical, ecological or social benefits from the rehabilitation program.

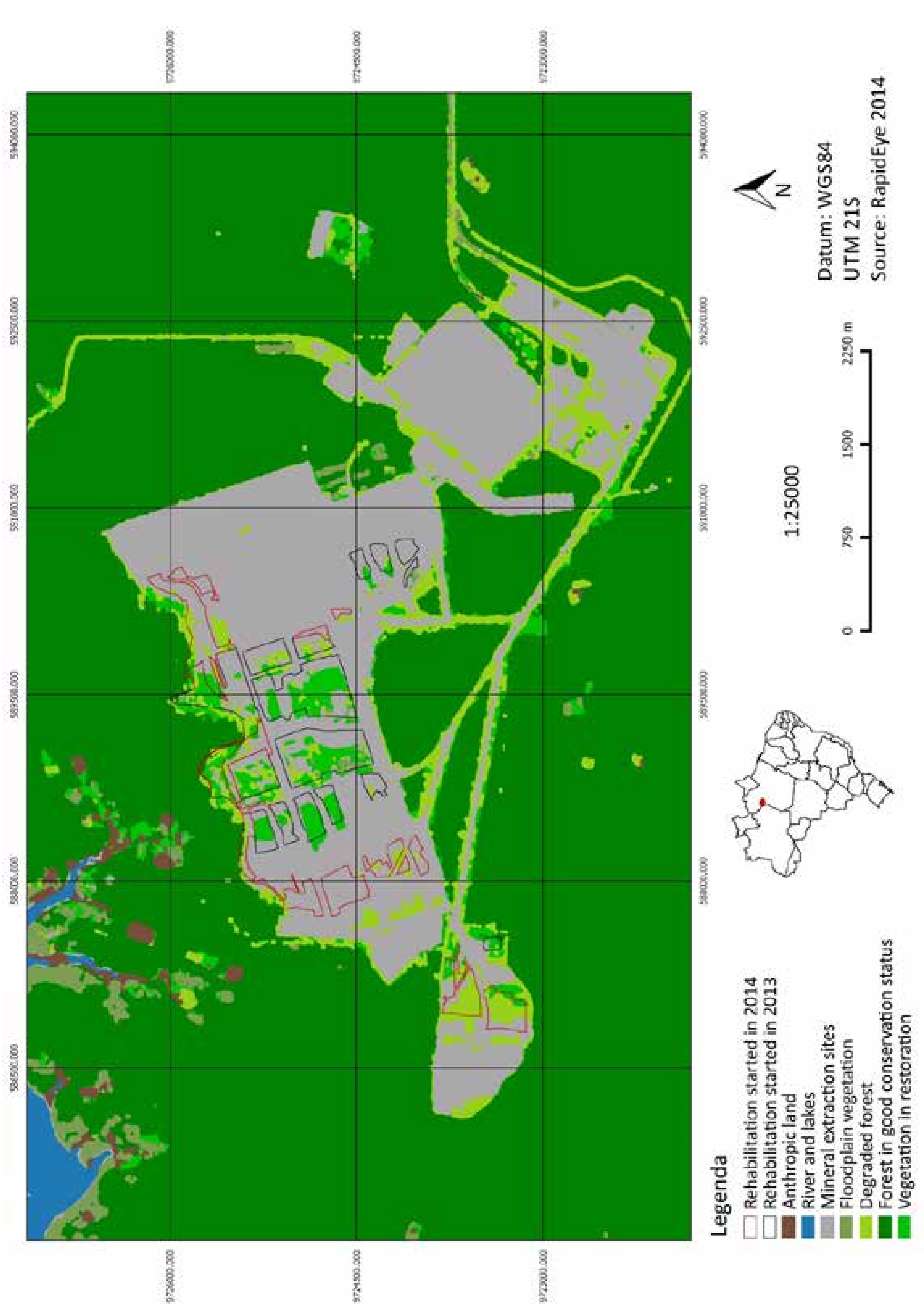


Figure 3 - Land cover of Juruti Project elaborated from RapidEye satellite image (2014).

| ***Land cover and use classes*** | **Ecosystem services** | | | | | | | | | | | | | | | | | | | | | | | ***Comments for supporting classification based on information from studies of environmental impact study, on rapid appraisal and on monitoring reports of rehabilitation program*** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Crops | Livestock | Capture fisheries | Wild foods | Hunting | Timber | Biomass fuel | Freshwater | Genetic resources | Biochemical/ Medicines | Diseases regulation | Air quality regulation | Local climate regulation | Water regulation | Erosion control | Water purification | Regulation of diseases | Soil quality regulation | Pest regulation | Pollination | Recreation | Educational values | Nutrient cycle | Primary production | |
| Forest in good conservation status | **0** | **0** | **0** | **5** | **5** | **5** | **2** | **5** | **5** | **4** | **5** | **5** | **5** | **4** | **5** | **5** | **5** | **5** | **5** | **5** | **5** | **5** | **5** | **3** | Amazon Forest provides almost all ecosystem services. There is no river in this classes, hence capture fisheries is not provide. It is an old forest hence it present medium capacity provide primary production. |
| Degraded forest | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | This class represent areas in process of vegetation suppression. Therefore, we consider that there is no supply of ecosystem services. |
| Vegetation in restoration | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **1** | **1** | **1** | **1** | **2** | **0** | **0** | **0** | **0** | **1** | **0** | **4** | **3** | **4** | According to monitoring reports older recovered areas control erosion, there is interaction between insects and plants. In these areas, there is high primary production and nutrient cycle. |
| Floodplain vegetation | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **2** | **4** | **5** | **4** | **0** | **2** | **0** | **0** | **5** | **5** | **0** | **3** | This a typical kind of Amazon vegetation that is important to controlling erosion, helping water purification. Local communities use these areas for recreation. |
| River and lakes | **0** | **0** | **5** | **5** | **0** | **0** | **0** | **5** | **0** | **0** | **0** | **0** | **1** | **2** | **0** | **5** | **0** | **2** | **0** | **0** | **5** | **5** | **3** | **0** | Socioeconomic studies from EIS demonstrated that local communities fishing, collecting fruits, swimming. Rivers usually regulation water flows, soil quality and purifying water. |
| Anthropic land | **5** | **5** | **0** | **0** | **0** | **3** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **2** | Local communities suppress vegetation to take timber and to develop crops and livestock in a subsistence scale therefore this land cover has relevant capacity to provide primary production. |
| Mineral extraction sites | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | This classes mainly mined land, hence there is no previsioning of ecosystem services. |

Figure 4 – Matrix for identifying ecosystem services provisioning by each land cover and use classes. The scale to estimate the capacity of land cover and use to provide each ecosystem service is from 0 to 5, and was defined in accordance with Burkhard *et al.,* (2012). 0= no capacity of land cover and use class to provide this ecosystem service. 1= low capacity. 2= relevant capacity. 3= medium capacity. 4= high capacity. 5= very high capacity.

The third and fourth criteria were organized in accordance with Harris and Diggelen (2010), who propose the concept of barriers for the rehabilitation process. They define two kinds of barriers, the physical one, related to topography, soil contamination, low level of organic matter and other physical or chemical barriers. The second frontier is biotic and refers to the absence of fauna species or the interaction between biotic and abiotic elements of the ecosystem. The latest criterion will demonstrate the social benefits of rehabilitation program. The decision tree for prioritization (Figure 5) will be reviewed by stakeholders (namely local communities, company and experts) and adjusted as needed. The level of ecosystem degradation indicates the need for the three level of ecosystem services indicator (Jorba and Vallejo, 2010). As mining degrades soil, it will be necessary to select at least three ecosystem services. For the case study, preliminary results selected : erosion control, carbon sequestration and provisioning of wild food (Brazil nuts) as priority ecosystem services..

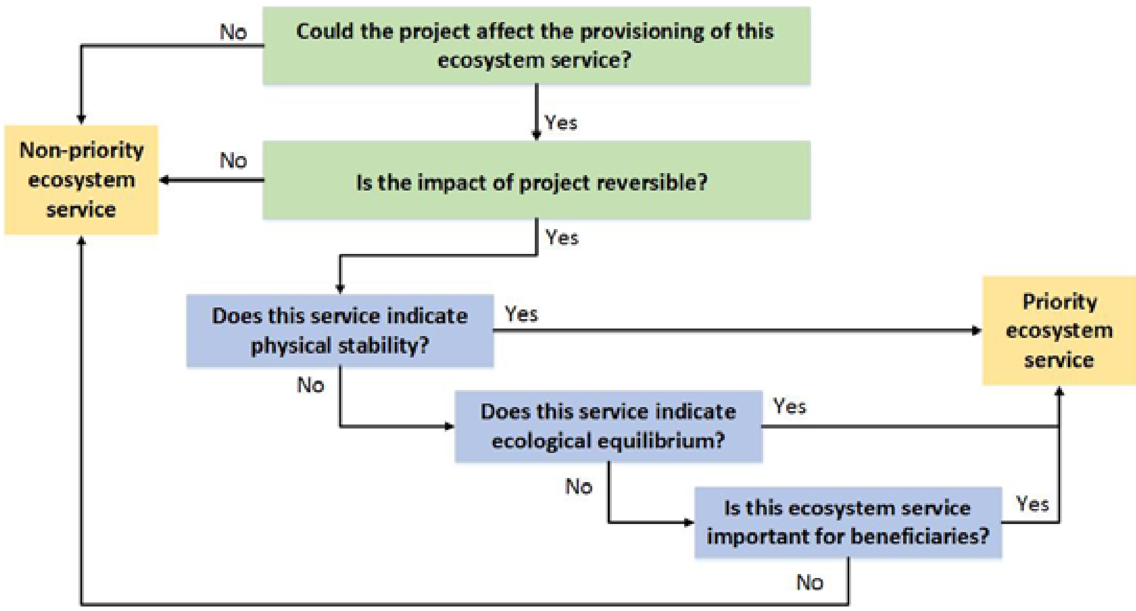

Figure 5 – Decision tree to select priority ecosystem services.

Although mine land rehabilitation can restore ecological processes and consequently improve the ecosystem services supply, rehabilitation does not automatically lead to restoring ecosystem services. Applying the ecosystem service concept in environmental assessments require at least two essential tasks, integration of ecological and social issues and the communities' involvement (Rosa and Sánchez, 2015). In addition, the land rehabilitation program should focus on the most important ecosystem services to communities (Figure 6).

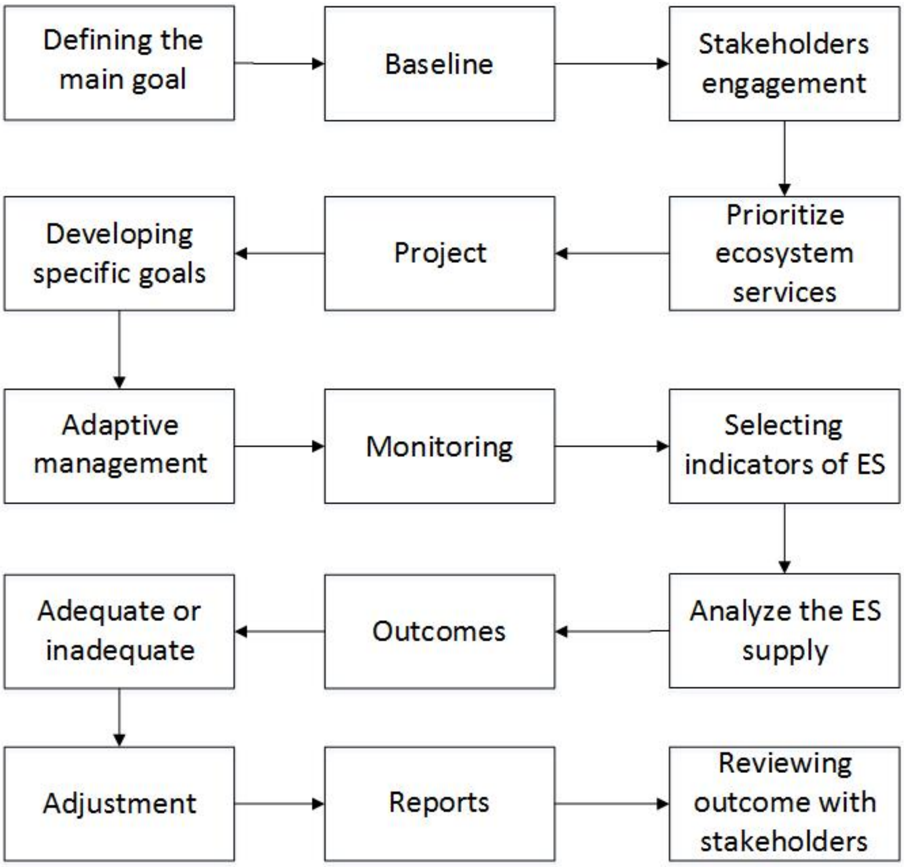


Figure 6 – Preliminary step-wise procedure to include ecosystem service concept in mine land rehabilitation

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# EMPLOYABILITY ANALYSIS IN THE FUTURE OF MINING ENGINEER IN CHILE

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# EMPLOYABILITY ANALYSIS IN THE FUTURE OF MINING ENGINEER IN CHILE

## ABSTRACT

In Chile there have been universities that have trained thousands of mine engineers over the country's history for decades. Since 2010 multiple academic projects were generated around the career of Mine Engineering, based on the large investments and high demand for qualified jobs that was projected by government agencies for the 2010 – 2025 period. Based on this, public and private universities and professional institutes started careers linked with mining, encouraged by the media, which wrote in their main pages about the large amounts of money that mining professionals were earning, higher than those of any other professionals in the country. Since then, academic offerings have increased in an overwhelming and uncontrolled manner. However, the projections that would be generated by labor demand in relation to the professional mining engineering careers did not go as had been predicted. This paper reviews the traditional training that the profession has given, showing the current academic offerings in 2015, the projections for graduates up to 2023, and the job offers according to the forecasts of national and international economies. Then the supply and demand are projected jointly to show the gap that there will be between both situations. All this puts in evidence a discouraging panorama for the graduates from the different universities and professional institutes due to the huge oversupply that is foreseen.

## KEYWORDS

Mining engineering, employability, education, Chile.

## INTRODUCTION

Talking about mine engineers in Chile may refer to various careers such as Civil Engineering in Mines (6 years), Mine Engineering (5 years), and Mine Technician (*Ingeniero de Ejecución*) (4 years), but the graduates will eventually get exactly similar jobs and/or perform the same functions. Therefore, in order to simplify the development of the paper we will talk about "mine engineering" without making further distinctions.

The objective of the present paper is to make an academic exercise to show the horizon which is faced by mine engineering graduates in Chile in terms of employment, based on recent events and on the projections made under the explicit assumptions discussed in the text.

## TRADITIONAL TRAINING AND THE NEW ACADEMIC OFFERINGS

Until the first years of this century, the number of mine engineers that the universities were providing seemed to be sufficient to satisfy the country's demand, and it was satisfied over the last 40 years by five state universities, namely the Universidad de Chile, Universidad de Santiago de Chile, Universidad de Atacama, Universidad de La Serena and Universidad de Antofagasta (the last four were part of the former *Universidad Técnica del Estado until 1981,* UTE), with a low degree granting rate. This happened mainly because it is a profession which, although well paid, often involves sacrifices that other careers do not require, such as distant workplaces, absence from home several days per week, physical conditions adequate for field work, supporting sometimes complicated environmental conditions (extreme cold or heat, dryness, darkness, exposure to the sun, excessive dust, toxic gases), long travelling time, among others. Because of this, historically the students' desire to enter this career had not been a priority, often being left at the end of the application preferences. Furthermore, from the standpoint of the cost to the institution, mine engineering is an expensive career due to the need to have adequate laboratories and well trained professionals to equip and maintain them. Some examples of these kinds of laboratories are rock mechanics, metallurgy, mineral concentration, structural geology, petrology, mineralogy, vein microscopy, mine ventilation, mine services, among others. To this we must add field outings or work, which require having permanent transport and maintenance of the vehicles and equipment used in the field. All this in addition to the requirements of the basic sciences and engineering courses (physics, chemistry, computation, among others).

Chile concentrates between 20% to 30% of the world's copper reserves. This is significant because starting in 2003 a growth began in the demand for commodities by a growing China, and later India, which led to a supercycle in the price of copper, which rose from 1.0 USD/pound to more than 2.5 USD/pound over the last ten years. This caused an increase in the number of mining projects and turned profitable several deposits which in the past had been considered non profitable. Consequently, employment of mine engineers reached its historical maximum, and they were considered highly desirable professional in the market, both by producing mine companies and by companies providing supplies and services to mining, increasing even more the average salaries. Since 2007 mine engineers became some of the best paid professionals in the country, surpassing the average income of geologists, physicians and dentists. Using information from different media, Table 1 shows the evolution of the salary scale of mine engineers, getting to double in 2015 the salary of 2007 on the fifth year of profession work (Trabajando.com, 2015) (Universia, 2015) (Laborum, 2015) (Servicio de Información de Educación Superior del Ministerio de Educación (SIES), 2006-2015).

Table 1 - Evolution of the salaries of mine engineers over the last years

| Year | Average Salary (USD) |
|---|---|
| 2006 | 2819 |
| 2007 | 2687 |
| 2008 | 3539 |
| 2009 | 4220 |
| 2010 | 3903 |
| 2011 | 4299 |
| 2012 | 4351 |
| 2013 | 4473 |
| 2014 | 5053 |
| 2015 | 5487 |

**New careers**

In 1981 the military regime of A. Pinochet issued the General Law of Universities, which "liberalized" the educational system. With this new legal body the dictatorship not only started the privatization of higher education through the possibility of creating private universities without state dependence, but it disrupted completely the network of existing public universities, regionalizing them and dividing them into countless universities with no relation to each other, in a deregulated educational system with the purpose of providing freedom.

Besides making use of the greater demand for mine engineers, in the 2000 – 2009 period new academic offerings appeared, such as the Universidad de Tarapacá, Universidad de Aconcagua, Universidad Pedro de Valdivia, Inacap, some of them with different majors and outlets adapted to the clients' needs.

Cochilco is an "*Agency of the State of Chile that advises the Government in matters related to the production of copper and its by-products… It also protects the State's interests in its mining enterprises through the supervision and evaluation of their management and investments, and it advises the Ministries of Finance and Mining in the preparation and follow-up of their budgets*" (Cochilco, 2016). In 2010 Cochilco's Evaluation and Strategy Division, in its report called "Analysis of Demand – Offer of Project Engineering in the Mining Industry" stated that in the 2010-2020 decade mining investments for more than 50 billion US dollars would be expected, a figure that in the following year was updated to 90 billion. Furthermore, Cochilco presented "Engineering Needs for the next 10 years" at the Institute of Mine Engineers of Chile (*Instituto de Ingenieros de Minas de Chile*), stressing the existence of a consensus in the mining sector projecting a deficit of human resources for the coming years, when the supply should grow 40% per year over the 2011-2015 period (Instituto de Ingenieros de Minas de Chile, 2010). In the face of this panorama, from 2011 there was a large increase of the academic offerings of several universities, both state and privately owned, and professional institutes (PI), which is illustrated in Figure 1. It shows an explosive increase of the offerings starting in 2011, the year in which the U. del Mar, U. Católica del Norte, and U. Adolfo Ibáñez presented their offerings; in 2012 it was the U. La República, U. Andrés Bello, UCINF, and U. Católica de Valparaíso; in 2013 the PI Dr. Virginio Gómez G., U. de Las Américas, U. del Desarrollo, U. de Los leones, U. de Talca, U. de Concepción, and U. Santa María; in 2014 U. Santo Tomas, U. de Viña del Mar, U. San Sebastián, U. Central de Chile, PI Libertador De Los Andes, and PI CIISA (Servicio de Información de Educación Superior del Ministerio de Educación (SIES), 2006-2015). Table 2 shows the number of universities and the names of the careers that were offering mine engineering.

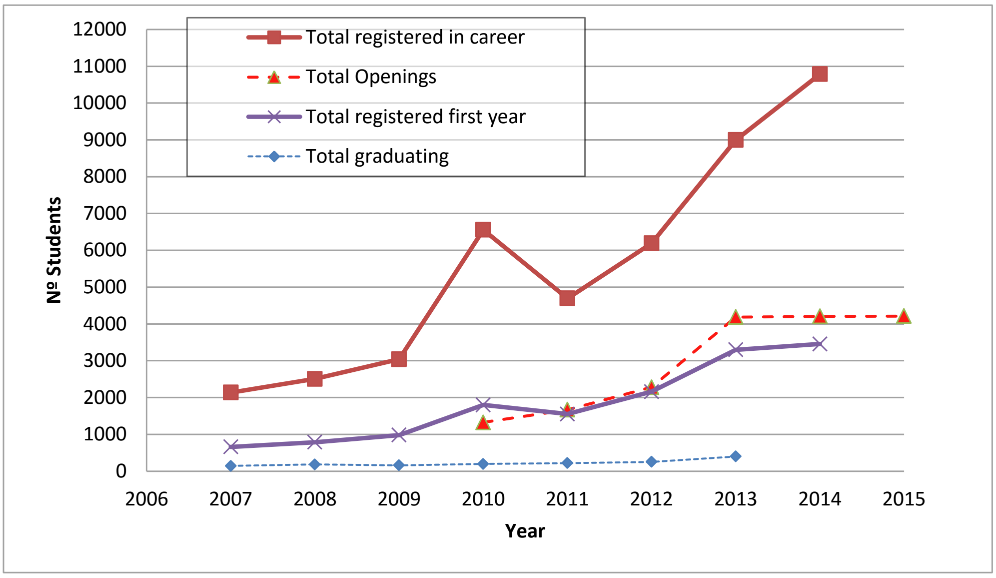


Figure 1 - Academic offerings of registered and graduated students per year.

Table 2 - Increase in the number of careers and campuses.

| Year | No. of universities and professional institutes offering mine engineering | Total campuses |
|---|---|---|
| **2010** | 9 | 45 |
| **2011** | 12 | 57 |
| **2012** | 17 | 57 |
| **2013** | 24 | 87 |
| **2014** | 29 | 117 |
| **2015** | 29 | 119 |

The data were obtained from the information available at the Ministry of Education (Servicio de Información de Educación Superior del Ministerio de Educación (SIES), 2006-2015), whose digital information is available only for the last eight years. Figure 1 shows that the academic offerings have increased the total number of registered students, exceeding more than five-fold the number of first year students that there were in 2007. A difference is also seen between the offerings and first year registrations, showing clearly that registration is not always completed or else there is overflow. Another important data in this figure is that the total graduates come from admissions to first year at least four years earlier for mining technicians, five years earlier for mine engineering, and six years earlier for mine civil engineering. Therefore, to relate the retentions we must consider this time lag, to which must be added the actual average graduating time, which is 18 semesters (9 years) for mine civil engineering, 13 semesters (6.5 years) for mining technicians and mine engineers –see Table 3, with information provided by some universities (Servicio de Información de Educación Superior del Ministerio de Educación (SIES), 2006-2015).

Table 3 - First-year dropouts and actual duration of the career

| Career | University | First Year Dropouts | Actual Duration (semesters) |
|---|---|---|---|
| Mine Civil Engineering | U. de Atacama | 12% | - |
| | U. de La Serena | 12% | 18.6 |
| | U. de Santiago de Chile | 13% | 17.1 |
| Mining Technician | U. de Antofagasta | 29% | - |
| | U. de La Serena | 23% | 14.9 |
| | U. de Santiago de Chile | 26% | 12.7 |
| | IP INACAP | 32% | 11.1 |

## PROJECTED SUPPLY AND DEMAND OF GRADUATES: EMPLOYABILITY

Over the last four years the competences committee of the Mining Council (it is an association of the large mining producers), through the Fundación Chile, has prepared the study “Labor Force of Large Scale Mining in Chile” (“*Fuerza Laboral de la Gran Minería Chilena*”) in its different annual versions (Centro de Innovación en Capital Humano para el Consejo Minero, 2011) (Centro de Innovación en Capital Humano para el Consejo Minero, 2012) (Centro de Innovación en Capital Humano para el Consejo Minero, 2013) (Centro de Innovación en Capital Humano para el Consejo Minero, 2014). This document reports on the specialists that will be required in the projected next ten years in the different specialization areas of mining and on the projected offerings, according to that time’s training offers. The study, updated with 2014 data, gives the projected total demand for mine engineers in Large Scale Mining, both by mining companies and by suppliers, in their different roles such as extraction professionals, engineers specialized in extraction, extraction supervisors, and processing supervisors. This projection is made taking into account both the projects on file for future development as well as the economic perspectives of future demand for commodities.

On the other hand, according to Table 3, which shows dropouts (2014) from the first year of a career and taking into account the graduation rate of students six years later, we can make a projection of the potential graduates who will get their degrees in the 2014-2023 period, assuming that the retention rate is increasing and the actual duration of the careers is getting shorter due to the current (and future) requirements for accreditation of the careers by the Ministry of Education. In this way, different retention scenarios are projected in the careers (offers of engineers) with 30%, 40%, 50% and 60% since 2014, and the demand for mine engineers in Large Scale Mining, and this is reflected in Figure 2. To this end it has been assumed that the number of registrations remains constant (the same figure as in 2014) over the next ten years and that no campuses, careers or universities are closing.

Similarly, Figure 3 shows the projection of the accumulated offer at 30%, 40%, 50% and 60% retention in the careers since 2014, and the demand for mine engineers accumulated in Large Scale Mining between 2014 and 2023. It should be noted that Figures 2 and 3 consider only new graduates since 2014, reaching around 18,000 new mine engineers in 2023 if 60% retention is considered (the worst case) and almost 9.000 new mine engineers if 30% retention is considered (best case).

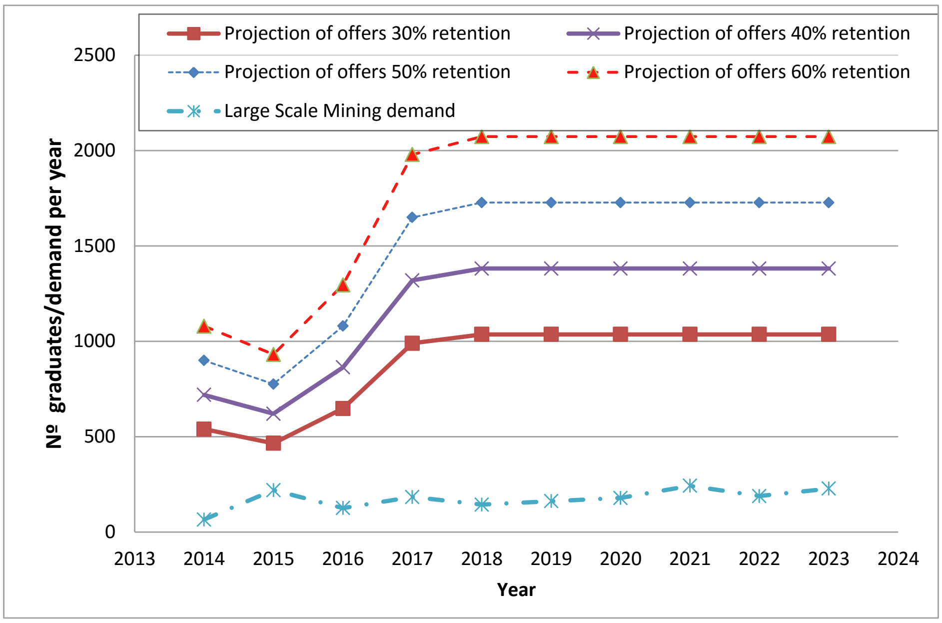


Figure 2.- Projection of the offer of graduates according to the average retention and the demand for mine engineers in Large Scale Mining per year.

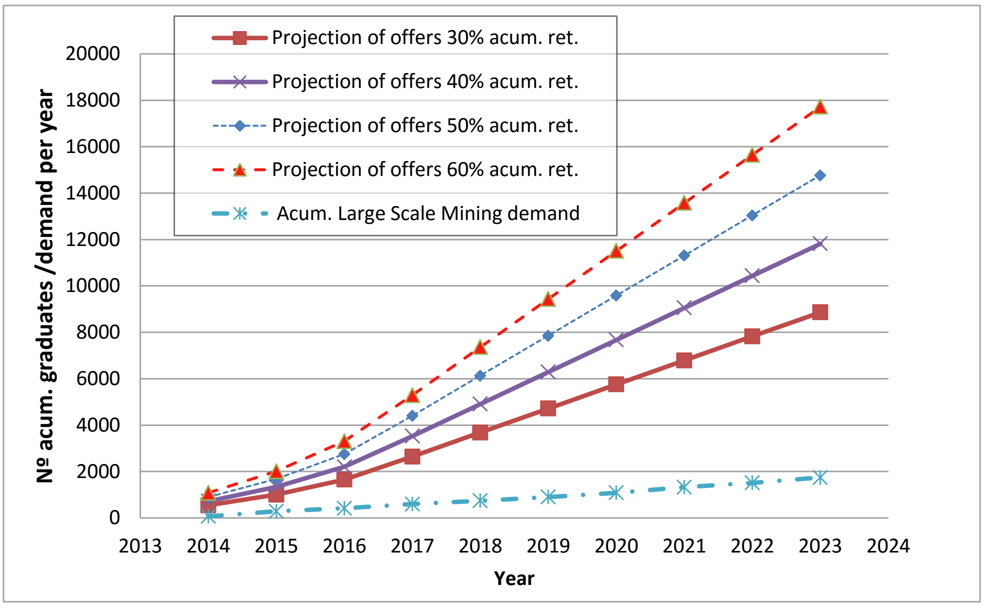


Figure 3.- Projection of the accumulated offer of graduates according to the average retention and the accumulated demand for mine engineers in Large Scale Mining per year.

## ANALYSIS AND REFLEXIONS

Making a brief analysis of the data shown in Figures 2 and 3, the difference between offer and demand would give by 2023 in the best case an employability in Large Scale Mining of 21.4% (with 30% retention) and of 12% (with 60% retention) in the worst case. This would mean that in the worst case there would be one out of ten engineers employed, and in the best case, two out of ten.

However, it can be argued that the employability does not consider middle and small scale mining, plus engineering companies, services, and mining support in these fields, or else the creation of new companies, and innovation that can cover part of the offer. Unfortunately, no current or projected data on employability in this respect are available, so a simple exercise can be made, making the assumption in which three cases are defined: the pessimistic, the moderate, and the optimistic. The "pessimistic" considers only employability in Large Scale Mining (L.S.M.) and its suppliers, or "x1", i.e., the data of demand contributed by the study of Labor Competences of the Mining Council, which have been projected in Figure 4. The "moderate" considers that beside Large Scale Mining there is an equivalent in middle-scale and small-scale mining plus others, which can contribute twice, or "x2", of the contribution of Large Scale Mining to employability. And the "optimistic" considers that beside Large Scale Mining there is an equivalent in middle- and small-scale mining plus others which can contribute three times, or "x 3" of the contribution of Large Scale Mining in terms of employability. In this way, this scenario can be graphed considering 40% and 50% retention in the offer of graduates with respect to registrations in first year, and considering a Pesimistic (x 1), Moderate (x 2) and Optimistic (x3) demand, as shown in Figure 4. It has been estimated that 40% and 50% retention in the offer of graduates with respect to registrations in first year is a most realistic scenario. All this is graphed in Figure 4.

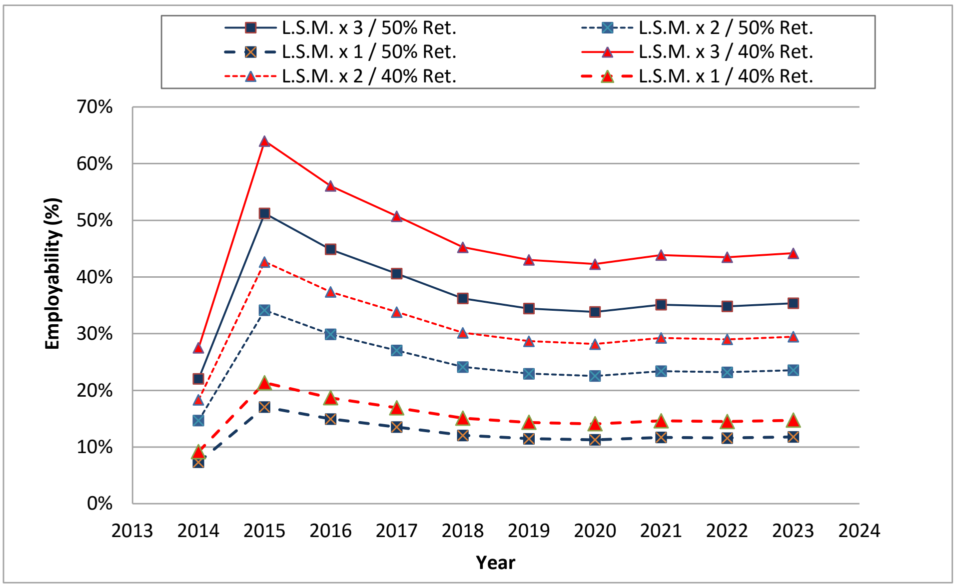


Figure 4 - Projection of employability in three scenarios according to retention per year.

Under the stated scenarios, employability would reach an optimistic scenario at 43% employability (with three times the employment projected by Large Scale Mining and 40% retention of first year registration), while in the pessimistic case the employability would be 12% (only with the employment projected for Large Scale Mining and 50% retention of first year registrations).

In Chile there has been an important drop in the employability of recent graduates according to an article in "El Mercurio" newspaper, in which inquiries were made at several recruiting companies such as *First Job*, *Page Personnel*, and *Adecco Profesional*. According to this "*mining supply companies are those that have mostly restricted their offers of untrained people between April 2013 and April 2015 by 93%, followed by mining companies, with a drop of 77%...*" (El Mercurio, 2015).

A survey made by the Psychology Institute of the *Pontificia Universidad Católica* for the National Youth Institute (*Instituto Nacional de la Juventud*) (Instituto de Psicología de la Pontificia Universidad Católica de Chile, 2014) shows a trend of young people preferring nowadays a good working environment, a good relation with their colleagues, and satisfaction with the work they are doing. Because of the characteristics mentioned previously about mine professionals must face, it is imperative that those who choose to study mine engineering do so by real vocation, since the near future is uncertain and it is highly probable that there will be low employability. It would be regrettable for someone to study something that they do not like only because they believe that they will get a high salary, wasting their financial resources that are often scarce to pay for their career and end up unemployed a large part of their life.

It can be inferred that in a scenario with low employability there will be two important effects: a substantial salary drop, reaching values even lower than those of 2006, and on the other hand, with so many offers of available engineers, they may displace to current mine technicians, occupying or competing for the positions that they occupy, such as nonprofessional foremen and supervisors. A possible third effect may be added, which is the migration of professionals to work in other countries.

A point that must be kept in mind is that students who have finished their studies but have not graduated also compete for jobs, in many cases getting their degrees several semesters or even years after leaving school, so this group can be an additional competing factor in work positions.

As a result, it can be stated that the careers linked with mining are not sustainable according to the effort and money invested in studying a long career and considering how costly is now education in Chile, all this in relation to the number of careers opened nowadays and the projected demand for professionals.

Finally, a question may be asked: Is it necessary for the State to invest money in training professionals with such an uncertain occupational future?

## CONCLUSIONS AND RECOMMENDATIONS

The academic exercise made in this paper gives a view of the perspective faced by mine engineers. Based on the sources examined and on the projected scenarios and the assumptions made, employability by 2023 may, in the best case, be close to 43%, and in the worst case around 12%.

One recommendation for the State is it must establish development policies for the country at middle and long-range in order to answer questions such as: what do we want to be or where do we want to be ten or thirty years from now? This would allow setting goals, and according to them, establish policies and plan the actions to achieve them, so it can be made better use of the resources to finance those careers that have priority for the country and will allow reaching those goals.

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# ENERGY AND $CO_2$ EMISSIONS IN IRON ORE MINING

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# ENERGY AND $CO_2$ EMISSIONS REDUCTION IN IRON ORE MINING


## ABSTRACT

Unit operations of mining have several energy savings opportunities and greenhouse gas emissions reductions. These two opportunities are what mining companies needs to achieve proposed challenges for coming years in sustainability and cost reduction. Increased recoveries of ore through better blasting practices have great impact in reducing overall mine emission intensities. This article is a case study, applying improvements in rock blasting to achieve energy savings and $CO_2$ emissions reduction in iron ore milling operations. The paper shows how important energy consumption tracking are to map $CO_2$ emissions in mining and demonstrate how Brazilian Energy matrix impact on $CO_2$ numbers in the country.



## KEYWORDS

Energy, Mining, $CO_2$ emissions, sustainability, cost reduction, Energy efficiency, milling.


## INTRODUCTION

Mining industry concerns regards to measurement and control of carbon emissions from operations has increased after some international agreements among countries to reduce emissions and increase investments to protect environment. Some of those agreements open possibilities of conversion and sale of carbon credits from emissions reductions and were seen by industry as a possibility of increase in revenues. In the real world, accounting these credits were extremely complex and bureaucratic and these opportunities haven´t seen as real by big players nowadays. Anyway, the challenge of reducing carbon emissions to preserve the environment remains active, especially in companies where sustainability is a key value.

In iron ore mining process we can identify several opportunities to reduce carbon emissions. An excellent way to map these opportunities is to understand how energy is consumed in their mining unit operations and measure the reduction of emissions by energy savings that can be achieved. Rock drilling, blasting, loading, hauling, crushing, milling and concentration of minerals are the major unit operations and are the most important energy consumers of production. The main energy sources necessary in these processes are explosives, fuel oil and electricity. Those sources are strategic and responsible for the major costs in a mining complex and consequently for greenhouse gas emissions in the atmosphere.

In iron ore unit operations of mining, the largest energy consumers are rock blasting and material haulage from mining fronts to crushers and waste dumps. Haulage is responsible for almost 80% of all carbon emissions in the production process, especially when off-road trucks are used in this process. Haul trucks are an integral part of the overall surface mining system and they consume a substantial quantity of fuel oil. Consequently, they produce a significant amount of $CO_2$.

An alternative could be conveyor belts that use electricity for this transport task. Energy consumption of truck haulage is four to twelve times higher than transport by conveyor belts and $CO_2$ emissions from truck transportation are three to ten times higher than those from conveyor belts. Figure 1 shows a parallel between truck haulage and conveyor belts system for ore transportation in terms of energy consumption of these two processes and their carbon emissions outcome according to Fuming et al. (2015).

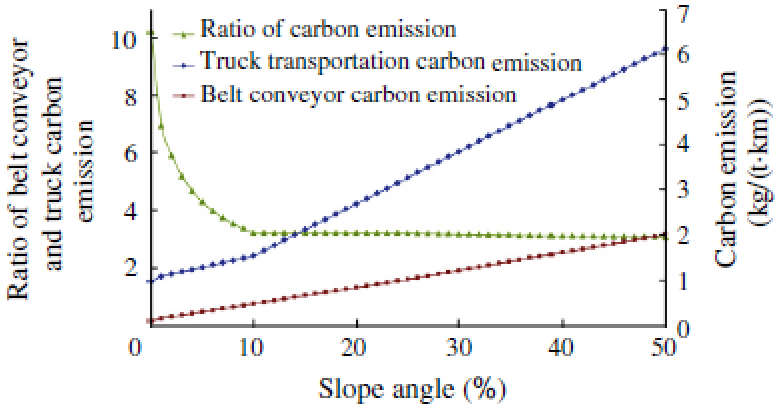



Figure 1 - Emissions between conveyor belts (Electricity) and trucks (Fuel oil) to transport ore (Fuming et al, 2015).

Mine site emissions from blasting may be problematic as they could vary according to the blasting conditions and are difficult to quantify precisely. It is demonstrated that impacts from downstream mining and mineral processes dominate over the explosive impacts. However, opportunities exist in mining cost reductions through better blasting. Increased recoveries of ore through better blasting practices have great impact in reducing overall mine emission intensities.

It´s well known that crushing and milling steps in ore process represents a substantial proportion of energy consumption, cost and carbon emission in mining (Eloranta, 1997). For instance a recent study calculated that 36% of energy consumed by gold and copper producing mines in Australia was attributable to comminution (Ballantyne et al, 2012). In 2009-10, Australia's Federal Government Energy Efficiency Opportunity (EEO) participants in the mining sector used 336.5 PJ, representing approximately 6 percent of Australia's total energy use. It is evident that the current practices of breaking rocks in mills are relatively inefficient (Fuerstenau & Abouzeid, 2002). Understanding this component is essential in a world seeking for lower production costs, better revenues and carbon footprint reduction.

Research and better engineering design has established that improvements in blasting, crushing and milling techniques can lower project costs and carbon footprint.

The main goal of this work is to apply improvements in rock blasting to achieve energy savings and $CO_2$ emissions reduction in iron ore milling operations and show how to calculate $CO_2$ emissions from energy savings. Another focus is to show with numbers how different World Energy matrix is among several countries and how it influence $CO_2$ emissions reduction projects.

**Case study**

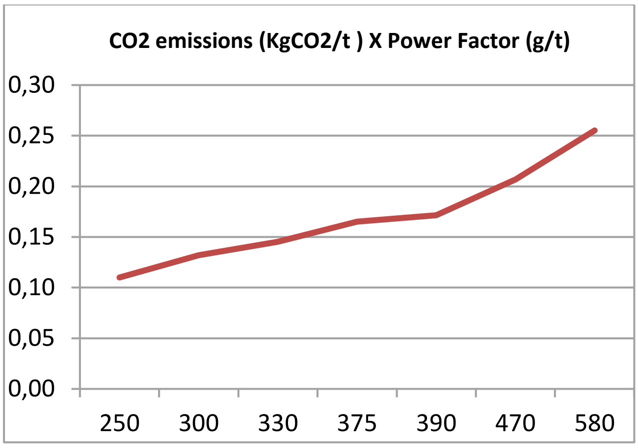
There are some statements in mining industry that defends a greater use of energy in rock blasting allowing less energy use in subsequent operations such as crushing and milling of ore (Workman & Eloranta, 1999). This idea can be extrapolated to carbon emissions in atmosphere mainly because explosives are most effective in size reduction of ore particles when better employed and are also less $CO_2$ emitter intensive.

The field work described in this paper was conducted in an iron ore mine in Minas Gerais, Brazil in 2015. Several blasting was carried out gradually increasing the explosive power factor from 200 g/t to 400 g/t on average. Another important variable is that the material to be removed changed from a friable Itabirites to a compact Itabirites with much larger uniaxial compressive strength and work index.

Several modifications were held in rock drilling and blasting process that enabled better use of available energy in explosive. Fragmentation results of these blasting were much better than expected and allowed the use of this hard ore in the concentration plants of the complex.

Higher explosive power factor also causes an increase in carbon emissions in the atmosphere. This depends on explosive characteristics used in blasting process. In these field tests, ANFO was used and for analysis we estimate the ideal mix of 5.4% fuel oil in explosive composition for emissions calculation.

Considering a change of explosive power factor from 200g to 400g per ton of material to be blasted, the additional amount of explosive to be used in this operation is approximately 1,600 t per year. This is equivalent to additional carbon emissions of 700,000 kg into the atmosphere. Figure 2 shows the increasing of CO2 emissions considering the increasing in the power factor.




Ref. = 0.44 $KgCO_2$ per Kg ANFO

Figure 2 – $CO_2$ emissions for each power factor.

A higher energy availability and process changes that were made, has reflected in fragmentation improvements on compact Itabirites during all blasting tests. This material, better fragmented, was sent to the concentration plant for processing.

After processing all material at the plant, mills energy consumption was measured. There are 6 ball mills operating uninterruptedly, processing material from crushing plants and delivering to subsequent concentration process. Milling average specific consumption went from 7.58 kWh / t to 6.81 kWh / t. Annually, energy savings would be 20,401 MWh in this operation.

This energy savings should be considered as potential because many process variables are involved in this operation. One of the most important is compact ore percentage that is going to feed concentration plant. This material has a higher work index (amount of energy necessary to break a mineral particle) and a compact feed increase could raise energy consumption. In this case described here, there was a small energy saving, even with an increase of almost 25% of compacts, which may be an indication that fragmentation improvements in blasting through a higher power factor have benefited milling process.

Energy savings can also be shown as carbon emissions reductions in atmosphere. Conversion from electricity to carbon emissions have to consider energy matrix of the country where that energy was generated. In countries where energy sources are mostly from fossil fuels (oil, gas or coal) have higher carbon emissions per MWh than countries with a predominance of renewable sources of energy such as hydro, wind or solar power.

As almost all countries in the world works in an integrated power grid, emissions factors for conversion from MWh to $CO_2$ are used to provide carbon emission from energy. In an integrated power grid it is difficult to identify where energy were generated for a specific porpoise. Exceptions occur when an industrial operation has its own infrastructure power generation. In this case the accounting of carbon emissions is proportional to the energy source used. Figure 3 shows emissions factors references of several countries and a parallel with World average and Brazil.

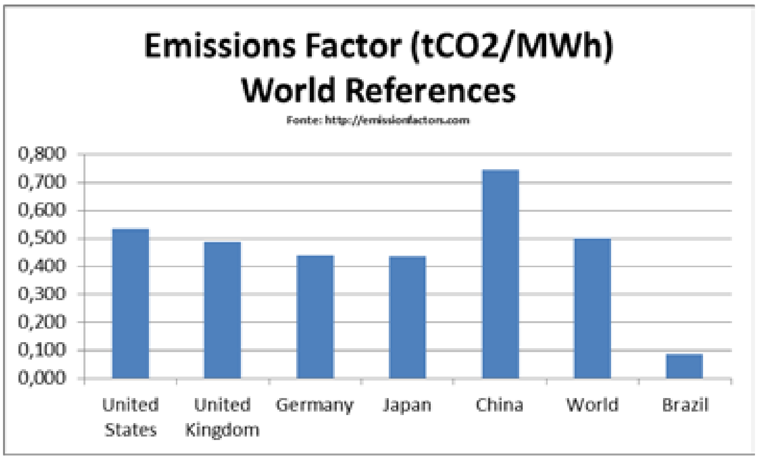



Figure 3 – Emissions Factors in several countries, World and Brazil.

As seen in figure 3, Brazil has a low emission factor when compared with other countries because Brazilian energy matrix is based on renewable energy sources, especially hydro power. To calculate emissions reductions, a particular index controlled by the Ministry of Science and Technology of Brazil was used. This index is based on Brazilian energy matrix and is published monthly on the ministry's web site. It has become a reference for Brazilian carbon emissions calculations. Figure 4 shows how Brazilian emissions factors changed in past few years.

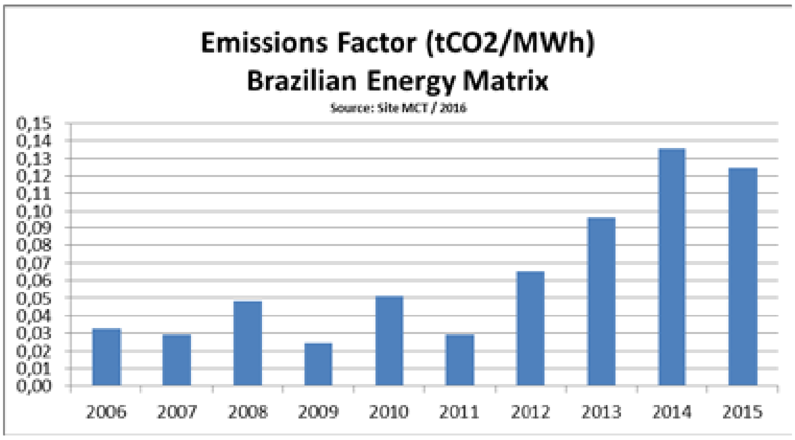



Figure 4 – Emissions Factors evolution in Brazil.

Source: Brazilian Science and Technology Ministry

Brazilian emission factor has increased considerably. It has happen with entrance of several power generation plants from fossil fuels. Even so, Brazilian index is one of the lowest in the world and this situation greatly reduces carbon emissions reduction numbers in energy savings projects when we calculate carbon emissions.

Considering potential reduction in milling specific energy consumption caused by improvements in blasting presented in this case, potential reduction of $CO_2$ emissions is shown below:

| | |
|---|---|
| Specific consumption reduction (kwh/t) | 0,77 |
| Energy savings – Annual (MWh) | 20.401,92 |
| Emissions reduction from energy savings - Milling ($tCO_2$) | = (20.401,92 x 0,1244[1]) = 2.538,99 |
| Additional $CO_2$ emissions from explosives ($KgCO_2$) | 699.494,40[2] |
| Total $CO_2$ emissions reduction from blasting improvements – Annual ($KgCO_2$) | 2.538.990 – 699.494,40 = **1.838.504,45** |

*1 – Brazilian Emission Factor 2015 ( $tCO_2/MWh$)*
*2 - Ref. - 0.44 $KgCO_2$ per Kg ANFO*

## CONCLUSION

The best way to achieve and measure potential $CO_2$ emissions reductions in mining is tracking process energy consumption in operations. In mining, the largest energy consumer is haulage phase that should get all attention from specialists. Blasting improvements with more energy intake by increasing power factor may therefore be very interesting since explosives are more effective in mineral particles reduction. When properly employed, explosives emit a small amount of gases in the atmosphere when comparing to other sources of energy. In our case, numbers for $CO_2$ emission reduction were important, but the potential could be much higher if a rock profile change haven´t carried out during field tests.

As the Brazilian energy matrix is based on renewable sources and fewer fossil fuel assets, $CO_2$ emissions reduction projects should spend more focus on processes that consume fossil fuels like fuel oil and coal. In iron ore mining, main processes based on fossil fuels are ore haulage by trucks, or in railways transporting ore products, natural gas consumption in pelletizing furnaces.

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# ENERGY EFFICIENCY AND RELIABILITY OF ELECTRIC MOTORS

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# ENERGY EFFICIENCY AND RELIABILITY OF ELECTRIC MOTORS

## ABSTRACT

According to “Useful Energy Balance” from Brazilian Energy and Mines Minister, an average 92% of the electrical energy consumed on a mining plant is used for driving force and, considering the recent energy costs increases, performance and competitiveness of mining plants end up being harmed if they operate with low efficiency. Therefore, it drives the search for more efficient solutions for electric motor applications. Recently, developed and developing countries has increased the requirements for their minimum motor efficiency standard. Thus, the investment in R & D (improvements in insulation, optimized electrical design and manufacturing processes) resulted in motors with the largest efficiency levels in the Market classified as IE4 and the unprecedented IE5 (IEC) which results in efficiency above 97%. The current installed base of the electric motors inside mining plants around the globe have low efficiency levels (IE1 and IE2) and sometimes the motors are deteriorated due to low quality rewinding procedures or even wrong application fit. Even with the efficiency level improvements, the WEG’s IE4 and IE5 squirrel cage induction motors are interchangeable with the previous lines (IE1 and IE2), resulting an easy global plant efficiency improvement (plug and play design). Many studies and implementations performed in variety types of mining applications (conveyors, slurry pumps, crushers and mills) can demonstrate the results of a higher efficiency and correct motor dimensioning. The direct results are low energy demands, thus lower greenhouse effect gases emissions considering that most of power generation could came from fossil fuels. Operational reliability and plant availability are indispensable features expected for electric motors operating in mining areas. The motors must operate as designed even in the toughest and aggressive environments. Therefore, WEG developed the Mining line that includes a number of special features to ensure highest level of protection and reliability avoiding further operational expenditures.

## KEYWORDS

Electric Motors, efficiency, mining, cost, maintenance, WMagnet, reliability, IP66, WEG, IE4, IE5, Brushless

## INTRODUCTION

Brazilian industry consumes 43,7% of the energy produced in Brazil, and Electric motors correspond to 68% of all this consumed energy, excluding electric motors used in domestic equipment [1]. In mining plants, an average of 92% of the electrical energy consumed is used for driving force [2]. Furthermore, the Brazilian and global production of electrical power, causes carbon emissions. According to study by Brazilian Ministry of Mines and Energy for each toe (ton of oil equivalent) it is issued 1.59 tons of carbon gases in Brazil. The global average is 2.37 tons of carbon gases.

Any investment to improve energy consumption efficiency certainly provides more competitiveness and better performance to the mines, and, not less important, more availability of energy and reduces the environmental impacts.

Brazil as an example, the reduction of energy consumers is not just a differential to the industry, but a necessity. The energy fees are getting much higher than the inflation in the last years, as showed in Figure 1.

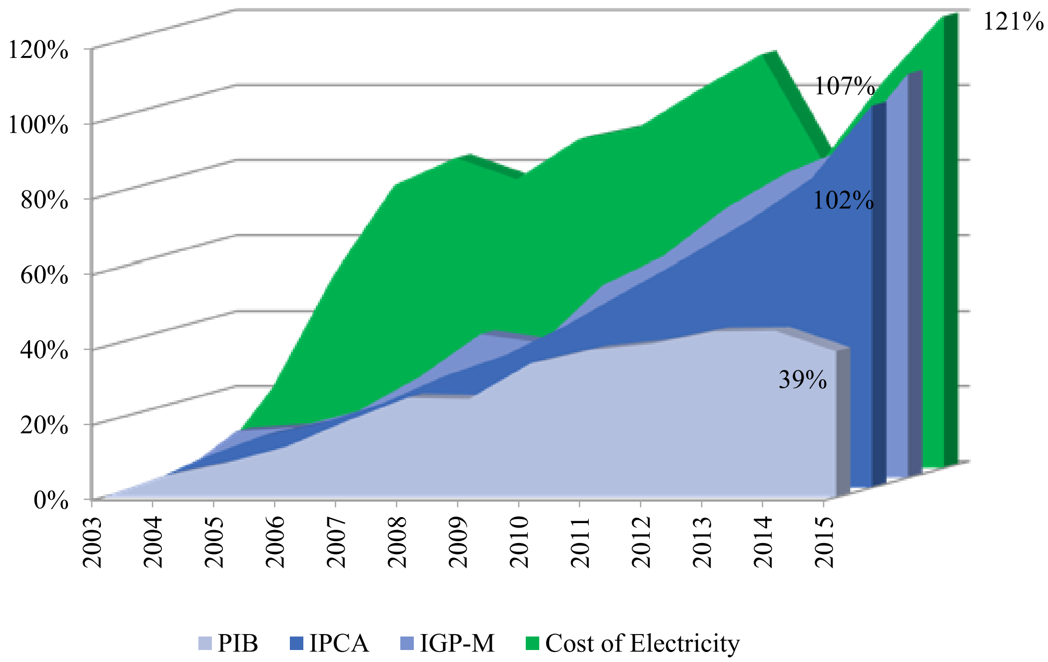


Figure 1- Energy Fees x Brazilian Inflation indexes x PIB

## EFFICIENCY OF ELECTRIC MOTORS

The electric motor can be described as machine that transforms electrical power into mechanical power; in this process, part of that energy is lost due to joule effect (electrical conduction dissipation), magnetic losses, bearing friction, fans, among others. The lowest these losses are, the more efficient is the machine. Considering the total cost of ownership of an Electric Motor in a period of 10 years, 96% is spent with the electricity the motor consumes to work. Only 4% represent the cost of acquisition and maintenance, as shown in Figure 2 [3]. Thus, the industry must focus the action into the efficiency levels to reduce that consumption.

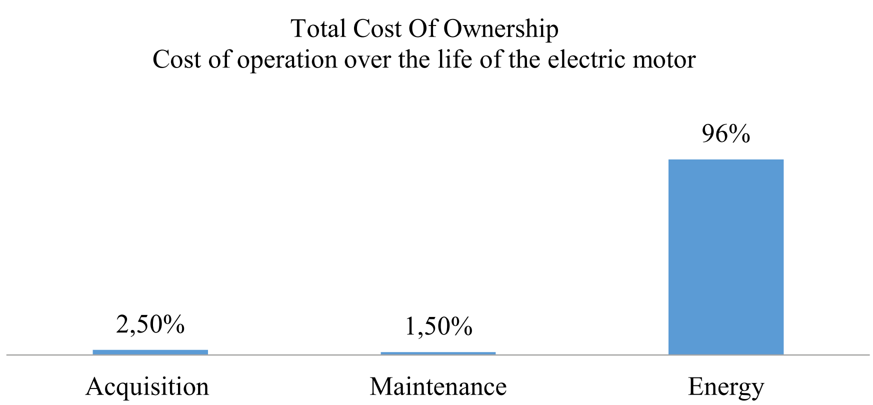


Figure 2 – Total Cost of Ownership share

Since its foundation, WEG has invested continuously to develop most efficiency manufacture process for its electric motors lines, with deep researches to improve electrical design, new materials, better mechanical components, among others, focusing to achieve the lowest losses inherent in the electric motor. The result is the highest efficiency level in the Brazilian market (IE4 and IE5 efficiency level according to IEC Standard), achieving efficiency above 97% [4].

Table 1 - Efficiency improvements through the years – 60cv 4 poles

| Year | Efficiency (%) |
|---|---|
| 1960 | 88,0% |
| 1980 | 89,5% |
| 1990 | 90,0% |
| 2000 | 93,9% |
| 2010 | 95,1% |
| 2010 | 96,0% |
| 2013 | 95,8% |
| 2014 | 96,5% |

## W22 MAGNET DRIVE SYSTEM – THE UNPRECEDENTED IE5 CLASS (IEC)

Following the continuous development in the electric motors, and investments in innovation, WEG developed the W22 Magnet Drive System. Based on eliminating the maximum losses as possible, WEG started a study based on the use of permanent magnets in the rotor instead of an aluminum injected squirrel cage.

For electric motors with high performance and efficiency it is interesting that the permanent magnets have elevated coercive field (Hc) and elevated remanent induction (Br). A High Hc prevents the magnet be easily demagnetized and a high value of Br results in a better magnetic flow.

Synchronous motors with permanent magnets feed by VFD are largely used in the industry in applications where constant torque and variable speed are necessary. Thus, they are very attractive in applications with reduced space eliminating the need of gearboxes/reducers, smaller frames and without independent ventilation. There are two main types of Synchronous motors with permanent magnets: brushless DC and brushless AC.

- Brushless DC: In this type of electric motor the electromagnetic force (fcem) and feed current (I) wave is rectangular, see Figure 3. The actuation control is simpler and there is no need of a position sensor of high performance. The permanent magnets are assembled in the rotor surface, as shown in Figure 5. Usually, these electric motors are used in applications with low power needs and low performance.

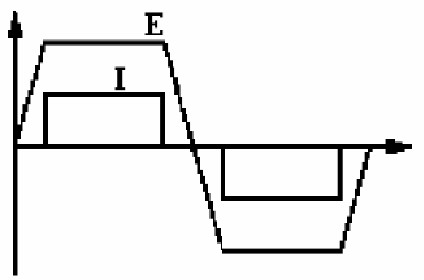


Figure 3 – Brushless DC *fcem* and *I*

- Brushless AC: The motor is projected to the *fcem* and the current are sinusoidal, see Figure 4, resulting in a soft torque. It can be designed with the permanent magnets superficial or inside of the rotor, as shown in Figure 5. This kind of application needs a perfect synchronization of wave form and angular position of the rotor. The brushless AC, in general, is used in applications where the high performance is need.

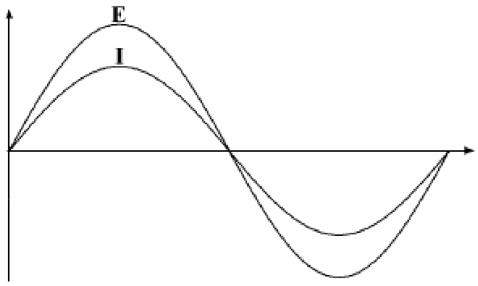


Figure 4 - Brushless AC *fcem* and *I*

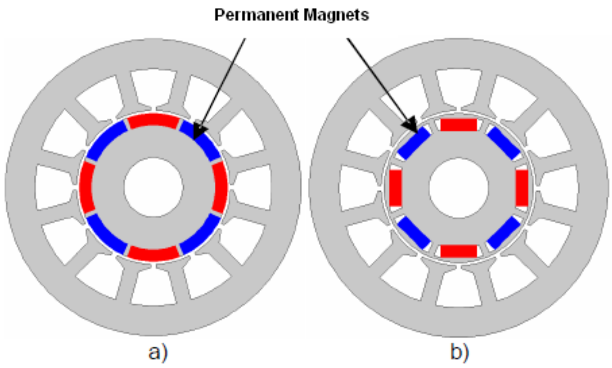


Figure 5 - a) Motor with superficial magnets; b) Motor with intern Magnets

The W22 Magnet drive system utilized by WEG is the Brushless AC type with permanent magnets inside of the rotor. These electric motors almost do not have joule losses in the rotor, instead of the regular squirrel cage motor. The Joule losses are a significant part of the total losses in the motor, and improving the squirrel cage to the magnet rotor the efficiency is much higher.

This technology ensures high electrical performance, and it is possible to achieve IE4 and IE5 efficiency levels. Comparing the W22 Magnet IE4 with the conventional squirrel cage motor of the same ratings and rotation, the size and weight of the motor is reduced up to 47%, optimizing the relation torque for frame/weight.

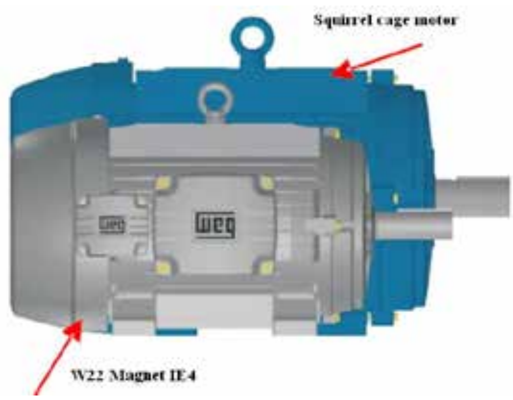


Figure 6 - Frame size comparison between squirrel cage and permanent magnet motor

**Drive System**

All development used the drive system CFW11 is manufactured by WEG. The drive of permanent magnet motors usually need a high resolution position sensor. However, the utilization of this sensors elevate the total cost of the equipment. Thus, WEG has improved a new technology in the system called *sensorless*, which improve an advanced control algorithm that estimate the position and motor speed and eliminates the positioning sensor, reducing system costs.

## EFFICICIENCY WITH VARIABLE SPEED

With this technology, it is possible to reach almost 20% of saving in energy consumption comparing with squirrel cage motors feed by VFD. As shown in Figure 7, the efficiency level stays almost flat for the complete motor speed range for the W22 Magnet motor, what does not happen with the squirrel cage motor.

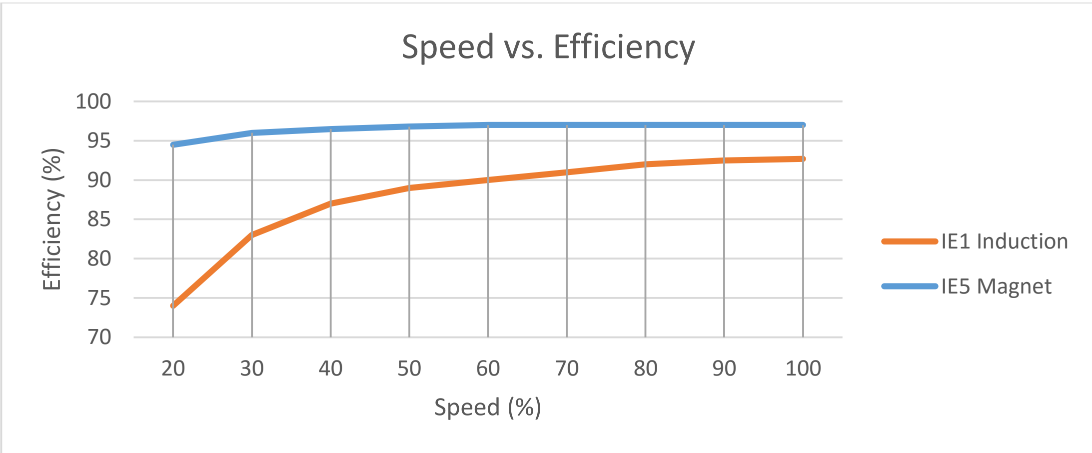


Figure 7 - Speed vs. Efficiency

One of the best systems to apply this technology is in pump systems. This type of equipment is responsible of 18% of the total driving force used in Brazilian industry. Using VFD to control the system, is possible to raise to 70% of electric power savings. The drive control the load variation decreasing losses with oversized equipment, providing higher efficiency. With the W22 Magnet Motor drive system, the efficiency is even higher than with regular squirrel cage motor controlled by VFD, as shown in Figure 7.

A recent success case was performed in the multinational compressor company Embraco (Brazil), focusing in the energy savings for their machines and fabrication process in their facilities in Joinville/SC unity. The energy diagnostic showed that the motors of central oil, responsible for the oil pumping to the machining area consumed more than the necessary to that application. This diagnostic pointed a potential reduction of 30% in electrical energy consumption. But the results were even higher. The change of the old motors to the IE4 and IE5 WEG Motors controlled by VFD, reached 47% of savings only in electrical energy, equivalent to 2.227MW/year.

## RELIABILITY IN MINING PLANTS

Another subject that is very popular in mining plants is the aggressive environment that the equipment is operating. The motor must operate as designed, even in the toughest and aggressive environments. Therefore, WEG developed the Mining line that includes a number of special features to ensure highest level of protection and reliability avoiding further operational expenditures.

The high degree of protection IPW66, ensured by the exclusive W3Seal bearing sealing system, as shown in Figure 8, extends motor lifetime when operating in aggressive environments by protecting the bearing and inside parts of motor against water and dust, guaranteeing proper degree of protection. Moreover, all mechanical connections receive a special sealing to avoid the dust inside the motor.

Figure 8 - W3Seal

All features, including painting plans, were design considering the worst-case scenario to supply the most reliable motor for the harshest mining application.

However, even improving all these points, in applications near of spilling materials (for example crusher, flotation cells), see Figure 9 - Spilling materials. It may results in some problems with heat dissipation by blocking the cooling air through the fins , The sunshield, optional in the Mining line, was developed to improve the lifetime in operations that may have spilling materials, protecting the motor against such problem, as shown in Figure 10.

Figure 9 - Spilling materials

Figure 10 - Sunshield

In the mining environment, the production cost of each mine heavily depends on of the extraction cost, and this is influenced by the ore content and the quality of the concentration system.

Throughout processing chain of this mineral, the electric motor is a constantly present equipment because it is responsible for Convert electrical energy into mechanical. By its great participation, more than ninety (90%) of electricity costs, the efficiency in these facilities impact on the final cost of the product. Improvements in design and innovation, as previously shown the use of magnets in motors, provides efficiency levels close to 97% (ninety seven) which when used in conjunction with drive system optimizes common applications by reducing the operating cost more than 20% (twenty). However, the motors also must be robust and reliable to withstand the mining environmental conditions as the special features fitted in the W22 line as IP66 degree of protection and IE5 efficiency level.

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# ENVIRONMENTAL IMPACTS GENERATED BY FARMS OF QUARTZITE IN THE REGION OF OURO PRETO

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# ENVIRONMENTAL IMPACTS GENERATED BY FARMS OF QUARTZITE IN THE REGION OF OURO PRETO

## ABSTRACT

In the past four decades there has been in Ouro Preto's proximities, the expansion of exploitation of quartzite dimension stones to used both for residential construction and exportation. This exploitation is being done without minimal mine planning, promoting several environment impacts. Although the quartzite dimension stone mining is only a temporary use of the surface land, it causes serious environmental impact. On the other hand, this is an important activity for the region in terms of employment. One of the main objectives of this paper is to analyze these activities identifying the main impacts and to propose corrective measures considering the future use.

## KEYWORDS

quartzites, environmental impact, exploitation.

## INTRODUCTION

The set of Black Gold quartzite quarrying incorporates a large number of mines of the same type, ie (same kind of material, similar mining methods and competition in the same market) and above 1 concentrations production units by km2 in certain areas, although the limits are not usually precisely defined.

It seems clear that the overall environmental impact produced by the set of quarries as a whole is not merely the sum of the effects of each quarry in particular regarded as a single unit, but also dependent on other factors. The mining of quartzite rock Ouro Preto, for coating purposes, is developed outside the technical, environmental and legal parameters. For the economic exploitation of this mineral well within the sustainable development criteria, changes are needed in the production process.

## MATERIALS AND METHODS

The implementation of this study was divided by the following steps: 1-study of the location and geology of the area, 2-studies in extraction methods, 3- identification and definition of environmental impacts and environmental control plans of these, 4 technician mining study and processing and 7-Interpretation and discussion of data.

## RESULTS AND DISCUSSION

### Location and Regional Geology

The Ouro Preto is located in the Iron Quadrangle. Quadrangle is located in the southern end of the San Francisco craton having an area of approximately 7,000 km2 and is bordered by the cities of Itabira, northeast, Mariana, southeast, Congonhas do Campo, southwest and Itaúna, northwest. Several other cities are included in the Iron Quadrangle as Belo Horizonte, Nova Lima, Sabara, Santa Barbara, Itabirito and Ouro Preto(Figure.1).


Figure 1. Map of the Iron Quadrangle indicating the Ouro Preto region.

**Local geology**

The area considered for this assessment is made mostly by quartzite formation Currency belonging to Caraça group Supergroup age of Mines Proterozoic.The quartzite is presented with a color ranging from white to pink and the texture varies from fine to medium, being locally changed. In some places these quartzites have curious features that stand out and become visitation points for tourists.

**First Method: Manual**

The extraction process is started after obtaining two free-faces of the rock surface; taking advantage of fractures plans, present in the tank and through levers, wedges and mallets. Initiate the separation of very slow and laborious block form. Obtained the block, proceed to the separation of the plates through the introduction of wedges in the rock cleavage planes concurrently with the application of blows with sledgehammers. At this stage wedges are used of various lengths to yield as final product the so-called slabs which are classified according to their size or area. In the range of 40x40cm, we have called lajões. In 20x20cm range we have lajinhas. The final product of mining is carried, by extension, to a place near a road about a 50 meters from the front service, which is stacked and transported for processing.

**Second Method: Mixed or Use of Explosive**

After removal of the capping or where the rock outcropping is, the worker makes holes with a diameter typically of 7/8 inch, as follows: - It will be crowning using a pointer, called "Tear" and sledgehammer being that the cap will receive the blows of the hammer and a man makes the manual rotation of the tip to a depth of about 1.0 to 1,1metros. Completed the hole, carries with explosive, often dynamite and detonating cord priming with NP-5, which is connected to simple fuze and mantopim. At this point the bore is ready to be detonated. Upon detonation, generally obtains a block with dimensions of 1,5m x 1,5m next x 1.0 m. The blocks are worked manually as mentioned in item 2.1 and the final product is obtained in the same manner mentioned above in the first method. The advantage of the method is low cost. The disadvantage is the low productivity. Typically detonates is a hole at a time.

**Third method: Mechanized**

The front plowing cleaning operation and removal of soil or rocks changed is carried by a tractor
mats and loader and as such the artisan method sterile is deposited in a place near the front of service, but in a more organized manner.Often, as the mining progresses, the mined areas are being covered, excluding the possibility of further use of quartzite in depth. Then, through the pneumatic drill, holes are made which reached 5.0 m to 15 m in length and 3 inches in bore diameter depending on the

thickness of the compact layer being drawn. Often these blocks are classified as sterile and need to be removed to give the mining sequence. Dismantling is in the detonation of a single row of spaced holes 4m each other with spacing of 3.5 m rock face.

## ENVIRONMENTAL DIAGNOSIS

### The mining and the provision of sterile

One of the most visible impacts on the environment and also to the historical heritage is caused by the processing units that are located at the highway margins Conspirators (between Black and Mariana Gold) where the waste from sawmills is arranged randomly on the highway margins without any worry with passers-by, including tourists visiting the historic site of Ouro Preto. In addition to the visual impact caused by debris, contaminated water generated in the sawmill and polishing of quartzite process is poured directly on the ground without any treatment for containing fine and reuse. In the areas visited in Ouro Preto (Neighborhoods Taquaral, Saint Kitts and parakeets) can be seen clearly, these types of impacts and practically nothing has been done by those responsible to reduce these impacts. It can be seen that as it advances the mining of quartzite, the barren has been deposited on the banks of rivers thereby causing the gap and a decrease of water volume. If you continue this procedure if you can reach even the silting of some watercourses in the region. This activity also was one of those responsible for the disappearance of some species of fish, according to information obtained on site, were quite plentiful.

The quality and quantity of water so shallow as groundwater is affected if mitigation measures are not practiced. Watercourses may be affected and the flow of these changes. Erosion may be excessive and surface and groundwater can reach undesirable levels of mineralization. The topography, drainage, vegetation and landscape of the mined site can be seriously impacted. The inclination of the waste material storage batteries may become inadequate topography for a future location of use (Williams, D.J. et al, 1997). The impacts of mining include landscape degradation, destruction of agricultural land and forest degradation and land usable for recreation.

### Mining and processing quartzite

The quartzite explorations are performed in the open, by banks, and the best selected quality of irregular blocks are removed from the slope and cut into slices that are thrown down and finally divided into casing stones according to the existing trade patterns. But mines conducted by small miners are handcrafted. First look up the areas of interest, classifying them by the texture of the material, color and proximity to the surface. Where the overburden is not very thick or outcropping rock is altered, that removes this material with hoe, shovel and picks and transports in wheelbarrow to one side of the front service, or deposited in the nearest location possible, thus avoiding transporting the material over long distances. In the field, we identified three different methods of operation which will be described below.

The processing facility is quite simple. It is usually manned by two machines. The products "in natura", are positioned on said structure, which is slowly displaced to the extent that rotates a crank positioned on one side in the lower part. As the structure moves slowly, the water flows freely over the mountain and rock, facilitating cutting and preventing the formation of dust. The pieces are cut in rectangular shape with dimensions according to customer specifications. The machines in general, have cutting capacity of 50 to 60 $m^2$ per day rock.

### Rehabilitation of degraded areas

Generally, mining activities only last a few years and the miners leave the place leaving the existing problems and future problems to be solved by others. A mine operation ceases when the quarry can not be exploited profitably. The exact time of this event is very uncertain due to uncertainty about mineral reserves, costs and prices of mineral products. In general, in a few years the mine closure occurs and this fact is a great new challenge for the mining activity. As commented, the mined areas represent potential sources of generation of long term impacts, such as impacts due to the inadequate sterile. These mined sites should be restored to a situation that is close to the original situation, although in many open pit mines this option is still not seen as feasible or desirable. For a small mining company making the closure of a mine, the option chosen is usually simply be the site of the abandoned leaving the existing and future problems for others (Sinding, 1998). Unfortunately, the

abandonment option is still possible in this part of Brazil. However, we believe that with the passage of time and the onset of problems and increasing community awareness of ecological preventive measures are adopted restricting predatory mining. An alternative is to require closure plans specifying the long-term monitoring ensuring that there are no unexpected impacts (Sinding, 1998).
Should draw up a project of rehabilitation of areas degraded by mining, following the standards of NBR 13030 of ABNT, so you must make the landscape suitability, ie the harmonization of mining areas with its surroundings, in order to minimize the visual impact; make topographic adequacy that is the topographical conformation with a view to the future use of the area.

## FINAL CONSIDERATIONS

After the study, a solution to the quartzite extraction must be found, since the tills economic perspective generates good profits from the domestic and international market with exports to Europe and Japan. But the use of techniques will be required to mitigate environmental problems caused by man's indifference to the environment. The quartzite competes in both the domestic and international markets with other ornamental stones, often surpassing them in price which carries a great return on investment.

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# ESTIMATION OF DIRECT GREENHOUSE GAS EMISSION FROM A FIRE AFFECTED OPEN CAST COAL MINE IN JHARIA COALFIELDS AND AN UNDERGROUND COAL MINE IN RANIGANJ COALFIELDS, INDIA

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# ESTIMATION OF DIRECT GREENHOUSE GAS EMISSION FROM A FIRE AFFECTED OPEN CAST COAL MINE IN JHARIA COALFIELDS AND AN UNDERGROUND COAL MINE IN RANIGANJ COALFIELDS, INDIA


## ABSTRACT

Direct emission of greenhouse gases like $CO_2$ and $CH_4$ from coal mine fire through fissures, cracks and vents has been measured with the help of closed chamber methodology and gas chromatography. Accumulation chamber was designed and gas sampling was done till the dynamic state of the chamber persists and greenhouse gas flux was calculated. Considering the rate of emission from surface manifestations of mine fire, optimization of sampling time has been done to maintain the sampling dynamic. $CO_2$ and $CH_4$ flux has been calculated for Ena Fire (Opencast) project in Jharia and Sangramgarh (underground) Mines in Raniganj Coalfields. In the Ena Fire (Opencast) project arithmetic mean of $CO_2$ flux is around 0.14 g $m^{-2}$ $s^{-1}$ and that of $CH_4$ is 0.0003 g $m^{-2}$ $s^{-1}$. Considering all the measurements made across the Ena fire project, the range of $CO_2$-e emission comes to 0.002 to 0.797 g $m^{-2}$ $s^{-1}$ with a higher standard deviation value of ± 0.255 g $m^{-2}$ $s^{-1}$. Emission factor has been derived as 28.2 t/day for $CO_2$ and 0.06 t/day for $CH_4$. In the Sangramgarh (underground) Mines the mean $CO_2$ flux is around 0.05 g $m^{-2}$ $s^{-1}$ and that of $CH_4$ is 0.002 g $m^{-2}$ $s^{-1}$ and the range of $CO_2$-e emission comes to 0.005 to 0.66 g $m^{-2}$ $s^{-1}$ with a standard deviation value of ± 0.088 g $m^{-2}$ $s^{-1}$. Emission factor has been derived as 9.3 t/day for $CO_2$ and 0.25 t/day for $CH_4$. Hence, the methodology developed, suggests a high $CO_2$ emission factor from opencast mine and a higher $CH_4$ emission factor for underground mines.



## KEYWORDS

Coal mine fire, greenhouse gas, direct emission, $CO_2$-e emission, emission factor


## INTRODUCTION

Mine fire in India has been reported in the Jharia Coalfields (JCF), since almost a century (Prakash, 2007; Sarkar et al., 2007), and Raniganj Coalfields (RCF). Coal burning in the reserve itself generates variety of gases in large quantity. These by-product of combustion, follow convection and advection movements and finds connectivity with the surface as surface and sub-surface coal mine fire introduce some changes in the local geological structures. Most coal fire-related landforms occur from volume loss underground if an underground coal seam burns and is reduced to ash. Kuenzer and Sracher, (2012) have broadly categorized coal fire geomorphologic manifestations into (a) surface fracturing, (b) surface subsidence and (c) bedrock changes.

Surface fracturing is the most abundant geomorphologic manifestations and preferred over surface subsidence and bedrock changes for the collection of gaseous emission. It is because of the uncertainty associated with the sampling of gaseous emission from the surface subsidence and bedrock changes. Surface fracturing has been further classified into surface features like fissures, cracks, funnels, vents and sponges by Kuenzer and Sracher, (2012). These surface features are the pathways for atmospheric emission of coal mine fire produced gases and smoke. Hover et al. 2013 reviewed the study characterizing the emissions generated from coal mine fire and listed up to 62 different compounds. At the interphase, gas samples were collected using accumulation chamber and the flux is determined. This method is designated as the direct estimation of greenhouse gas emission from coal mine fire. Fissures and cracks are the surface features found ideal for the direct estimation of greenhouse gas emission from coal mine fire.

Surface changes were initiated with the formation of fissures in the direction of progress of fire. According to the classification of Kuenzer and Stracher 2012, fissures are defined as linear structures within the bedrock surface, which are extremely narrow (<0.5 cm). In both the study areas fissures of 0.5 m to approximately 2.0 meters in length were found. In situ, they appear as dark lines on the bedrock surface (Figures.1.0 a).

Figure 1.0: (a) Young and mature fissures (b) cracks at sampling site

Cracks are narrow linear structures of large extent, strike in one direction and are basically "open fractures" of the bedrock surface (Kuenzer and Stracher, 2012). In the study area, depending upon the age and progress of fire, cracks have been found several meters in length and 0.5 cm to 1.0 meters in width (figure 1.0 b). Depth of cracks may reach several meters. As the time progresses cracks usually increase their width and ultimately may subside due to volume loss. Funnels, vents and sponges are the structures not commonly encountered at the site, hence, not considered for gas sampling.

The dominant transport mechanism for coal fire exhaust gases includes the following: 1) convection and advection outward from gas vents and fractures; and 2) diffusion up into the soil column and eventually the atmospheric boundary layer (Engle et al, 2011). For the estimation of direct emission through fissures and cracks closed accumulation chamber method was used. The accumulation chamber technique has been adopted by several workers (Bergfeld et al., 2006; Welles et al., 2001) for flux measurements. In this technique, the rate of increase in $CO_2$ concentration is determined within a closed-loop system. The diffuse emission, on the other hand, was estimated using an automated closed dynamic loop chamber, fitted with sensitive high resolution Infra - red gas analyzer for immediate measurement of small change in gas concentration i.e. flux and described elsewhere. The study, therefore, has been made with an intention to develop protocol for direct greenhouse gas emission estimation technique at colliery level for opencast and underground mines.

## STUDY AREA

### Ena Fire Project

Ena fire project of Bharat Coaking Coal Ltd (BCCL), falling under Jharia coalfield, the only coalfield which is having the reserve of prime coking coal in India and is operated by opencast technique. Jharia coalfield is bounded by the latitudes 23˚39' – 23°50' N and longitudes 86˚05'– 86°30'E. This sickle shaped coalfield occupies an area of approximately 450 km$^2$. Bharat Coking Coal Limited (BCCL) is the major coal producer of this coalfield. Ena fire project (EFP) falls in the latitude 23° 45' 35" N and 86° 24' 10" E at the northern boundary of Jharia Coal field and had been extracted with opencast method. In the EFP, fire is exposed to the surface at several places in the out crops of XIII and XIV seams and underlying XI-XII seams and have been reported to reach temperature around 456°C (Pandey, et. al., 2013). These red glowing exposed fires are hazardous, hence, sampling for gases has been ruled out from these places.

### Sangramgarh Mine

Sangramgarh Colliery is located in the north central part of Raniganj Coalfield in Burdwan District of Bengal State. The mine is about 14 km north of Asansol and connected by all-weather roads. Geographical coordinates of mine are 23° 47' 00" N to 23° 48' 00" N and 86° 54' 00" E to 86° 57' 00" E. Within the leasehold area of the mine, four coal seams are present namely (from top to bottom); Salanpur 'C' (B-IV), Salanpur 'B' (B-III), Salanpur 'A' (B-II) and Salanpur Special (B-I). All the coal seams are degree-I gassy. Salanpur 'C' (B-IV) seam is having coal of C-F grade, Salanpur 'B' (B-III) seam is having D-E grade coal while Salanpur 'A' (B-II) and Salanpur Special (B-I) are having C-D grade coal. Sangramgarh mine is the combination of opencast and underground operation.

## METHODOLOGY

At the colliery level, the most widely used methodology for estimation of GHG emission is direct measurement of greenhouse gas flux using accumulation chamber. The flux calculation through direct estimation methodology involves (i) periodical collection of gas samples and (ii) and analysis of gas samples.

**Sample Collection**

The two basic designs for chambers used to measure soil gas fluxes are: closed accumulation and dynamic open chambers. Closed accumulation chamber were installed at the interphase to determine the rate gas accumulation inside the chamber as a result of exchange across the soil–air boundary. It is placed firmly against the soil surface so that the exchange with the surrounding atmosphere is restricted. The system attains a steady-state with the underlying of soil gas as the gas concentration inside the chamber continue to accumulate, but it is the period of accumulation which is of most interest. Accumulation chamber is designed on the basis of the rate of gas emission from cracks and fissures prevalent at the site.

The chamber (Figure 2.0) was used for both low and high greenhouse gas emission rate measurements with the adjustment of time for periodical gas sampling. Based on the saturation time of the chamber i.e. time taken for the arrival of steady state of gas concentration with respect to time, of the accumulation the periodical sampling time was kept 30 sec., 120 sec. and 300 sec. Without exceeding the dynamic range of the instruments, these time periods allow to take 4 to 6 samples. Gas samples were collected manually with the accumulation chamber using aspirator with Teflon inlet. One end of the inlet tube was connected to the 8 mm outlet of coupler valve and the other with the inert and impermeable container for storage and transportation to the laboratory for analysis. For collection of gas sample and bringing to the laboratory, the method was adopted as discussed by Pone et. al. (2007).

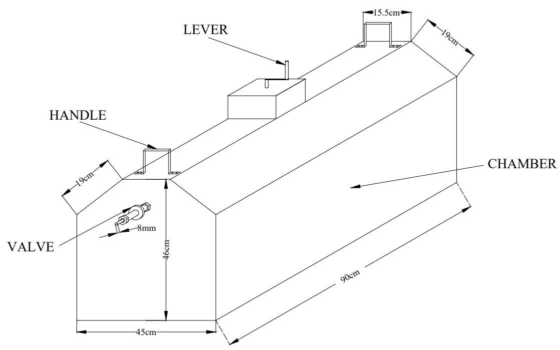


Figure 2.0: Outlay of accumulation chamber

**Site Selection**

The most popular approach of field-sampling survey is mapping a regular spaced grid, of an identical shape, across the study area and collecting samples at the grid nodes. Engle et al., (2013) have highlighted two major short comings of this approach in terms of application to coal fire survey: (1) potential for under sampling or missing data for small, highly active emission zones (i.e., in proximity to vents and other thermal features) and (2) lack of data point pairs in close proximity, which makes the difficulty in examining autocorrelation. In this study the monitoring has been carried out from fissures, cracks and thermally active features ensuring that data from high emission areas should not be avoided. The fissures and cracks undertaken for the study were of various stages of development i.e. newborn, young fissures and cracks representing areas with very low emission rate. Samples within the active portion of the fire are taken from mature cracks and fissures representing high emission zones, to ensure the inclusion of samples at varying emission rates during December 2012 to June 2013.

**Sampling and Analytical Protocol**

In both the mines i.e. Ena Fire Project and Sangramgarh Mine more than 400 gas samples were collected using the above - described methods. Ambient air at the ground level near emission zone was also sampled with the help of water displacement method in glass containers, or using aspirators in bladders made of inert material to reduce uncertainty in deriving $CO_2$ & $CH_4$ concentration.

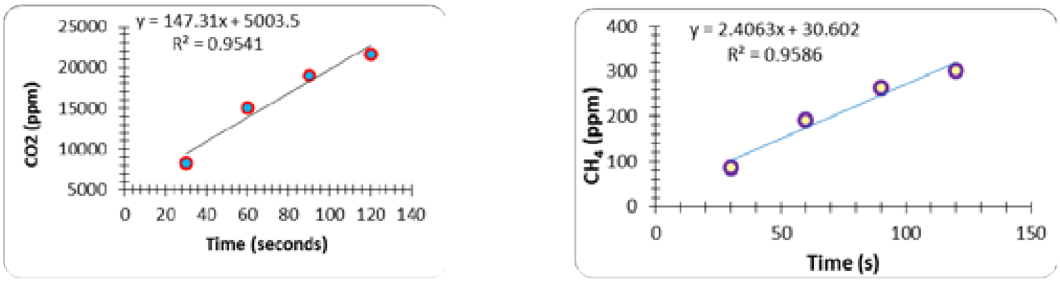


Figure 3.0: Plot of $CO_2$ & $CH_4$ concentration vs time with a periodical sampling of 30 seconds

30 Seconds Periodical Sampling

Mine fire gas samples were collected, following the protocol, periodically after every thirty seconds, and analyzed for $CO_2$ and $CH_4$. In order to reduce the uncertainty at this step, arithmetic mean of all the eligible samples at a particular stage has been derived and plotted against time as shown in the figure 3.0 for $CO_2$ and $CH_4$ to confirm the linear rate of accumulation of gases. From the figure 3.0, it is observed that in the accumulation chamber, concentrations of carbon dioxide increases with respect to time and reaches to steady state after 120 seconds i.e. after fourth sample. Therefore, values after 120 s were discarded for further calculation of flux and not included in the graph. The high value of correlation coefficient (0.95) validates the increase of $CO_2$ concentration in the accumulation chamber with respect to time.

120 & 300 Seconds Periodical Sampling

The emission sources representing this monitoring protocol were very young cracks and fissures and less frequently some very old cracks which were characterized with very low emission rates. Concentration of $CO_2$ samples of each stage were averaged and a high correlation coefficient value ($R^2$ = 0.96) has been received from the plot of $CO_2$ concentration (ppm) with respect to time (s) (Figure 4.0).

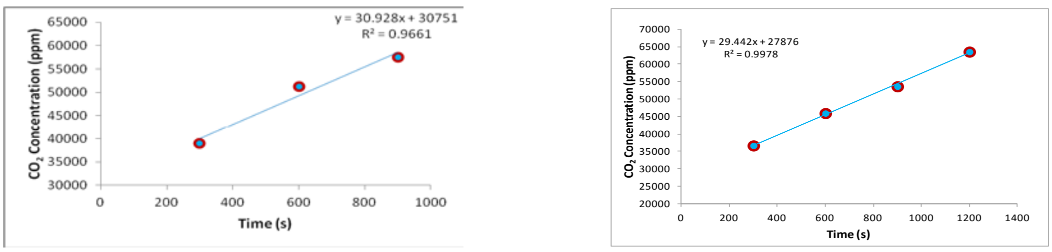


Figure 4.0: $CO_2$ flux calculation with 300 s monitoring at (a) Ena fire project & (b) Sangramgarh Mine

At Sangramgarh mine, temporal increase of $CO_2$ concentration in accumulation chamber has shown a significantly high correlation coefficient of nearly unity (0.99). This shows a relatively stable emission with minimum external disturbance (Figure 8.0). Following the same pattern the $CH_4$ has been plotted and a range of correlation coefficient ($R^2$) from 0.89 to 0.98 has been derived.

## RESULT AND DISCUSSION

### Deriving Gas Density

In view of short in situ conditions and short sampling period pressure changes marginally while temperature changes substantially from measurement to measurement and controls the density of $CO_2$ and $CH_4$ emitted in the accumulation chamber. Deriving gas density inside the chamber requires the measurement of temperature and pressure of gas for that particular dataset. Temperature inside the chamber for each measurement has been measured with the help of inserting a thermocouple probe at the start of the sampling. Pressure value, has been taken from barometric pressure value of same time. Ideal Gas Law is used to calculate the density of $CO_2$ and $CH_4$ for each set of measurement:

n/V = P/RT .......................................................................................................... (1)

Where, (n) is number of moles, (V) is volume, (n/v) is density, (P) is pressure, (R) is universal gas constant and (T) is temperature of the gas.

Instead of taking a uniform value of density for all the calculations of flux, consideration has been given to the variability of temperature and pressure during each set of measurement from accumulation chamber and value of density has been derived for every set of measurement.

**Flux Measurement**

Flux has been estimated to derive mass of gas being emitted per unit area and time. The equation given by Engle et al., 2011 has been used to calculate the flux. With reference to the developed monitoring protocol a stable measurement of the linear gas accumulation rate (∂C/∂t) can be made.

The flux F is then calculated via:

$$F = \left\{ \frac{\rho V}{A} \frac{\partial C}{\partial t} \right\} \qquad \text{.............................................................................. (2)}$$

Where, ρ is gas density, V is the total volume of the closed accumulation chamber and A is the area of the chamber footprint. Equation 1 has been used in the study to calculate $CO_2$ and $CH_4$ emission flux for emission through advection. Change in gas concentration with respect to time (∂C/∂t) is the basic data and has been calculated in ppm/sec for each dataset.

**Ena Fire Project**

<u>XIV Seam Quarry (Patch D) Site</u>

At patch D site, $CO_2$ emission rate varies significantly, with a maximum of 0.596 g $m^{-2}$ $s^{-1}$ as represented in the figure 5.0, which shows $CO_2$ emission from Ena fire project with reference to geographical coordinates. Similar pattern of temporal and spatial variability with lower emission rate has been shown by $CH_4$. The values of standard deviation for both the gases are very high if compared with the arithmetic mean value. Statistically, it defines the uncertainty in the large number of measurements taken at this site. Engle et al. (2012) have reported a decrease of ~ 50% $CO_2$ emission from vents in measurement sets collected within 48 hrs at the Welch Ranch fire. The temporal variability in datasets is a common phenomenon with coalmine fire events as discussed by Engle et al., 2012.

$CO_2$-e results have also been calculated by using the global warming potential (GWP) of $CH_4$ of 25 with respect to that of 1 for $CO_2$, we can derive $CO_2$-e as follows:
$CO_2$-e= $CO_2$ emission (g $m^{-2}$ $s^{-1}$) + $CH_4$ emission (g $m^{-2}$ $s^{-1}$) * 25 .....................................(4)

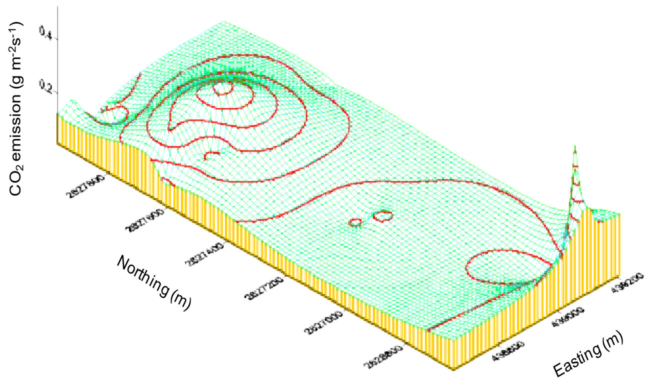


Figure 5.0: Surface contours of $CO_2$ emission at Ena fire project.

XIII Seam outcrop (View Point)

The surface area at this site is under the influence of mine fire in exhausted XIII seam outcrop and developed XI – XII seams and covers approximately 1942 $m^2$ area. This site is also marked with wide emission values ranging from 0.0007 g $m^{-2}$ $s^{-1}$ to 0.179 g $m^{-2}$ $s^{-1}$ $CO_2$. $CH_4$ followed the same pattern with the maximum value of 0.002 g $m^{-2}$ $s^{-1}$. $CO_2$-e emission at this site is marked with overall low rate values. It can be said that the lower emission rate of < 0.06 g $m^{-2}$ $s^{-1}$ is strongly represented in the dataset from this site. High $CO_2$-e standard deviation value of 0.036 g $m^{-2}$ $s^{-1}$ endorses wide range of emission rate.

At both the sites spontaneous combustion is happening in the underlying XI - XII coal seams as well as overlying exhausted and fire affected XIV seam at Patch D site and exhausted and fire affected XIII seam at View Point site. Higher range $CO_2$-e emission values of Patch D site may be attributed to the higher calorific value 7400 k cal $kg^{-1}$ and higher carbon content 75.5% of seam XIV with respect to seam XIII (6940 k cal $kg^{-1}$). Henceforth, considering all the measurements made across the Ena fire project, the range of $CO_2$-e emission comes to 0.002 to 0.797 g $m^{-2}$ $s^{-1}$ with a higher standard deviation of ± 0.255 g $m^{-2}$ $s^{-1}$. Average of $CO_2$-e emission derived at Ena fire project is 0.207 g $m^{-2}$ $s^{-1}$.

**Sangramgarh mine**

The permanent measuring points at Sangramgarh underground mine are Muchipara (representing the gaseous emission from underground developed gallery near a residential area [719 $m^2$ surface area]) and Yadavpara (representing fire and gaseous emission from underground developed galleries of Salanpur 'A' seam and above [2884.02 $m^2$ surface area]). Salanpur 'A' seam is having poor grade coal with Calorific value 3891 k cal $kg^{-1}$, moisture content 1.7%, ash 34.6% and Volatile Matter 21.6%.

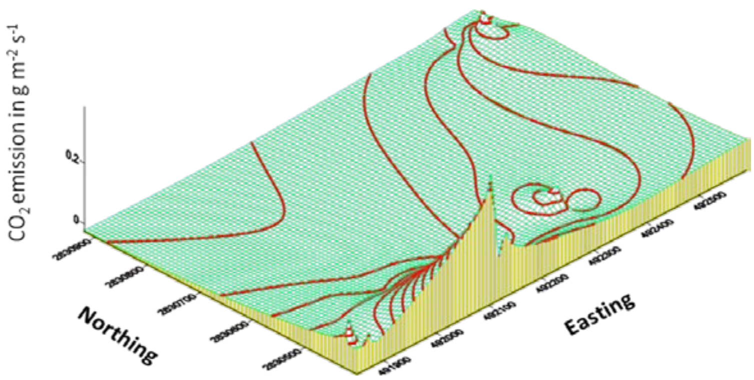


Figure 6.0: Surface contours of $CO_2$ emission at Sangramgarh mine

The Muchipara site is near to human settlement blanketing with alluvial material is being practiced regularly. Temperature at this site was in the range of 89 to 106 °C. The maximum $CO_2$ concentration is 0. 165 g $m^{-2}$ $s^{-1}$ (figure 6.0) and $CH_4$ concentration is 0.003 g $m^{-2}$ $s^{-1}$ while this value for $CO_2$-e stands as 0.185 g $m^{-2}$ $s^{-1}$. Standard deviation has remained very high and almost equate to the arithmetic mean. This site too has followed the characteristics spatial and temporal heterogenic nature of coal mine fire emission. $CO_2$-e emission in the majority of samples were measured between the lower quartile of 0.025 g $m^{-2}$ $s^{-1}$ to the upper quartile rate of emission i.e. 0.065 g $m^{-2}$ $s^{-1}$. This is the reason behind consistently lower emission rate encountered at this site.

Yadavpara is another site where underground developed gallery of Salanpur 'A' and above seams are under fire. This site has same coal seam distribution as Muchipara, and marked with high $CO_2$-e emission of 0.66 g $m^{-2}$ $s^{-1}$. $CH_4$ emission has contributed substantially and the reasons for high $CH_4$ production than all other sites have possible explanation that, at elevated temperatures present in coal material affected by spontaneous combustion, parts of the coal can be starved of oxygen with the result that the chemical reactions change and appreciable quantities of $CH_4$ can be produced. Similar observation has been recorded by Carras et al., (2009) in their study. This is represented at all the sites where emission measurements were made. This inherited biasness in the direct measurement of emission from spontaneous combustion of subsurface coal can be taken care of by introducing a more frequent sampling protocol represented by diurnal variation.

**Surface Temperature and Greenhouse gas Emission**

Temperature along with the gaseous emission is one of the most substantial expressions of spontaneous combustion at the surface. Plotting both the signatures of spontaneous combustion, one can see that there is a positive correlation between emission rate and surface temperature. However, the temporal and spatial heterogeneity in the sample, brought considerable scatter in the results, and hence, a weaker correlation.

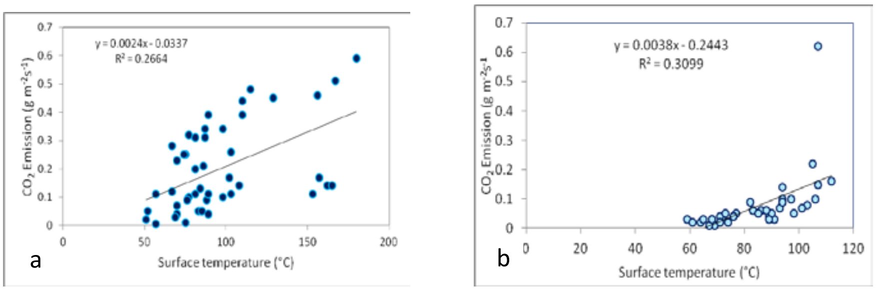


Figure 7.0 a & b: A plot of direct $CO_2$ emission versus surface temperature at (a) Ena fire project and (b) Sangramgarh mine

Average values of entire $CO_2$ emission rate when plotted against the corresponding crack temperature a weak correlation was established at Ena fire project ($R^2$=0.26) and Sangramgarh mine ($R^2$=0.31). However, the increasing trend of the emission rate with increase in surface temperature was found (**Figure 7.0 a & b)** Further, when sample size is reduced a better correlation was achieved (**Figure 8.0 a & b**). Isolation of samples belongs to a particular crack in a fire area with consistent fire, provided opportunity to reduce the temporal and spatial heterogeneity in data sets. In this way of data interpretation, averaged GHG emission rate were compared from source to source in a particular monitoring site and temperature values can be used to predict the emission. Emission rate of $CH_4$ showed similar pattern with temperature. $CH_4$ emission rate was found low at Ena fire project and relatively high at Sangramgarh mine. When this is correlated with temperature in cracks and fissures it shows relatively stronger correlation in comparison to $CO_2$ at Ena fire project ($R^2$ = 0.79).
The other study site, i.e. Sangramgarh mine, had shown a weaker correlation between $CH_4$ emission rate from fire in developed underground galleries and increase in temperature at the surface cracks and fissures.

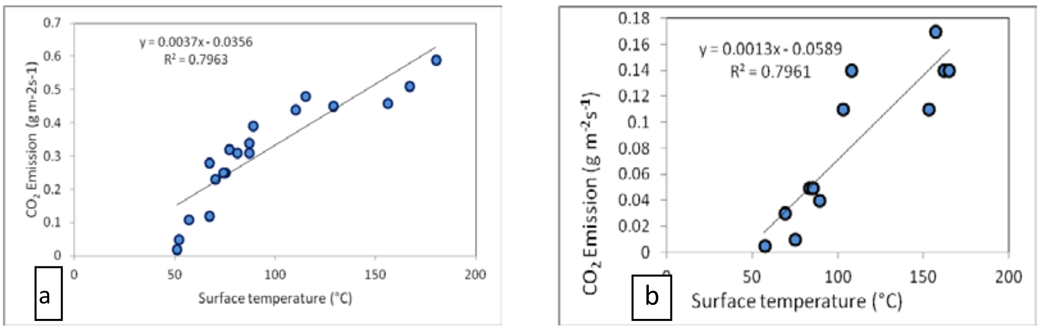


Figure 8.0**:** Correlation between $CO_2$ emission and temperature (a) Patch D site and (b) View Point in Ena fire project.

The inconsistency in the relation between $CH_4$ emission rates and surface temperature can be attributed to the voidage and particle size distribution which controls diffusion and permeability characteristics of the overlying strata. Due to repeated blanketing of alluvial covering over the underground gallery fire, temperature of the surface cracks and fissures does not correspond to the fire in the most natural way of heat transfer in deeper fires i.e. conduction. Hence, though the $CH_4$ emission rate is higher at Sangramgarh mine, the thermal signature at the surface is weaker due to relatively deep fire. Dijk et al., 2011 reported that deep fires might lead to weaker signal than a shallow fire, even though the amount of coal burning underneath might be more. It can be concluded that the higher surface temperature is associated with high emission rates and thermal signature of underground fire on the surface may not necessarily, always, describe the extent and intensity of subsurface spontaneous combustion.

**Significance of $CO_2$-e values**

The climate effects of a greenhouse gas can be identified from the ability of the gas to absorb heat radiation, its residential time in the atmosphere, and on the emission of gas to the atmosphere. In order to make it possible to compare the effects of different gases in an easy manner the most common metric used is Global Warming Potential (GWP) value of the gas that integrates Radiative Forcing (or its greenhouse gas potential) out to a particular time horizon. Since the greenhouse gases exhibit different dwell times in the atmosphere it is common to use a time perspective of a hundred years to calculate the GWP potential. Usually one normalises the other greenhouse gases using carbon dioxide, which therefore always has a greenhouse potential of one (GWP = 1) for all the calculated time horizons (i.e. 20, 100 or 500 years). On 100-yr time horizon the global warming potential of $CH_4$ is 25 (IPCC, 2007). The GWP has limitations and suffer from inconsistencies related to the treatment of indirect effects and feedbacks, for instance, if climate–carbon feedbacks are included for the reference gas $CO_2$ but not for the non-$CO_2$ gases (IPCC, 2013). Hence, $CO_2$-e values have been derived in this study.

A comparison of average $CO_2$-e emission for the entire study area has been made. The highest average $CO_2$-e emission of 13 kg $m^{-2}day^{-1}$ has been obtained at Patch D XIV seam Quarry site of Ena fire project. $CO_2$ has been found as the significant contributor at both the sites in Ena fire project. $CH_4$ on the other hand showed very sparse presence. The importance of the use of global warming potential (GWP) of $CH_4$ can be easily understood by carefully observing the average $CO_2$-e, $CO_2$ and $CH_4$ emission data of Sangramgarh OB Dump site (SOBD). At this site though the average emission of $CO_2$ is very low, $CO_2$-e emission is considerably high. It is happening due to the high concentration of $CH_4$ measured at this site. The maximum $CH_4$ emission rate observed at this site is 0.044 g $m^{-2}$ $s^{-1}$, which is the highest $CH_4$ emission rate among all the sites. Once the GWP factor of $CH_4$ was applied to its emission value of this site, the $CO_2$-e value increased sharply. Hence, $CO_2$-e brings all the greenhouse gases on a platform which makes the estimation of their radiating effect easy and comparable.

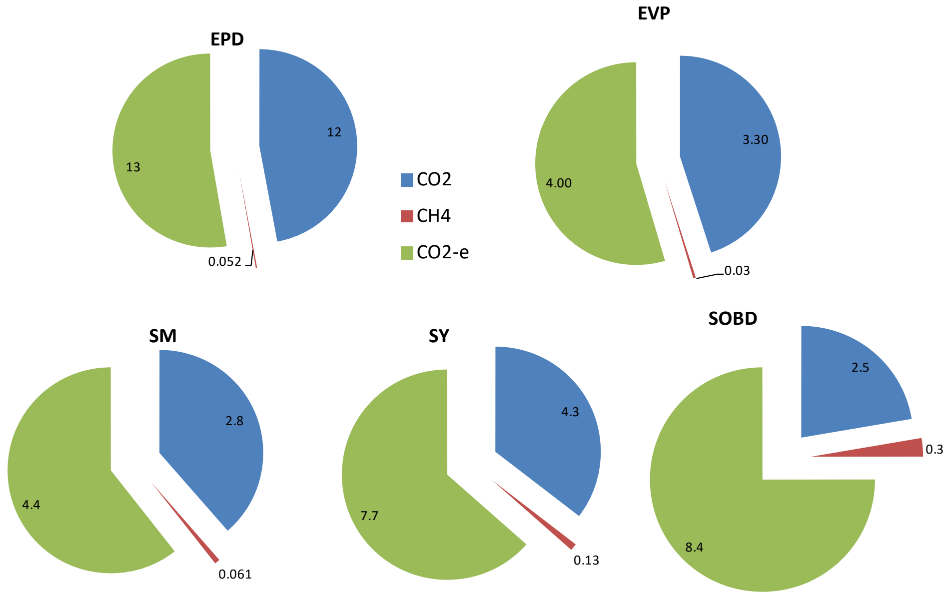


Figure 9.0: Composition of average $CO_2$-e emission (in kg $m^{-2}day^{-1}$) of all five measuring points in Ena fire project and Sangramgarh mine. In the figure abbreviations used are (EPD = Ena fire project, Patch D of XIV seam Quarry; EVP = Ena fire project View Point; SM = Sangramgarh mine Muchipara; SY = Sangramgarh mine Yadavpara; SOBD = Sangramgarh mine Overburden Dump)

**Emission Factor**

Some of the country specific emission factors with respect to India are available, including, emission factors for $CO_2$ from coal (Choudhary et al., 2004) and $CH_4$ from coal mining (Singh, 2004). However, there is no emission factor available for $CO_2$ and $CH_4$ emissions from coal mine fires in India.

For the determination of emission factor basic requirements are quantity of a particular GHG emitted per unit activity. In the case of coal mine fire emissions activity data can be the amount of coal burning in situ or the surface area having indicator of active fire. In the present case it is not possible to determine the amount of coal burning in situ; hence, surface area under active fire has been calculated and used as the activity data for deriving the emission factor of $CO_2$ and $CH_4$ as follows:

Emission factor (g/s) = Flux (g/m$^2$/s) * surface area with active fire (m$^2$) ---------------- (4)

Table 1.0: $CO_2$ emission factor in Ena fire project and Sangramgarh mine

| S No. | Mines | Site/ Coal Seam | $CO_2$ Flux g/m$^2$/s | Fire Area m$^2$ | Emission Factor g/s | Emission Factor t/day |
|---|---|---|---|---|---|---|
| 1 | Sangramgarh Underground Mine | Yadavpara, Salanpur 'A' Seam & above | 0.031 | 2884 | 89.40 | 9.27 |
| 2 | Sangramgarh Underground Mine | Muchipara, Salanpur 'A' Seam & above | 0.025 | 719 | 17.97 | |
| 3 | Ena fire project | View Point, XIII and XI – XII Seam fire | 0.027 | 1942 | 5<br>2.43 | 28.2 |
| 4 | Ena fire project | Patch D, XIV seam Quarry | 0.092 | 2977.00 | 273.88 | |

The emission factors determined in this study were established with bituminous coals; coals of other ranks may yield different factors. Using the equation 4, $CO_2$ emission factor has been derived as 28.2 t/day and $CH_4$ emission factor has been derived as 0.06 t/day for Ena Fire Project (table 1.0 & 2.0).

Table 2.0: $CH_4$ emission factor in Ena fire project and Sangramgarh mine

| S No. | Mines | Coal Seam | $CH_4$ Flux g/m$^2$/s | Fire Area m$^2$ | Emission Factor g/s | Emission Factor t/day |
|---|---|---|---|---|---|---|
| 1 | Sangramgarh Underground Mine | Yadavpara, Salanpur 'A' Seam & above | 0.0008 | 2884 | 2.30 | 0.23 |
| 2 | Sangramgarh Underground Mine | Muchipara, Salanpur 'A' Seam & above | 0.0005 | 719 | 0.36 | |
| 3 | Ena fire project | View Point, XIII and XI – XII Seam fire | 0.00006 | 1942 | 0.12 | 0.06 |
| 4 | Ena fire project | Patch D, XIV seam Quarry | 0.0002 | 2977.00 | 0.60 | |

The Underground mine (Sangramgarh) showed a high $CH_4$ emission factor 0.23 t/day than the Opencast mine with the possible reason of oxygen starved conditions and subsequent chemical reactions in the sealed underground galleries. This is a site specific measurement and a site specific emission factor has been derived which largely depends upon the coal quality geomorphology and extent of fire in the respective mines.

## CONCLUSIONS

$CO_2$ and $CH_4$ were identified as the only greenhouse gas being emitted from coal mine fire and $CO_2$ dominates in all the samples. To estimate the emission at colliery level, direct emission estimation technique using dynamic closed chamber methodology has been found feasible and applied. Uncertainty removal has been done at various levels during the sampling and calculation of flux. Surface temperature contour of mines can be related to the greenhouse gas emission profile, and the correlation improves while restricting the sample size to the minimum. For calculation of emission factor, it is not feasible to estimate the amount of coal is burning as an activity data, hence, area with the signature of fire underneath and sign of surface manifestations has been adopted as the activity data. At the global scale it has been estimated that $CO_2$ emissions resulting from coal mine fires vary from 12 kg $CO_2e$ $yr^{-1}$ $m^{-2}$ to 8200 kg $CO_2e$ $yr^{-1}$ $m^{-2}$ and that the annual $CO_2$ emissions from coal fires in the US is approximately $1.4 \times 10^7$ to $2.9 \times 10^8$ tonne per year (Carras et al., 2009; O'Keefe et al., 2010). The annual $CO_2$ emission from a single coal fire of Jharia Coalfields comes to $1.02 \times 10^4$ tonne per year which is quite comparable and implementation of further automation and uncertainty reduction can provide more actual picture of greenhouse gas emission from coal fire in India. Engle et al., 2013 indicates the requirement of further sophistication of modelling to fully appreciate the contribution of coal fires to greenhouse gas emissions.

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# EXPERIMENTAL OF SHELLS MARINE POWDER USED IN PORCELAIN STONEWARE FORMULATION

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# EXPERIMENTAL OF SHELLS MARINE POWDER USED IN PORCELAIN STONEWARE FORMULATION


## ABSTRACT

Fishing is one of the major activities of the Brazilian primary sector. In the coastal city of Ares, 60 kilometers from Natal, the extraction of shellfish mussels, generates solid waste that impact the mangrove area. In order to make minimum the environmental impacts, was thought to use shells - briefly composed of CaCO3 - in the mass of the ceramic coating in order to make a quality product at low cost. The trials were carried out following the technical standards of the ceramic coating (NBR 13818: 1997). Two different formulations were tested: F1 - 10% - shell powder, 10 % - quartz 40 % - clay and 40 % - feldspar and F2 - 15 % - shell powder, 10 % - quartz 35 % - feldspar and 40 % - clay. Sintered, the pieces were subjected to physical testing. The absorption of water by an average of 0.7 and 1.0 % for formulations F1 and F2 (respectively), so that the specimens would fit the specification group: Stoneware – Bib.



## KEYWORDS

Shells, economy, fishing, porcelain stoneware, environmental impact


## INTRODUCTION

According to the Ministry of Fisheries and Agriculture, Brazil produces annually Two Million Tons of fish, being 40 % grown. The activity generates a GDP (gross domestic product) of R$5 billion. On aquaculture, the country is at tenth second and, if the production is expanded to 2 Million Tons per year, will figure among the world's top five's in 2020. Aquaculture grew 8.6% in 22 years, from 32.4 million tons to 66.6 million tons/year (Portal Brasil, economia e emprego, 2016). The Northeast region has the largest number of fishermen, with 386,081, representing 46.3 % of the country. The state of Rio Grande do Norte has a total of 32,512 registered fishermen, and 65.4 % male and 34.6 % female, ranking third in the Northeast in amounts of registered fishermen.

The material in this article comes from the town of Ares, located sixty kilometers from Natal.

The National Policy on Solid Waste lays down the guidelines on the integrated management and treatment of solid waste, dictating the responsibilities of each generator and the government. Thus, municipal institutions have the need to manage waste generated by both the general population when the production levels of low to large scale.

Because it is an extractive activity, waste is generated and, in most cases, do not have a correct destination. According to the National Research Council of the United States, the main environmental impacts of malacoculture are natural disturbances communities of phytoplankton, deterioration of water quality due to the accumulation of waste, the introduction of species that compete with existing and the transmition of diseases.

The presence of these waste in inappropriate places causes environmental problems of the most diverse, as pollution of mangrove, the proliferation of insect vectors of disease beyond the stench caused by the decomposition of organic matter present in the shells.

In this work, the debris will be worked sea shells, which of them is extracted a sea fruit very appreciated at the northeast coast, a bivalve mollusk popularly called Sururu (*Mytella charruana)*.

The process of formation of the shells of mollusks is a biological process caused by the secretion of nacre to ectodermal cells. The blood of mollusks is rich in liquid form of calcium that is concentrated off blood flow and is crystallized into two layers, being an intermediate between scleroproteins layer and another as the protective carapace, the two are formed by carbonate calcium ($CaCO_3$ - aragonite and calcite).

The crystals differ from the shape and orientation during crystallization according to each layer of ectodermal cells. It is noteworthy that the shells are very strong and durable, and over time, where there is a large accumulation of such material can generate sediments, which by means of a compressive rock will become limestone.

The ceramic tile is, according NBR 13 816 - 1997: Material comprised of clay and other inorganic materials commonly used for coating floors and walls, being processed by extrusion, by pressing, or by other processes. The plates are then dried and fired at sintering temperature. Can be enameled (GL = glazed) or unglazed (UGL = unglazed). The plates are incombustible and unaffected by light.

Aiming to minimize environmental impacts and make viable material to reuse, this research is intended to join the fishing and ceramist activities with the incorporation of marine shell on ceramic coating formulation and thus generate a product with a lower cost, that is relevant to technical standards proposed by the agencies and regulatory institutions.

## EXPERIMENTAL

The raw materials used were traditional: quartz, plastic clay and sodium feldspar that were collected in Parelhas/RN at the company Armil Mineração do Nordeste Ltda, while the shells were collected in mangrove Jacu River located in the city of Ares/RN (fishermen discard material after removing.

The tests that are described below followed NBR 13818: 1997 for ceramic tile. The processing of the materials and the conformation of the ceramic body were performed at Laboratório de Processamento Mineral e Resíduos [Mineral Processing Laboratory and Waste] and technological characterization of the shells was performed on characterization Laboratório de Caracterização de Minerais/Materiais [Characterization Laboratory Minerals / Materials] do Instituto Federal de Educação, Ciência e Tecnologia do Rio Grande do Norte – Campus Natal Central.

The above materials passed through comminution processes: crushing (jaw crusher), grinding (hammer mill and ball mill) and at the end, after sieving, obtained the expected particle size of #200 (mesh) /0.074 µm (parameter for laboratory tests). The figure 01 systematizes processes.

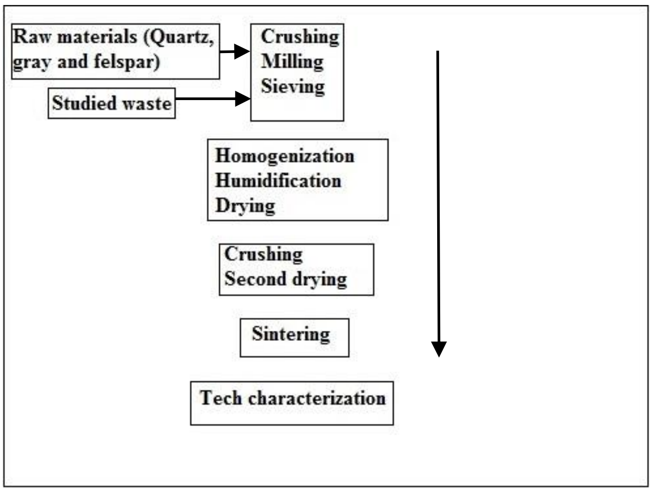


Figure 1 - Flowchart of processes performed during this work

To characterize chemically the shells was used in X-ray fluorescence technique using equipment Niton ™ XL3t GOLDD + XRF Analyzer.

After the comminution and the screening was initiated to conformation tests. Two formulations of test samples have been proposed, F1 and F2, containing 10% and 15 % of shell by weight respectively. In the stock preparation process, the materials are weighed and homogenized manually reaching a final weight of 12 g dry mass. Then distilled water is added to 10 % by weight relative to the final dry mass. Finished the mixing of materials, products are bagged and left to rest for a period of 24 hours before being shaped by uniaxial pressing. Pressed, the samples go to a greenhouse for a further 24 hours in order to lose any remaining moisture before moving to sintering. The burning takes place in a muffle furnace, where the temperature of the environment follows to a maximum of 1200 ° C with a heating rate of 10 ° C per minute and remained at 1200 ° C level for 1h.

After firing, it was made the technological characterization of the specimens with the test: linear firing shrinkage (LFS), loss on ignition (LI) and water absorption (WA). For microstructural characterization was used to scanning electron microscopy (SEM) and energy dispersive spectroscopy (EDS) using the equipment VEGA3 LM.

**DISCUSSION**

As a result of X-ray fluorescence, the shells showed a high percentage of calcium carbonate ($CaCO_3$) and some common contaminants such as silicon (Si), chlorine (Cl), strontium (Sr) and iron (Fe) in smaller proportions, as shown in table 01, "Bal" is a balance in percentage of unmeasured chemical elements with X-ray fluorescence.

Table 1 – percentage in mass of the measured chemical elements

| Element | Bal | Ca | Si | Cl | Fe |
|---|---|---|---|---|---|
| % mass | 61.328 | 37.279 | 0.377 | 0.098 | 0.028 |

The results of the Linear Firing Shrinkage test held two means very close in two formulations, Formulation 01, the percentage of shrinkage of the specimen was 5.7%, while Formulation 02, the percentage of shrinkage was 5.8% in relation to the length of the specimens before sintering, as well as the figure 2 illustrates.

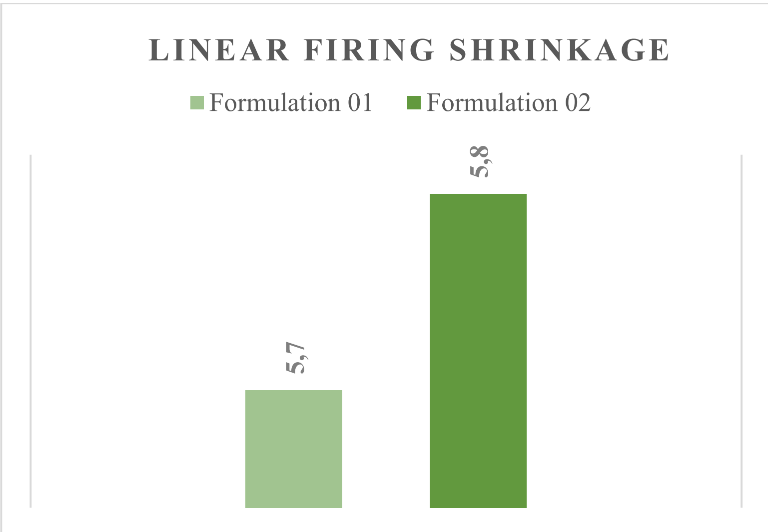


Figure 2 - Average of Linear Firing Shrinkage

The results of Water Absorption tests show the percentage by weight of water absorbed by the dry specimen. The percentage expresses an average absorption in the range of 0.2% to 0.3 % of the total weight of the specimen in the formulation 01 and 02, respectively, as shown in figure 03.

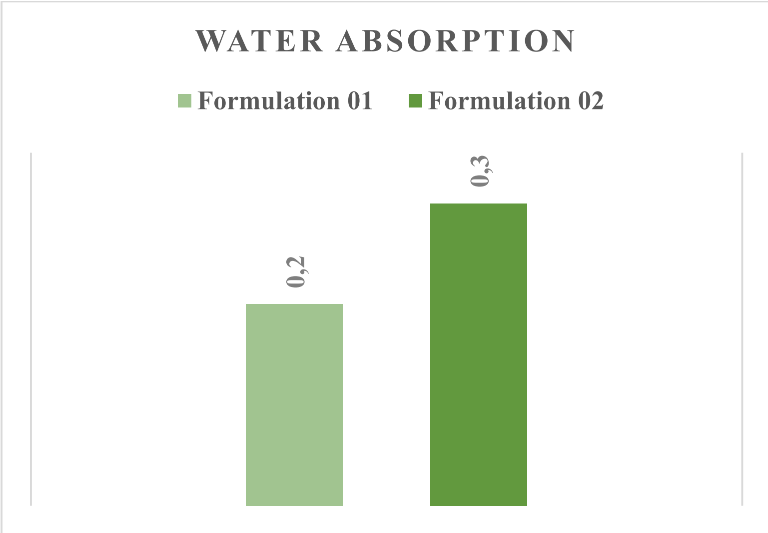


Figure 03 – Averages of Water Absorption

Resulting from loss on ignition teste, the mean of weight loss during sintering were 8.3% for the formulation 01, and 9.3% for the formulation 02. Indicating the process of calcination of calcium carbonate, which upon reaching about 900°C, the compound undergoes a reaction where part of the mass turns into calcium oxide (CaO), and the other part is transformed into dioxide carbon ($CO_2$), or gases which slow the process of densification of ceramic bodies, generating pores, this process accounts for the high percentage of mass lost during firing, the chemical equation below shows the calcination process. Figure 04 presents the averages percentages of Loss on Ignition test.

$$CaCO_3 = CaO + CO_2 \quad (1a)$$

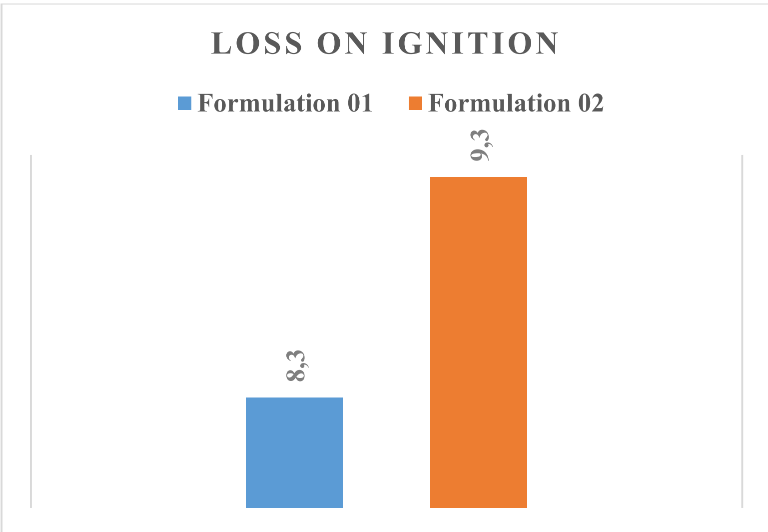


Figure 04 – Means of loss on ignition test

The microstructural characterization by scanning electron microscopy (SEM) and spectroscopy of X-ray energy dispersive (EDS), showed results that are extremely relevant for understanding the effects of the use of the shells in the ceramic bod. Figure 05 show the results of microscopy to formulation 01. In the images it is possible to identify a uniform porosity and a discrete glassy phase.

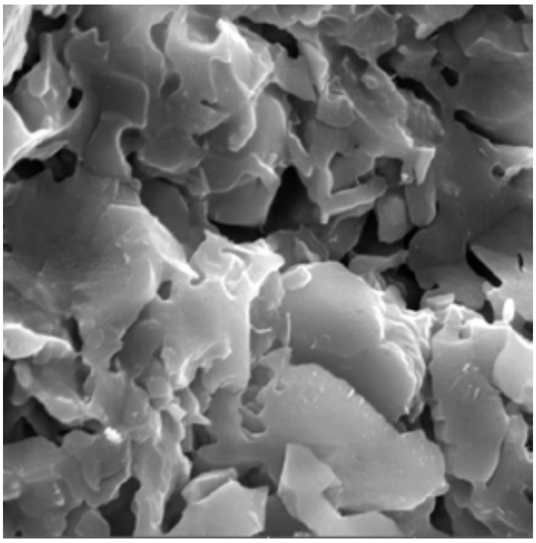

Figure 05 – micrography magnified 7000x

The figure 06 show the results of microscopy of a specimen of the F2 formulation containing 15 % of shells. In the pictures you can notice small pores, resulting from $CO_2$ accumulation during sintering of the piece, the glass phase is hardly present.

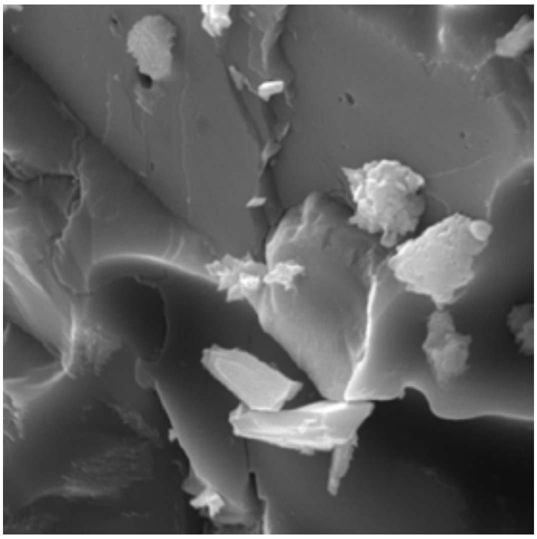

Figure 06 – micrography magnified 7000x

## CONCLUSION

The study shell is rich in calcite, with around 98 % of its measured mass.

Technological tests resulted in specimens with little glassy phase, loss to high fire and water absorption by an average of 0.5% and 1.0% which characterizes the samples as porcelain stoneware, BIb group according to the coating parameters NBR 13818: 1997 - classification.

Having a low water absorption and a high resistance, this type of coating is suitable for use in areas of high traffic of people such as shopping centers, schools, hospitals, etc.

The shells studied proved viable for use in the manufacture of ceramic coating as an additional material in the formulation.

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# GASIFICATION ZONE EVALUATION USING AE TECHNOLOGY FOR EX-SITU UCG EXPERIMENTATION USING AN ARTIFICIAL COAL SEAM

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# Gasification Zone Evaluation using AE Technology for Ex-situ UCG Experimentation using an Artificial Coal Seam


## ABSTRACT

During Underground Coal Gasification (UCG) operations, evaluation of coal combustion cavity growth and precise control of the reactor are important to ensure effective combustion and efficient gasification. Enlargement of the oxidation surface around the gasification channel with crack initiation and development inside the coal seam both influence the gasification efficiency directly. Fracturing activities inside the coal seam serve an important role for the enlargement of the gasification zone because surface area oxidization increases continuously during coal cracking. For effective coal gasification, the fracturing activity must be controlled. Therefore, monitoring and control of fracturing activity underground constitute key technologies for efficient and safe UCG. To monitor fracturing activity, we used acoustic emission (AE) technology.

For this study, experiments were conducted using an artificial coal seam to elucidate the combustion cavity growth processes of by monitoring the temperature and AE activity. The experiment also facilitated observations of the fracture configuration and cracks, yielding fundamental information related to the technology and simulation methods to estimate and evaluate the extent of the combustion area. The artificial coal seam designed to have rectangular shape was about 2.74 m (length) × 0.60 m (width) × 0.55 m (height). Results show that coal fracturing developed inside the coal with AE activity under burning. These AE generations apparently result from crack initiation and extension around the coal combustion area under the influence of thermal stress. Comparison of the temperature variation and accumulated AE event curves revealed close correlation among them. The expansion and the movement of the combustion zone were estimated based on results obtained for AE source locations. Monitoring of AE during UCG can enable identification of failure mechanisms, estimation of damage zone development, and provision of important data and parameters to visualize the gasifier underground.



## KEYWORDS

Underground coal gasification, Acoustic emission, UCG models, Combustion cavity


## INTRODUCTION

Coal is widely expected to be the primary energy source for the 21st century. Improving the production and usage of existing coal resources is an important issue that also presents an environmental problem that must be confronted. As a clean coal technology, Underground Coal Gasification (UCG) is used to create a combustion reactor in an underground coal seam, thereby enabling the collection of heat energy and gases (hydrogen, methane, etc.) through the same chemical reactions that are used in surface gasifiers.

However, associated environmental issues, improperly executed operations, and designed gasification processes can restrict the applicability of UCG. Most problems that might occur with UCG, such as subsidence, gas leakage, and groundwater pollution, are caused by fractures near the combustion area and the cavity formed by the coal combustion. Precise control of the combustion reactor is difficult. Moreover, techniques used to evaluate and control the coal seam fracture activity around the combustion area are underdeveloped. Therefore, fracturing inside the coal seam during burning is important to evaluate and control coal gasification in-situ because enlargement of the free surface around a linking hole with cracking inside the coal seam directly influences the gasification efficiency.

Construction of a secure and efficient UCG system requires development of a reasonable design for expansion of the gasification zone and for effective control of the combustion area in the coal seam. We realized that the UCG cavity growth is a complicated phenomenon associated with coal fracturing operating parameters. For the evaluation of fracturing activity around the gasification zone, we applied acoustic emission (AE) monitoring (Itakura et al., 2010; Su et al., 2013).

For this study, ex-situ UCG model experiments were conducted using an artificial coal seam to identify the process of combustion cavity growth and fracture configuration by monitoring the local temperature change, AE activities, etc. Results obtained from this experiment revealed coal-generated AEs with special AE activity patterns caused by thermal stress. The AE technique can visualize fracture extension around the combustion reactor. The crack distribution model constructed through three-dimensional calibration of AE sources and moment tensor analysis is expected to be useful to evaluate the gasification process, and to provide important data and parameters for development of the UCG simulation.

## EXPERIMENTAL

Designing a reasonable gasification model to evaluate the underground combustion area and the fracturing activity inside the coal seam and rocks is crucially important for the development of a secure and efficient UCG system. In a typical UCG process, two boreholes are drilled into the coal seam. They are connected at a proper distance by an underground gasification gallery created using various linking techniques. With the development of the UCG technology, plenty of design approaches have arisen for underground reactor structures. An underground reactor is created. It expands around the linking-hole, i.e., the gasification channel, with cavity growth. Herein, the UCG system was prepared within an artificial coal seam for three independent tests according to the ignition position and linking-hole type, as presented in Fig. 1. Table 1 presents a description of these three tests. Air, oxygen, and steam are injected into the combustion reactor to sustain the gasification process.

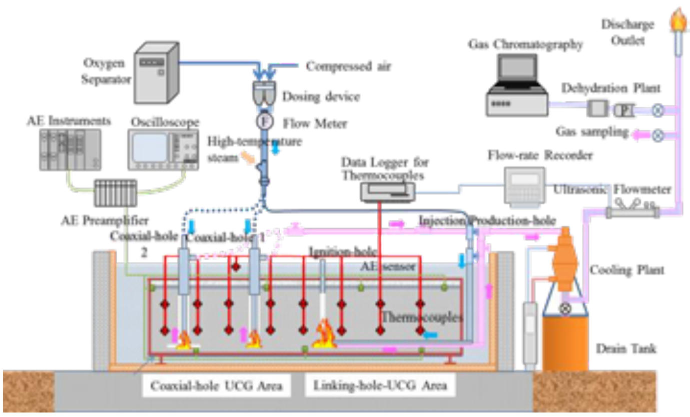


Figure 1 – Schematic diagram of experimental setup.

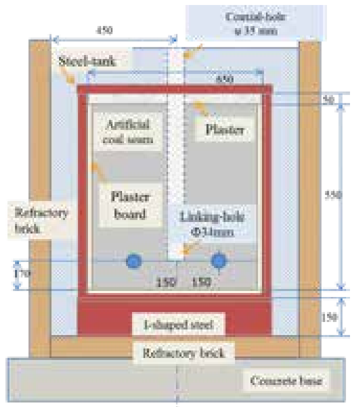


Figure 2 – Vertical cross-section.

Table 1 – Operating conditions of three tests

| Model No. | Test 1 | Test 2 | Test 3 |
|---|---|---|---|
| Model Types | Coaxial hole model | Coaxial hole model With a directional branch hole on the bottom | Linking-hole model |
| Ignition Location | bottom of coaxial hole 1 | bottom of coaxial hole 2 | bottom of ignition hole |

Typical dimensions and structures of the gasifier applied in simulations of underground gasification are presented in Fig. 2. In this ex-situ UCG model, the actual underground conditions can be simulated both in terms of the coal seam and the surrounding rock layers.

The locations of AE sensors and thermocouples are depicted in Fig. 3. The AE counts and events from sensors mounted inside the coal seam were recorded using a data logger (GL900; Graphtec Corp., Yokohama, Japan). In this measurement system, the AE count rate reflects the magnitude of an AE event. The number of AE events shows the number of cracks initiated inside coal samples. All AE waveforms from sensors were first recorded using a multi-recorder (GR-7000; Keyence Co., Osaka, Japan) with sampling time of 10 µs. Then they were processed in the computer. These AEs are generated during crack generation and development in the coal.

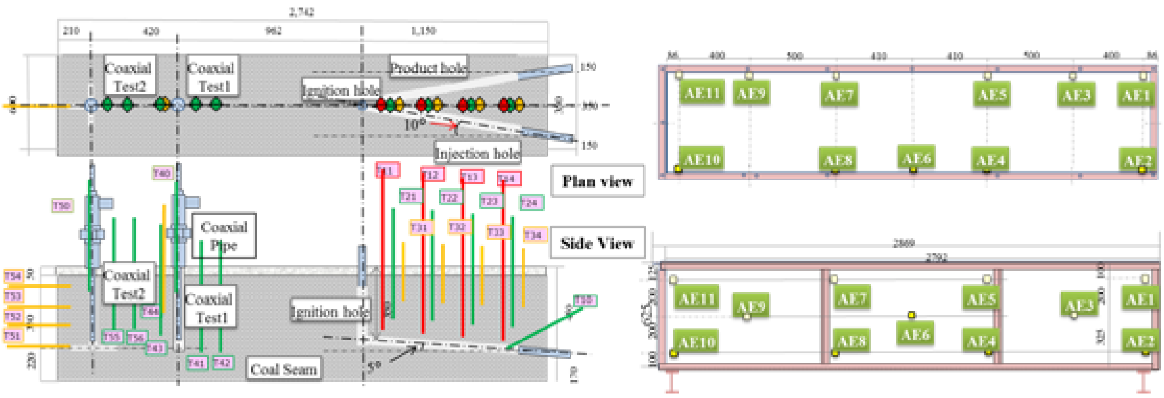


Figure 3 – Thermocouples and AE sensor arrangement.

We obtained the triggering time of a microcrack occurring inside the gasifier, which is useful for calculating the source location. The AE source locations were obtained by application of the least-squares iteration technique (Hardy, 2010). As a method of calculating AE source locations, the process presented in Fig. 4 was conducted. The density of the simulated coal seam inside the UCG model is inhomogeneous. Therefore, we obtained the primary wave velocity using a knocking test (artificial seismic source) before the experiments. The AE source coordinates were calculated using this presumptive primary wave velocity.

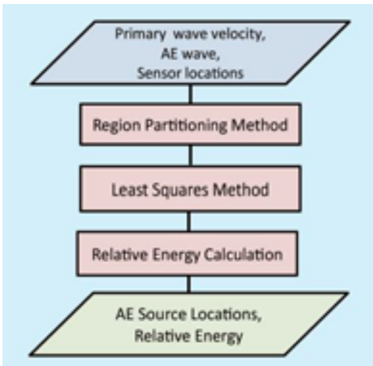


Figure 4 – Procedure for calculating AE source location.

The results of AE source locations and local temperature changes with respect to the operational time are presented in the following figures. The carbon dioxide and nitrogen were applied to extinguish combustion during the last stage of the gasification process. Respectively corresponding to the locations of thermocouple inside the model, the rates of temperature increase of each thermocouple and the high-temperature areas are clearly marked in these figures.

The relations between the temperature change and AE events that occurred inside the combustion zone were investigated. The AE events generated with the increase of temperature inside the UCG gasifiers were also analyzed using statistical methods, as shown in the figures. Data collected at the period of coal ignition (unstable combustion) were excluded from analyses. Results show that AE is active during the initial stages of coal fracture, but that it is stable in the middle and later periods.

Red, green, and blue spheres in the 3D models respectively depict the AE sources of the early, middle, and later periods. The extent of damage, i.e. the relative energy emitted from cracking, can be differentiated from the sphere size. The extent and movement of combustion and the gasification volume inside the coal seam can be inferred from AE source locations. In the early stage of experiments, the AE sources are concentrated around the ignition points. Subsequently, the AE source clouds expand and move along the linking holes in the middle and later periods.

In the right panels of Fig. 6 and Fig. 8, the colored circular rings express the centers of gravity of the AE cloud. They had been calculated through statistics reflecting the event energy and event count. The lengths of arrows in the horizontal and vertical directions represent the breadth of the AE cloud region. The movement of AE cloud center also reflects the size of the combustion area and the cavity growth in the gasifier.

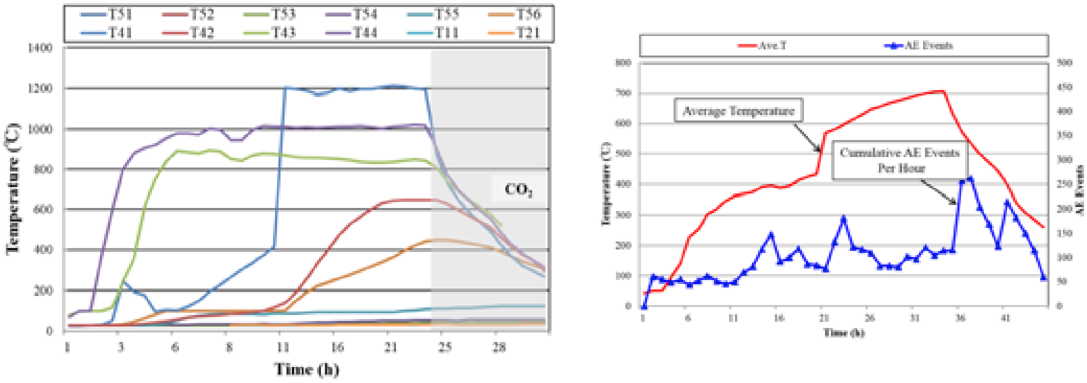


Figure 5 – Temperature profiles and AE activities of Test 1.

For Coaxial test 1, after igniting the coal seam, the temperatures of T43 and T44 increased rapidly, which locate around left side of coaxial hole. Subsequently, the higher temperature zone moved along the right side and expanded around the coaxial hole. After about 24 h, The $CO_2$ was injected into the reactor to investigate the effect of fire extinguishing. It is apparent that the temperatures drop sharply with the feeding of $CO_2$. The AE events also increase considerably when the combustion area temperature changed.

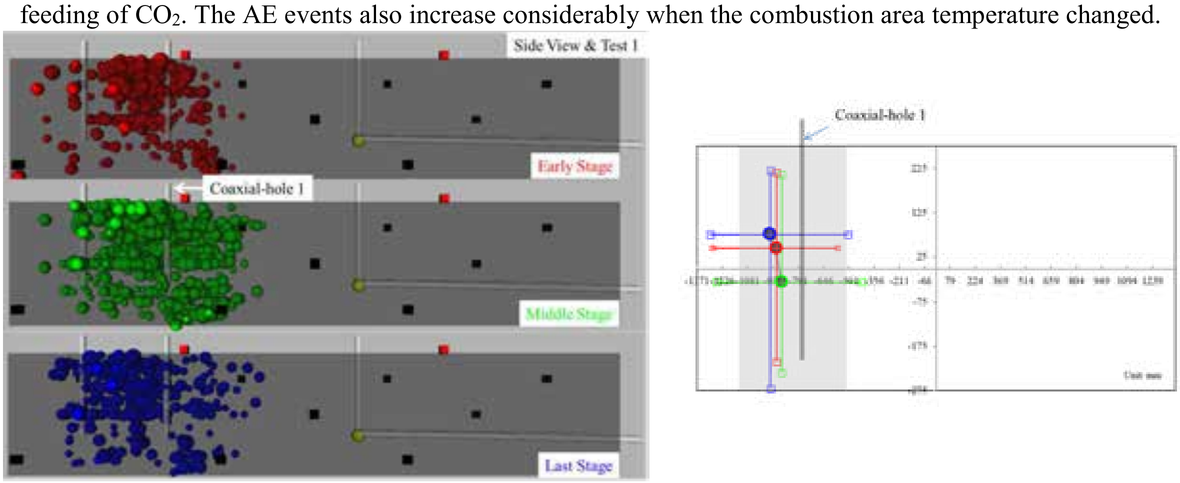


Figure 6 – AE source locations and gasification zone movement of Test 1.

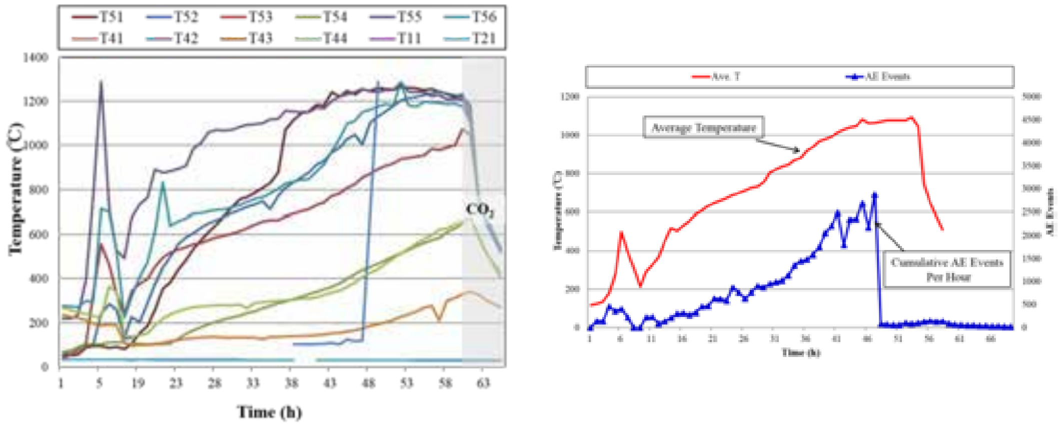


Figure 7 – Temperature profiles and AE activities of Test 2.

During the initial part of the coaxial test 2, temperature T55 maintained rapid growth until arriving at the highest value. The gasification zone moved from the underside to upper part along the coaxial pipe. We also monitored the fire extinguishing process with AE. A sudden drop in the temperature of combustion area occurred with the increment of AE events.

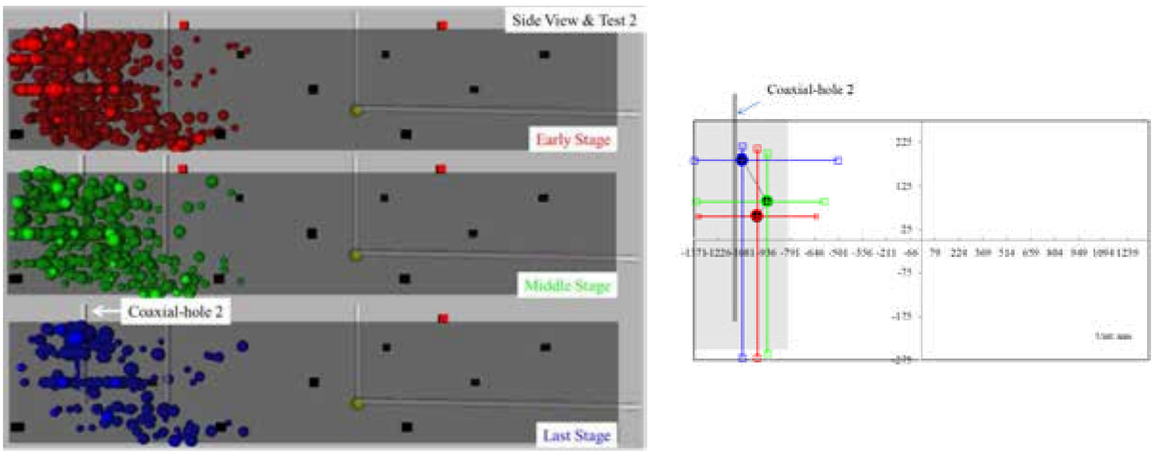


Figure 8 – AE source locations and gasification zone movement of Test 2.

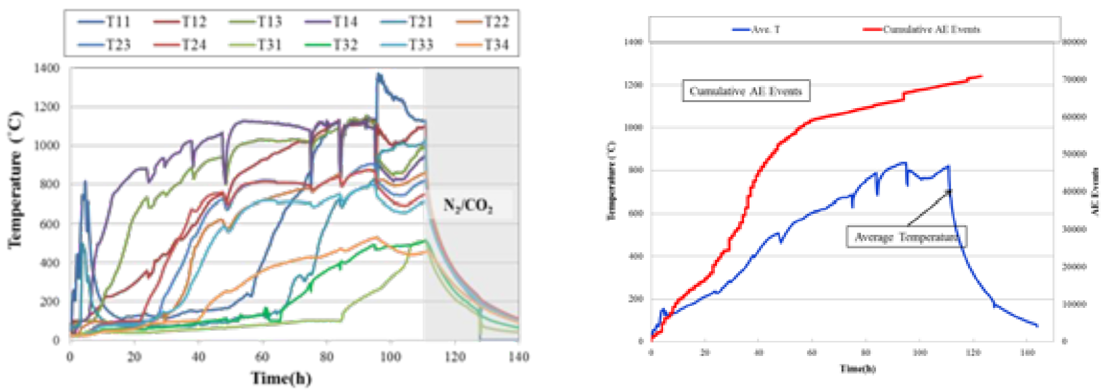


Figure 9 – Temperature profiles and AE activities of Test 3.

We obtained the center of gravity only by calculating the average coordinate values of the horizontal axis. It is apparent that the movement of gasification zone can also be roughly reflected by the AE cloud center. At the early stage, the most cracks occurred near the ignition area; then, the AE active area moved to the central region and expanded around the linking-hole.

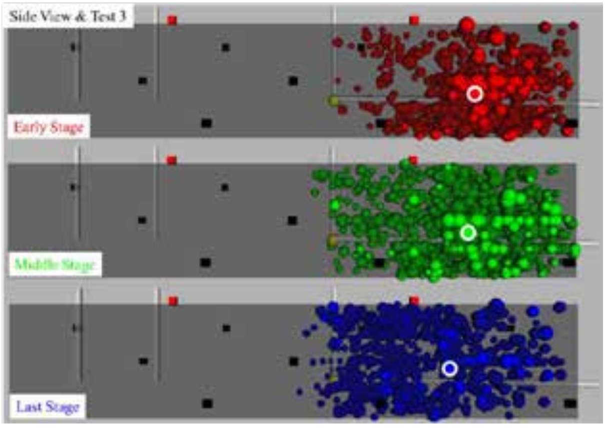


Figure 10 – AE source locations and gasification zone movement of Test 3.

It is apparent that the AE activity was active while the local temperatures changed inside the coal. These three tests were of processible AE events occurring respectively at 6627 (Coaxial test 1), 46676 (Coaxial test 2), and 72654 (Linking-hole test 3). The geometry, dimensions, and the linking-hole types of the experimental model affect the gasification efficiency. Around the fire extinguishing phase, the AE events increased considerably along with the decrease of temperature in the gasification zone. The experimentally obtained results demonstrate that many AE events were generated during coal combustion. The AE activity was closely related to the change of local temperature inside the coal. These AE generations apparently result from crack initiation and extension around the coal combustion area under the influence of thermal stress.

To assess the AE monitoring techniques applied during UCG, we compared the experimentally obtained results related to the temperature change and AE event, as well as the AE source location. To receive much more information obtained from the monitored AE data that represent the actual cracks that occurred inside the coal, we assessed the results of moment tensor analysis. The cracks are represented by multipronged disks in moment tensor analysis. Tensile-type and shear-type fractures can also be confirmed. In Fig. 11, crack distribution models estimated using the moment tensor analysis are shown.

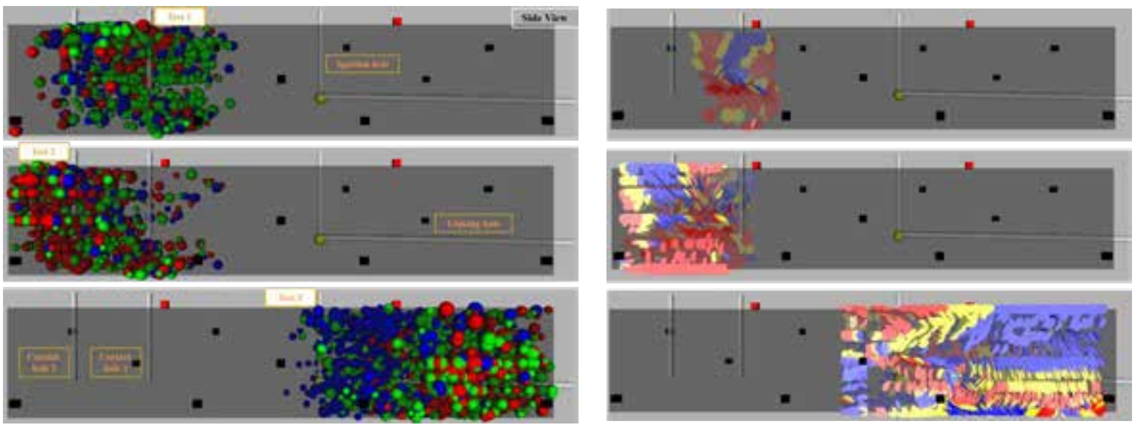

Figure 11 – Moment tensor analysis results (3-D disk models) of three tests.

In these models, pink and blue disks respectively represent the tensile fracture and shear fracture. The mixed mode fracture is represented by gradient colors of purple and yellow. The center of the crack disk is at coordinates of the AE source locations. The disk radii show the relative AE energy. Orientation of the disk presents the principal direction of moment tensor and the compensation of additional source is fractal and random in the crack distribution model. Tensile-type and shear-type fractures can also be confirmed. Results of moment tensor analysis are presented in Table 2.

Quantitative information related to three-dimensional locations of cracks, crack types, and directions of crack motion are obtainable. Results show that the shear type cracks are distributed at the center of the combustion region and the tensile type cracks are distributed outward of the combustion region. Results show that the shear type cracks are distributed at the center of the combustion region and that the tensile type cracks are distributed outward of the combustion region. With respect to the accuracy of results based on AE waveforms, it was unavoidable because of the computational error's influence on the P-wave velocity and random noises during the operational process.

Table 2 – Results of moment tensor analysis

| Model No. | Tensile-type (count) | Shear-type (count) | Mixed-type (count) |
|---|---|---|---|
| Test 1 | 657 | 341 | 379 |
| Proportion (%) | 47.7 | 24.8 | 27.5 |
| Test 2 | 1412 | 759 | 616 |
| Proportion (%) | 50.7 | 27.2 | 22.1 |
| Test 3 | 3198 | 3888 | 4069 |
| Proportion (%) | 28.7 | 34.8 | 36.5 |

After the experiment, the coaxial pipes and connecting pipelines were torn down. Then plaster was poured into the reactor for observation of the cavity shape and cracks. The cutting scheme of UCG model sections is presented in Fig. 12. Figure 13 presents photographs of vertical sections of coaxial model test 1/2 and linking-hole test 3 cutting the coal seam parallel to the locations (No. 12, No. 16, and No. 2/6) given in Fig. 8. The white area shows the cavity and cracks cemented by plaster.

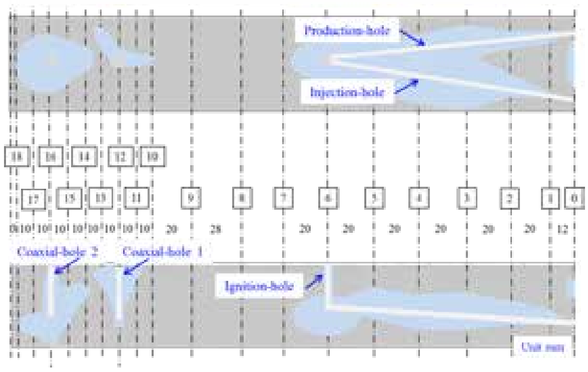


Figure 12 – Cutting distance of vertical cross-sections.

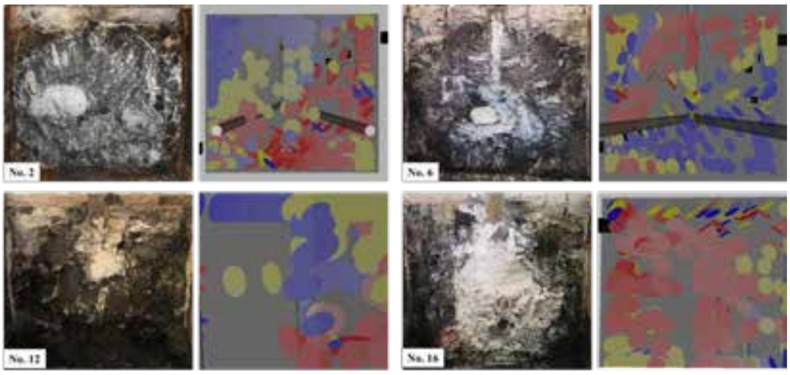


Figure 13 – Vertical cross section with results of moment tensor analysis.

## CONCLUDING REMARKS

Evaluation of combustion zone and fracturing activities of ex-situ gasification of coal was done using in a large laboratory-scale UCG model. Results show that the number of AE events increased with the whole operation time. These AEs generated along with the crack initiation and extension around the coal combustion area in the influence of thermal stress. Comparison of the temperature variation and accumulated AE event curves revealed a close mutual correlation. The local change of temperature inside the coal induced fractures with AE. The AE sources and crack distribution models show that most cracks were generated at the fracture position and around the combustion area. From the AE source locations, the expansion and the movement of combustion zone were estimated. The same tendency was observed from changes in the temperature distribution in coal.

The extent and size of the combustion area was confirmed by the monitoring results of local temperature changes and the AE source locations. The evolution of the gasification zone was evaluated by the movement of the AE cloud center. Monitoring acoustic emissions (AEs) during the UCG process is a useful technique to infer the mechanisms of failure and to estimate the damage zone development. The crack distribution model constructed by moment tensor analysis is also important to visualize the cavity configuration and fracturing extent for control of the underground combustion reactor.

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# GEODYNAMIC ZONING OF MINING AREAS USING AUTOMATED LINEAMENT ANALYSIS AND SATELLITE IMAGES

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# GEODYNAMIC ZONING OF MINING AREAS USING AUTOMATED LINEAMENT ANALYSIS AND SATELLITE IMAGES


## ABSTRACT

The paper reports the results of automated lineament analysis of synthesized satellite image of LANDSAT-5. Using statistical features of lineaments on different hierarchical scales, the authors detect morphostructural lineaments, delineate rock blocks these lineaments divide, and characterize jointing and stress field of rock masses.



## KEYWORDS

Analysis, lineament, image, density, fault, block, rose diagram, geodynamics, zoning.


## INTRODUCTION

In view of recent advances in remote sensing systems, increasingly much more attention is paid to discovery and analysis of lineaments (linear discontinuities in the earth crust and lithosphere, of various rank, length, occurrence and age) using satellite images. Research of the linear structures is highly important for operational evaluation of jointing of vast areas, detection of underground water flow paths, prospecting of new mineral deposits, prediction of hazardous events and processes, selection of sites for construction of infrastructure of vital importance (atomic power plants, underground repositories for radioactive waste, sports facilities, highways, tunnels, etc.). In particular, geodynamic zoning and delineation of block structure of the earth crust widely uses data of automated lineament analysis of satellite images, namely, rose diagrams of different rank local lineaments (stripes). For instance, it is typical that uniform blocks in the earth crust have similar rose diagrams of lineaments. The pattern changes upon intersection of a morphostructural lineament between heterogeneous blocks. Stress and strain state of the earth crust blocks is assessed by the schemes of density of lineaments (stripes). Higher density zones are connected with tension in the earth crust, lower density—with compression. Paths of fracture water migration are identified by increased density of lineaments oriented across river valleys. Landslide hazard is forecasted based on the presence of fracture water migration zones related with fracture water discharge in river valleys.

The automated lineament analysis enables geodynamic zoning of subsoil; in other words, it allows revealing block structure of rock masses, active faults and faulting intersections, and zones subjected to high tectonic stresses, and enables assessment, prediction and control of rock masses at any stage of open pit or underground mining (Petukhov & Batugina, 1996; Gvishiani, Gorshkov, Zhidkov & Trusov, 1987; Gvishiani, Agayan, Dobrovolsky & Dzeboyev, 2013; Solovyov, Gvishiani, Gorshkov, Dobrovolsky & Novikov, 2014).

The present research into block structure of rock mass, modern active faults, heavy jointing zones, landslide areas and groundwater migration paths in the area of the Second Baikal Tunnel project of the Baikal–Amur Mainline has been implemented using proprietary technology of automated lineament analysis of satellite images (Uchaev, Malinnikov, Uchaev & Fam Suan Hoan, 2011).

## AREA OF RESEARCH

The Second Baikal Tunnel 6682 m long is driven in parallel to the existing tunnel under the Davan Pass of the Baikal Ridge (see Figure 1). The maximum depth of the tunnel is 300 m under the saddle of the Davan Pass (survey stake 10079), and the average depth along the tunnel route is 180 m. Rock mass to be crossed with the Baikal Tunnel is composed of magmatic rocks. Tectonically, this is the zone of a regional deep fault, or the Davan shear zone, with widespread tectonic dislocations the majority of which are overthrusts, zones of heavy crushing and mylonitization of rocks, and neotectonics sutures. The tunneling project area belongs in the zone of the Baikal Rift with the seismicity up to magnitude 9. There are a few zones of faulting revealed immediately in the tunnel construction site. Rocks in the faulting zones are heavily jointed and often crushed. Hydrogeological conditions are classified as complicated. Groundwater is mostly present at Quaternary deposits, and fracture and vein water occurs mostly in faulting zones. Solid and weakly jointed rocks with hardness f = 6÷10 are rated good and stable. Jointed, heavily jointed and crushed rock mass is classified as fair (f = 4÷6), poor (f = 2÷4) and very poor (f < 2), respectively, with high inflow of water. Weakly jointed, good and excellent quality rock mass composes 94% of the tunnel, and construction conditions are favorable here. The rest 6% of the tunnel extent is hosted in fair and good tectonized jointed rock mass. The geological section consists of the mid-Proterozoic granitoids of the multi-phase Irel Complex, composing the Kunermian Massif, within which 5 sequential formation stages are distinguishable. Each phase features specific type of rocks; phase 1—granodiorites; phase 2—granosyenites; phase 3—orthoclase gneiss; phase 4—diorite-syenite; phase 5—pseudoporphyritic bastard granite. The parent magmatic rocks are overlaid with the loose Quaternary formations.


( a ) General geographic map (b) Synthesized satellite image

Figure 1. The area of the Baikal Tunnel construction

The construction site of the Baikal Tunnel is situated in the tectonic structure of a regional deep fault, or in the Davan shear zone, characterized by the following features: predomination of magmatic rocks in the geological section, widely spread tectonic dislocations and diverse geochemical composition. Tectonic dislocations have the form of inclined crumpled rock folds with limbs dipping at 25–30° and with gneissoid structures. Among the numerous tectonic faults in the Davan zone, the most representative are: overthrusts (5–10 m thick, mostly in the west tunnel face area); heavy crushing and mylonitization zones; neotectonics sutures. The zones of heavy rock crushing and mylonitization are connected with the Kunerma overthrust—the largest disjunctive-type tectonic structure bounding the Davan shear zone on the west. The overthrust extends from the south-west to the north-east and shows itself as a projection on the western side of the ridge. Rocks in the overthrust zone are mylonite and breccias. In the area of the tunnel, the Kunerma overthurst represents the boundary between phases 1 and 5 of the Irel Complex. Neotectonics in the Davan zone shows itself as displacements along block interfaces and renewal of sliding on pre-existing sutures. There are up to six neotectonic sutures, well distinguishable, observable as projections on the relief and identified based on data of core drilling and geophysical surveying. The amplitude of displacements along the neotectonic sutures is the first tens of meters. Neotectonics plays a key role in the formation of modern relief by means of uplift of ridges and subsidence of depressions.

The exogenous geological processes that complicate construction and operation in the tunnel project site include gravitational and seismo-gravitational (rock falls, rock slides, avalanches), erosion (deep and lateral erosion, rainwash and flow erosion) and weathering. All geological processes are genetically inter-connected, and are activated by engineering and construction activities: area layout; cutting of slopes; deforestation and stripping; arrangement of runner systems for land drainage, soil soak with foul water, etc. Among the endogenous processes within the site of the First Baikal Tunnel and a drainage gallery, it is worthy of mentioning slabbing of face rocks and seldom rock outbursting. By engineering-geologic estimate of the pass area (Davan Pass) of the Baikal Ridge based on the geological, structural and tectonic data obtained by the North Baikal Integrated Team of the Buryatia State University and the Institute of the Earth Crust, Siberian Branch of the USSR Academy of Sciences, this rock mass experiences extra stresses, and geodynamic processes, such as slabbing, outbursting and even rock bursting, are quite probable.

## RESEARCH PROCEDURE

Aimed to implement geodynamic zoning, the geostatistical analysis of the lineaments and stripes detected in the satellite images is first performed. This analysis allows revealing statistical regularities in spatial distribution of lineaments either over an entire area under analysis, or within specified subareas, and provides additional information on a set of linear structures. In the framework of the statistical analysis, it is possible to estimate density and frequency of spatial pattern of the stripes, lineaments and their intersections, to generate rose diagrams of stripes and lineaments, and to estimate spacing of lineaments. The analysis uses statistical features of development of lineaments [(Uchaev, Malinnikov, Uchaev & Fam Suan Hoan, 2011; Sonder, 1938; Methodical study-guide of a planetary jointing and lineaments, 1977; Katz, Poletayev &, Rumyantseva, 1986; Nechayev, 2010; Koronovsky, Bryantseva, Goncharov, Naymark & Kopayev, 2014; Zlatopolsky, 1991). The study of oriented lineaments begins with identification of linear elements—rectifiable boundaries or lines not less than 10 pixels in length. These local linear unit elements are called stripes. Orientation of each stripe is determined at a step of $22.5^0$, i.e. stripes are detected in eight directions: $0^0$, $22.5^0$, $45^0$, $67.5^0$, $90^0$, $111.5^0$, $135^0$, $157.5^0$.

In addition to generating the fields of stripes (local lineaments), density of the stripes is defined summarily for all directions and for each individual direction, and lines of elongation of rose diagrams of stripes (per window 50 pixels in diameter). Also, another option of the stripe analysis is used, namely, the stripes are combined into lineaments to go through the entire image under analysis—the so-called through lineaments consistent with the regional or global lineaments with regard to the rank. Rock blocks are delineated based on the change in the shape of rose diagrams and in the orientation of stripes. Delineation of blocks of various hierarchical levels in the earth crust (Zverev, Malinnikov & Donov, 2009) uses different resolution satellite images.

The input information of the lineament analysis is the images of the area under discussion, synthesized from satellite images of spectral bands 2, 3 and 5 of LANDSAT-5.

## RESEARCH FINDINGS

Figure 2 shows the resultant detected through lineaments at validity measure of 50. It is clearly seen that the morphostructural lineaments with the north-easterly strike prevail and split the earth crust into a series of narrow blocks extended in the north-eastward direction. Also, some diagonal morphostructural lineaments with the north-westerly strike are observable. The Baikal Tunnel (the rectangle in the figure delineates the tunnel site) occurs at the intersection of two diagonal lineaments with the north-easterly and north-westerly strikes (Figure 2). The intersection of active faults implies probable local stress concentrations and the related stress-induced displacements in this zone.

The area under study is mostly composed by Pre-Cambrian granites and grano-syenites that break through the Pre-Cambrian metamorphic rocks westwards of the tunnel. The governing role of the intrusive rocks and the related prime tectonics (jointing induced by formation of intrusive) conditions the most intricate and branched pattern of the regional drainage basin (refer to Figure 1). This is confirmed by the branched pattern of elongation lines of the rose diagrams of stripes in Figure 3.

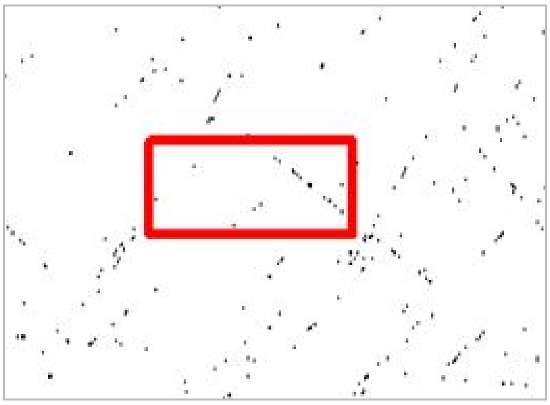


Figure 2. Through lineaments detected in the zone of the Baikal Tunnel site

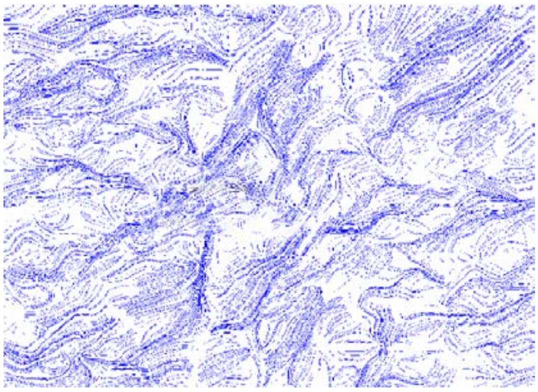
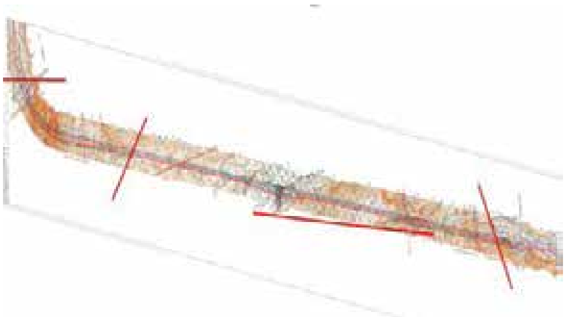


Figure 3. Elongation lines of rose diagrams of stripes

The through lineaments and the lines of elongation of the rose diagrams conform with the morphostructural lineaments of the first and second order, respectively. In order to reveal higher order faults and blocks, it is advisable to use fields of rose diagrams of stripes and patterns of vectors of stripes, characterizing value and direction of elongation of their rose diagrams. The change in the shape of a rose diagram, or in its elongation direction is reflective of the transition to another block of the earth crust, and the block boundary is a fault.

Figure 4 shows a magnified segment of the schematic representation of block structure of the Baikal Tunnel area under study, after the processing of an original LANDSAT-5 image with a spatial resolution of 30 m/pixel. Such spatial resolution has allowed a more detailed examination of the field of stripes, and generation of rose diagrams and patterns of vectors of the rose diagrams. The statistical processing of the data shows a complex block structure of the local rock mass. The blocks are shaped as different size polygons bounded by the third order active faults (see Figure 4), out of which two faults intersect the tunnel route (Figure 5) and entail potential risk of aggravating geo- and hydro-dynamic processes. The other two active faults occur in the direct vicinity of the tunnel: southwards and westwards of the Western Portal of the Baikal Tunnel.

Figure 4. Third order faults between blocks with different orientations of rose diagrams of stripes



Red lines are faults,
zones of boundaries of blocks

Figure 5. Segment of schematic representation of block structure of the Baikal Tunnel host rock mass

The analysis of the pattern of vectors of the rose diagrams yields that the Baikal Tunnel occurs at the juncture of blocks having different shape rose diagrams of stripes and their orientations. Westwardly, eastwardly and northwardly of the tunnel, there are lineaments of mostly sublatitudinal orientation. Southerly of the tunnel, there is a large block with the vectors of stripes oriented north-north-eastward (NNE) and north-eastward (NE). The automated lineament analysis of the original LANDSAT image (spatial resolution 30 m/pixel) shows that the large southern block has heterogeneous structure and is composed of smaller blocks that feature different shapes and orientations of rose diagrams of stripes and are bounded by the fourth order faults.

Thus, the automated lineament analysis has enabled delineation of different rank (order) blocks with different stress states indicated by shapes and elongations of rose diagrams of the lineaments. The study of the spatial distribution of the overall density of the stripes reveals the adjacency of the increased density anomalies to the river valleys, which implies tension. The mountain slopes feature medium density of the stripes. The minimum density of the stripes is observed in the local areas mostly southerly of the Goudzhekit River.

Based on the revealed statistical regularities in the system of the lineaments, there are three kinds of the geodynamic zones in the area under study (see Figure 6): 1—zones of heavily jointed rock mass under tension; 2—zones of medium jointing of stable development; 3—minimum jointed rocks under compression.

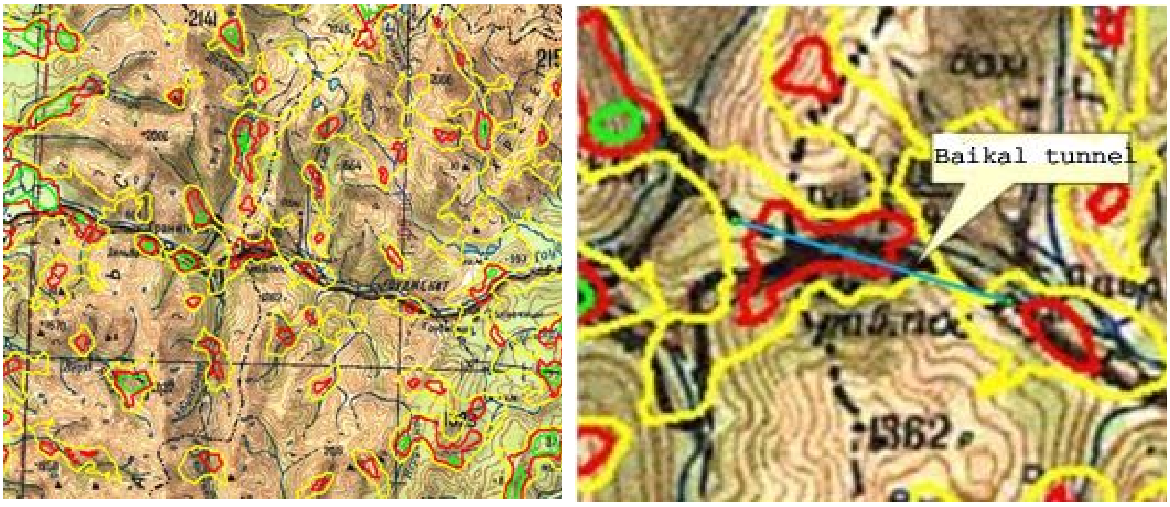



Figure 6. Schematic of stress field: (a) area of the Baikal Tunnel construction; (b) the tunnel site; tension zone 1 (yellow); stable zone 2 (red); compression zone (green)

The Baikal Tunnel is situated within the second zone, i.e. transient geodynamic state zone. The proximity of the tension zones—valleys of the Goudzhekit and Delbichinda Rivers—complicates the geodynamic situation and aggravates stability of the mountain sides. The Goudzhekit River has sublatitudinal orientation of stream (refer to Figure 1), while its main tributaries are of submeridional direction in the tunnel area (NNE $0^0$–$22.5^0$). From the view point of geodynamics, these directions of strike of the local and regional lineaments are of the major concern, as it appears that the main paths of fracture water and slope processes intersect parent side-slopes of the Goudzhekit River valley in the submeridional direction while the river tributaries intersect the valley in the sublatitudinal direction. For this reason, it was decided to analyze density of the stripes resultant from the automated lineament analysis of LANDSAT-5 image in the directions of $0^0$ and $90^0$.

In the direction of $0^0$, near the tunnel, there are two anomalous areas with the increased density of the stripes (local lineaments). One anomalous area is localized directly at the tunnel, the other—a little bit northerly. In these areas of the heavily jointed rock mass, oriented across the parent slopes of the valleys of the Goudzhekit River and its right-hand tributary of the Delbichinda River, fracture water paths run and promote intensive development of slope processes (landslides, solifluction, mudflows, etc.), which endangers the Baikal Tunnel project.

In the direction of $90^0$, the anomalously high density of stripes is observed along the left- and right-hand tributaries of the Goudzhekit River, namely, Delbichinda, Gramna, Kunerma streams and others, which are zones of discharge of ground fracture water from major morphostructures of the region (mountain ridges). Heavy humidification of parent slopes in the valleys of the Goudzhekit River tributaries contribute to activation of slope processes and downward slip of the slopes.

**CONCLUSIONS**

The route of the Baikal Tunnel is intersected by two faulting zones bounding blocks with different orientation of lineaments earlier omitted in the geological engineering survey maps with a scale of 1:5000 (as of 2014). Moreover, another zone of an active fault is located at the Western Portal of the tunnel. Such zones constitute a risk of negative geo- and hydrodynamic processes.

The analysis of statistical data on density of lineaments detected in the area under study and in the neighborhood has revealed three kinds of geodynamic zones with different stress state: 1—tension zones with excessive jointing (crushing) of rocks; 2—transient zones with medium jointing and density of lineaments; 3—compression zones with minimum jointing (crushing).

In the east of the Baikal Tunnel, there is a zone of anomalously high density of lineaments oriented at 0°, i.e. the lineaments crosscut the Goudzhekit River valley and the framing mountain slopes. This zone is the migration path for ground fracture water the discharge area of which is the Goudzhekit River valley.

The main part of the tunnel (in the north-east) occurs in the relatively stable geodynamic zone, in-between the tension zone at the valley of the Goudzhekit and Delbichinda Rivers and the compression zone above the tunnel. However, the location of the tunnel at the intersection of two active diagonal faults of the north-eastward and north-westward orientations implies potential stress concentration and the related induced movement of rocks (geodynamic activity).

The south-west part of the tunnel partly falls at the tension zone. The anomalously high density of local lineaments in this zone implies probable local movements, too. One more area of the kind is identified northerly of the tunnel. These areas of excessively jointed rock masses are adjoined with the paths of ground fracture water migration, which contributes to activation of slope processes (landslides, solifluction, mud flows, etc.).

The revealed through lineaments conform with the modern active zones of faulting and fracturing. Accordingly, considering the regional seismicity and proneness of rock intercalations to brittle failure under increase in the tunneling-induced stresses, there is a risk of geodynamic events in the form of outbursts, spalling, rock falls, etc. For these reasons, the construction site of the Second Baikal Tunnel is classified as rockburst-hazardous, and geotechnical control is required during tunneling with abiding with the Statements on Metallic and Nonmetallic Mineral Mining Safety.

## ACKNOWLEDGEMENTS

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# INDUSTRY SUSTAINABILITY KNOWLEDGE AND PRACTICE TO IMPROVE HEALTH, SAFETY AND ENVIRONMENTAL PERFORMANCE OF ARTISANAL AND SMALL SCALE MINING THROUGH CORPORATE SOCIAL RESPONSIBILITY PRACTICES: CASE STUDIES REVIEW

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# INDUSTRY SUSTAINABILITY KNOWLEDGE AND PRACTICE TO IMPROVE HEALTH, SAFETY AND ENVIRONMENTAL PERFORMANCE OF ARTISANAL AND SMALL SCALE MINING THROUGH CORPORATE SOCIAL RESPONSIBILITY PRACTICES: CASE STUDIES REVIEW


## ABSTRACT

Mining is an important player to economics of several countries, including Brazil. Despite the major role of Large Scale Mining (LSM) in the minerals sector, Artisanal and Small Scale Mining (ASM) also shares the mining market and has a huge social role, mainly in developing countries. Both LSM and ASM cause environmental and health impacts. In some successful cases as Corporate Social Responsibility (CSR) reports demonstrate, Health, Safety and Environmental (HSE) impacts have been addressed by cooperation between LSM and ASM, what can benefit communities as a whole. While certification has been a drive for the LSM, it constitutes a great challenge to be implemented in the ASM. A question guide of our research is where, when and how artisanal and small scale gold mining certification can be a tool for a win-win game in the minerals sector and for mercury emission reduction as proposed by Minamata Convention. Is Brazilian ASGM certification a market trend that could receive support of LSM towards cleaner technologies and mining industry better practices? To answer that our methodology included a review of mining companies CSR worldwide, whereas the results from LSM and ASM cooperation are classified in regards to types of actions implemented for good practices guidance. The applicability to Brazilian ASGM is analyzed and challenges and opportunities are addressed.



## KEYWORDS

Artisanal and Small Scale Mining, ASM, Artisanal and Small Scale Gold Mining, ASGM, Corporate Social Responsibility, CSR, Sustainability, Large Scale Mining, LSM, Minamata Convention


## INTRODUCTION

According to official data, from the approximatelly 68 tons of gold produced annually in Brazil, about 70% comes from three large-scale multinational mining companies operating in the country; and about 13% are produced by small-scale mining enterprises (IBRAM 2012; DNPM, 2014; Ribeiro-Duthie & Castilhos, 2016). With different forms of mineral processing and investment sizes, these companies of different scales coexist and contribute to local, national and international economies. Whether large-scale mining (LSM) has a major role in Brazil as a whole; in Pará State and Mato Grosso State, for example, the artisanal and small-scale mining (ASM) activity accounts for nearly 90% of the state production, given that two of the largest gold mining companies in Brazil are located in Minas Gerais State. This data highlights the fact that in some contexts, ASMs can be the main local players in the gold mining market and this is of relevance when talking about diverse effects of ASM and how to address them.

ASM is a reality with socioeconomic roots and it constitutes a practice very common in developing economies, what includes Brazil. The World Bank (WB) reveals that ASM accounts for 20 % of gold production globally (WB, 2013). This "small" sector has potentially upwards of 20-30 million workers (IIED as cited in WB, 2013) while the LSM employs about 7 million people (WB, 2013). Data related to gold was not available, and one of the reasons can be the seasonality so common in the ASM. In the case of gold, the value of the metal in the stock market is also of influence on the frequency of the activity. In spite of this known features of ASM activities, “the sector represents an important livelihood and income source for the poverty affected local population” (WB, 2013: p. 1).

It is of note that United Nations Development Programme (UNDP) refers to this subsector as small-scale, not using the term artisanal, and adds a G to form an acronym as follows: SSGM. We must be aware that ASM, however, can be applicable to all minerals. In this sense, ASM of gold mining will be also referred to as ASGM in this work, as we talk about the artisanal and small-scale gold (subsector) of the minerals industry. There is no international consensus on how to define ASM, and we underline UNDP definition, for whom small-scale gold mining (SSGM) is considered “mining with rudimentary methods and limited mine planning, by a workforce that is not formally trained in mining engineering or geology and operates entirely or partly in the informal economy” (UNDP, 2011, p.13). There is a framework for mining companies scales based on production in Brazil: LSM for production >1.000,000 t/y; MSM for production <1,000,000t/y and >100,000 t/y; ASM for production <100,000 and >10,000 t/y. Considering small scale, the production can be <10,000 t/y (CPRM/Geological Service of Brazil, 2000). We add a remark that in case of gold, the unit should be adapted to ounces (oz). Brazilian legislation defines small scale mining according to the area mined and the practices of mineral processing. We will follow Brazilian legislation as a parameter based on the International Council in Mining & Metals (ICMM) observation: “ASM activities occupy a spectrum from small, informal subsistence activities through to organized formal small commercial mining activities” (ICMM, 2010: p. 3). On the other hand, LSM covers a wide variety of enterprises, and what is deemed small to medium-scale mining in one country may be considered large-scale mining in another (ICMM, 2010). Figure 1 highlights views on ASM (or ASGM) of some important agencies.

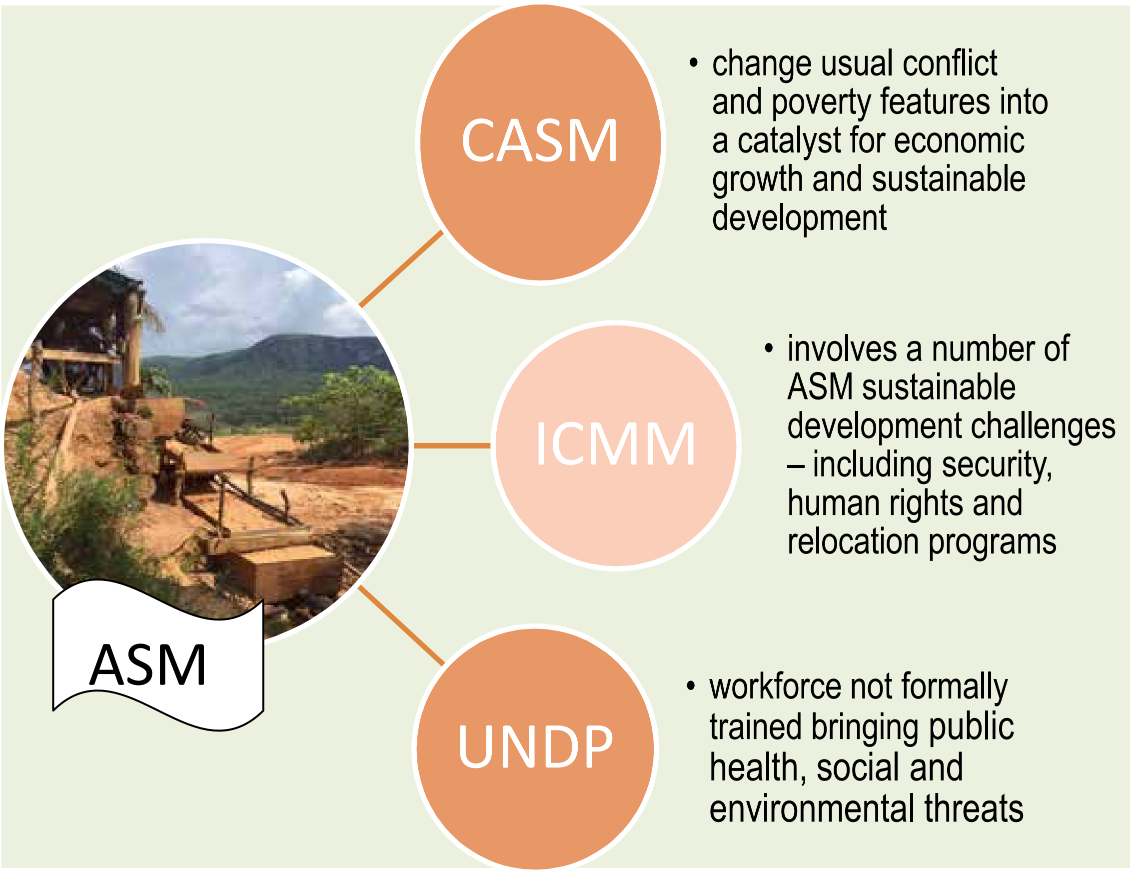


Figure 1 – Views on Artisanal and Small-Scale Mining from Communities and ASM (n.d.); International Council on Mining & Metals (2010); and United Nations Development Programme (2011). [Photo credit: Ribeiro-Duthie, A.C. 2016]

UNDP highlights some effects of small-scale mining based on a global overview, as such: “SSGM brings important economic gains to individuals and nation states but also causes environmental damage, public health threats, and social problems” (UNDP, 2011: p. 4). It is interesting to reflect in what sense this quotation would be different between ASM and LSM? Perhaps the difference is clear only in the second part of the quotation, when talking about the negative aspects related to ASM, as it follows: “specific negative impacts associated with SSGM include deforestation, Mercury contamination, turbidity of waterways, violence, the uncontrolled spread of malaria, and the spread of Sexually Transmitted Infections - STIs” (UNDP, 2011: 4). Even some of these challenges are also addressed by LSM at some point, especially the ones related to diseases. We know that malaria and STI are still a noticeable concern of LSM globally and it depends on the area where the LSM is located (Ribeiro-Duthie *et al*, 2014). There are some countries where malaria is still endemic, as for example in the North region of Brazil. On the other hand, STI (Sexually Transmitted Infections) appear on the health actions of LSMs worldwide, commonly associated to commuting workers in the resource industry (Ribeiro-Duthie *et al*, 2014).

However, what is remarkable on impacts of ASGM is Mercury emissions. According to UNEP (United Nations Environment Programme), ASGM is responsible for 37% of global anthropogenic Mercury emissions (UNEP, 2013). Chemical features of Mercury including toxicity and vapor pressure (ATSDR) – what can spread it across extensive geographical areas – has potential to affect populations globally, despite ASGM being a practice in developing economies. Some studies have adressed Mercury contamination associated to ASGM (Gunson & Veiga, 2004; Castilhos *et al*, 2006). And “the nature and severity of the toxicity that may result from Mercury exposure are functions of the magnitude and duration of exposure” (ATSDR, 1999, p. 220). Mercury contamination risks are of such concern that a global treaty was assigned among 140 countries in 2013 to reduce Mercury threats to human health: Minamata Convention. This treaty led by United Nations carries this name due to a catastrophic poisoning by Methyl Mercury occurred in Minamata-Japan in the 1950’s.

As Mercury is of large use in small-scale gold mining, the certification system based on fair trade of gold produced by ASGM can be seen among efforts to control its health and environmental impacts. However, there is still many “challenges to bring about a more responsible mining” within ASGM (UNDP, 2013, p.3). This is of relevance specially because gold consumption has peaked worldwide, as well as in Brazil, due to the increased purchasing power of classes C and D, according to the Brazilian Mining Association (Ibram, in Portuguese acronym). “Gold is part of this consumption not only in the form of jewelry, but also as electronics, computer parts, notebooks and tablets, mobile phones, parts for the automotive industry, hospital and dental care industries, as well as construction industry components” (Ibram, 2012, p. 55). Gold is the second mineral in the Brazilian exports ranking (Ibram, 2012). Hence, we see the relevance of certification and its potential for change including sustainability values as protection to health and environment as well as human rights in this subsector of gold mining industry.

In this sense, innovation in the sector perhaps would count for a win-win game? However, how to balance the benefits in both senses is one of the challenges, as per figure 2. Innovation can be promptly associated to cleaner Technologies, but it can also be applied to market practices of innovation in management. As LSM has expertise in following HSE guidelines and show a remarkable trend on attending distinct types of market certification, a question guide of our study was where, when and how ASGM can benefit from LSM support for good practices improvement in the minerals sector? And how both LSM and ASGM can mutually benefit in regards to sustainable market practices; and not simply send the bill of the health and environmental risks from ASGMs to the LSMs. We will see in this paper some examples of socioeconomic actions undertaken in collaboration between LSM and ASGM worldwide that may have impacts on and benefit both, as well as the communities.

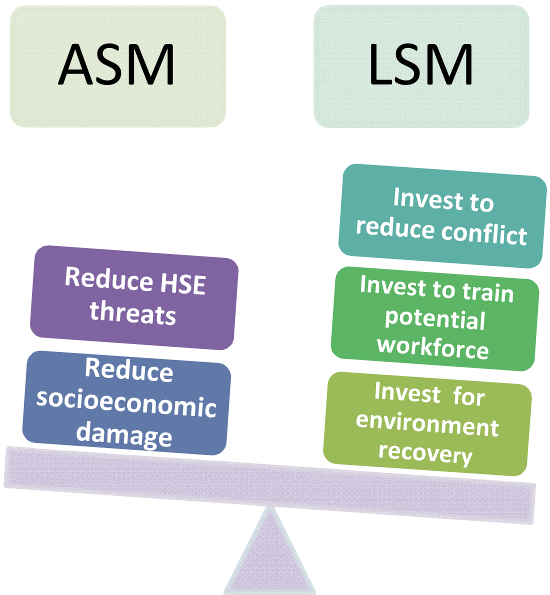


Figure 2 – How to balance benefits of cooperation in both senses in the gold mining industry?

## METHOD

Retrieve of the corporate social responsibility (CSR) reports of the three largest scale gold mining companies in Brazil. We reviewed a total of 38 CSR reports from 2004 to 2014 both in English and Portuguese and 2 case studies. Sustainability reports, annual reports, integrated reports were included as they also informed on CSR (as per table 1). Keywords guided search on CSR reports: ASM, ASGM, *garimpo*, Mercury, health safety and environmental (HSE) practices, Minamata Convention, conflict. Qualitative analysis of CSR reports and case studies released by LSMs and MSM to support ASMs through their CSR published practices, available on their respective webpages. Comparison between findings about LSM support to ASGM in Brazil and another countries; analysis complimented by empirical knowledge from field work within ASGM subsector in Brazil to address possible challenges and opportunities for the improvement of good practices between LSM and ASM in the Brazilian gold mining industry.

Table 1 – LSM and MSM identification, type of reports, and respective years of all reports reviewed

| LSM A: AngloGold Ashanti<br>Type or name of Report/Year | LSM B: Kinross Gold Corporation<br>Type or name of Report/Year | LSM C: Yamana<br>Type or name of Report/Year |
|---|---|---|
| Integrated Report 2014. | Corporate Responsibility Report Data Supplement 2014.<br>Conflict-Free Gold Report 2014. | Conflict-Free-Gold-Report 2014.<br>Corporate Social Responsibility Report 2014.<br>Relatório de Responsabilidade Social Corporativa 2014. |
| Relatório de Sustentabilidade 2013.<br>Case study (2013): Developing alternative livelihoods at Gramalote in Colombia | Corporate Responsibility Report 2013.<br>Conflict-Free Gold Report 2013.<br>Relatório de Responsabilidade Corporativa 2013 Brasil. | Corporate Social Responsibility Report 2013.<br>Relatório de Responsabilidade Social Corporativa 2013. |
| Relatório de Sustentabilidade Brazil 2012.<br>Case study (2012): ASM unpacked | Data Supplement 2012.<br>Communication in progress 2012. | Corporate Social Responsibility Report 2012. |

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| Relatório de Sustentabilidade 2011. | Relatório de Responsabilidade Corporativa 2011 Brasil. | Corporate Social Responsibility Report 2011. |
| Relatório de Sustentabilidade 2010. | Global Compact Communication on progress 2010.<br>Data tables 2010. | Corporate Social Responsibility Report 2010.<br>Relatório de Responsabilidade Social Corporativa 2010. |
| Sustainability Review 2009. | Kinross Brasil: Assumindo Responsabilidades 2009. | Sustainaibility Report 2009. |
| Country Report Brazil 2008. | Nothing found available for 2008. | Annual Report 2008. |
| Country Report Brazil 2007. | Relatório de Responsabilidade Corporativa 2007. | Annual Report 2007. |
| Country Report Brazil 2006. | Relatório de Desenvolvimento Sustentável Brasil 2006 [Bilingual] | Annual Report 2006. |
| Country Report Brazil 2005. | Nothing available for 2005. | Annual Report 2005. |
| Country Report Brazil 2004. | Nothing available for 2004. | Nothing available for 2004. |
| **MSM: Eldorado Gold** | Relatório de Sustentabilidade 2014<br>Sustainability Report 2012 | **Total ( 9 + 13 + 14 + 2 )<br>= 38 Reports & 2 case studies** |

**RESULTS**

We identified three LSMs operating in Brazil, called LSM A, LSM B, LSM C in the body of this work; for companies identification refer to table 1. And one MSM with CSR reports available, but no actions towards ASM reported, therefore MSM will not figure in the results and duscussion sections.

In 2004 and 2005 nothing appears in the CSR reports from LSMs A, B and C about ASM or ASGM. In 2006, LSM B refers to the damage of ASM practices and all the work and expenses required to fix its environmental impacts. In 2007, LSM A states in regards to ASM that it "engages with international advocacy and voluntary bodies, such as the International Council on Mining and Metals (ICMM) and the International Organization for Standardization, to develop standards and best practice." (LSM A Country Report/Brazil 2007, p.32). It is of notice that from 2007 to 2014 CSR reports, there was no action reported to have been implemented in Brazil. In 2008, LSM A reports a statement in favor of minorities where ASMs were also included.

In 2009 LSM A report, there is an explanation on what ASM is and also information on which LSM A sites are the most affected by ASM operations. They are Siguiri in Guinea, Obuasi and Iduapriem in Ghana, Geita in Tanzania and exploration sites in the Democratic Republic of Congo. No actions towards ASM in Brazil appear (LSM A Sustainability Review 2009, p. 41). In 2010, LSM A reports some possible solutions for coexistence between LSM and ASM. In 2011 LSM A highlights the need of looking for customized solutions according to communities circumstances in regards to ASM. This report lists actions undertaken by LSM A in Tanzânia and Congo, but do not report actions in Brazil despite stating that the company has "Pro-active participation in standard setting on 'responsible gold'" (LSM A Sustainability Report 2011, p. 16). Still in 2011, LSM B mentions ASM referring to the investments done to recover a riverbed impacted by ASGM operations surrounding the company sites (LSM B CSR Report 2011, p. 14). Only in 2012, actions in Brazil are directly referred by LSM A, however they are not related to ASM (LSM A Sustainability Report 2012, p. 39).

In 2013, actions on training of ASM miners in Colombia for subsequent hiring are stated by LSM A, as well as efforts in regards to the coexistence between the LSM and ASM in Tanzania plant (LSM A Sustainability Report 2013, p. 54); no actions related to Brazilian mine sites appear. Finally in 2014, it appears again a more mature information on ASGM – when compared to the statements from 2007 abovementioned – as for instance in the following quotation: "Our policy is driven by the appreciation that minerals have a role to play in transforming communities. We therefore support formalisation of the sector, and regulation of those aspects of ASM activity which pose risks – either to employees, community members or our operations" (LSM A Sustainable Development Report 2014, p. 24). Perhaps ASGM in Brazil do not pose risks to LSM and for this reason they are misconsidered?

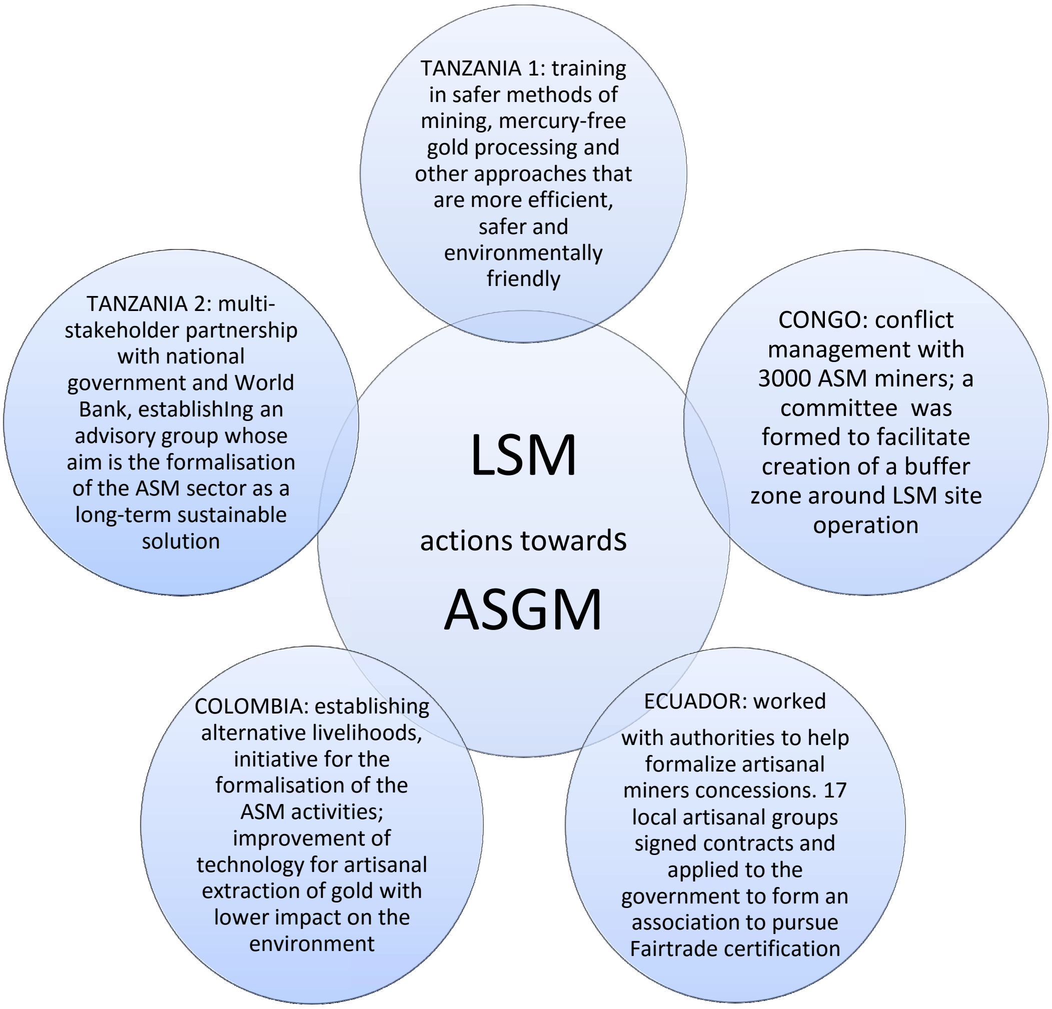


Figure 3 – LSM practices towards ASGM worldwide

Still in 2013, actions to formalize ASGM activities in Ecuador are reported by LSM B. In 2014 report, the focus of LSM B was on their compliance to the Conflict Free Gold Standard, and Brazilian gold mine sites are not considered as areas of conflict according to the criteria adopted (Heidelberg Conflict Barometer), hence they have no actions towards ASGM in Brazil (LSM B Conflict Free Report 2014).

LSM C reported only in 2011 a first straightforward action towards ASGM in Brazil. This is a sole example of local cooperation agreement. The CSR report says: "(LSM C) signed an agreement with the environmental protection agency to support artisanal mining cooperatives" (LSM C 2011 Report, p. 60). And it continues in the same document: "(LSM C) offers professional training to artisanal and small scale miners" " (LSM C 2011 CSR Report, p. 60). However, what type of training is not stated except for 2012, when LSM C referes to the possibility of hiring the ASM miners trained. In 2013, the report states: "there were no conflicts with artisanal miners" in that year (LSM C 2013 CSR Report, p. 68).

It is of note the data appearing repeatedly from 2011 to 2014, with no new data being added, no results presented, no information if there was any former ASG miner hired, for example. For our analysis it matters that ASM employs around 20-30 million people globally and LSM employs 1/3 of that, i.e., around 7 milllion workers. This single data demonstrates that ASM miner's training in regards to potential hiring by LSMs is a limited action in addressing the socioeconomic aspects of ASGM. Anyway, this was actually a rare finding from a LSM settled in Brazil addressing Brazilian ASGM. As per results listed above, almost all data collected are related to comments or information on ASGM in general, but not actually applied as a practice implemented in Brazil. This shows constrast with practices from the same LSM in other countries, where actions tend to be more robust, as it can be seen in figure 3 and table 2.

These findings were followed by a basic question: given that ASGM is an old and overly spread activity in the Brazilian territory; with legal enterprises occupying around 350,883 hectares (Alamino, Silva & Castilhos, 2016); and estimated by DNPM (2014) to involve hundreds of thousands of ASM miners – why there is no CSR reporting practices (at least between 2004 and 2014) towards collaboration between LSM and ASGMs in the country? Analysis of case studies from LSM practices in other countries demonstrate similar conditions to those found in Brazil, and we use this comparison to point out opportunities to improve LSM and ASGM cooperation in the Brazilian mining set, as per table 2.

Table 2 – Practices of LSM towards ASGM in other countries and features of ASGM in Brazil

| | LSMs Practices in another countries | ASGMs Features found in BRAZIL |
|---|---|---|
| **Practices in place by LSM A for ASGM in CONGO** | LSM A support started during exploration phase of mine life cycle. Successful negotiation with 3,000 ASM miners to create an exclusion zone (a buffer zone around LSM A mine sites) to avoid conflict.<br>Since September 2012, 70 former artisanal miners have been supplying LSM A with gravel and sand for construction. The value of material provided to date is US$90,000. | Not found reports of conflicts and types of negotiation addressed in Brazil.<br>ASGMs in Mato Grosso and Amapá have activities in place and projects for their living expenses after mine sites depletion, but no support to their parallel initiatives on farm, agriculture, pisciculture, reforestation, grass plantation to feed cattle, horticulture.<br>. |
| **Practices in place by LSM A for ASGM in TANZANIA** | LSM A supported efforts for formalisation of ASMs through agreements with government.<br>Government has long history of success with formalisation in the region but actions need to be expanded.<br>LSM A spent US$4.4m in water upgrade project to provide clean water to the burgeoning population. | Formalised ASGMs are found, but there are smaller ASM miners who struggle in the paths to formalisation and legalization of ASGM activities.<br>Government support is not always available for orientation in formalisation or legalization steps.<br>Great part of mine sites do not have clean water so they use alternative methods as carrying water from rivers and have chloride added to turn water drinkable. |
| **Practices in place by LSM A for ASGM in COLOMBIA** | LSM A discussed alternative livelihoods with 153 ASM miners mining around LSM A concession. Those who were interested in building their own business were trained in rural entrepreneurship. Action undertaken with a Colombian foundation devoted to such work. Over the course of 2013, business | ASGM in Mato Grosso expressed interest in developing alternative livelihoods. An example being agriculture. Barriers to success include lack of agriculture knowledge and expertise, while they have been practising mining for long years, almost their entire life. |

| | | |
|---|---|---|
| | ideas were generated, plans developed and rigorously tested to start new cooperatives. Action also involved local and regional governments. | |
| **Practices in place by LSM B for ASGM in ECUADOR** | LSM B helped to formalise ASGM activities. Seventeen local artisanal groups have signed contracts and have applied to the government to form an association that would allow them to pursue international fair trade certification. | There are ASGMs in the country willing to apply for gold fairtrade certification. They have potential to attend Standard but need support to understand requirements and implement necessary changes. |

**DISCUSSION**

Results show that actions of cooperation between LSMs annd ASGMs in Brazil are scarce. Why good practices between LSM and ASGM in Brazil were not found is our main issue to discuss. Perhaps LSMs are driven to address ASGMs challenges only in case they bring risks to their operations. As publications on this challenging issue progresses, maybe other answers can be found. In table 1 a comparison between LSMs actions globally and features of ASGMs in Brazil is demonstrated. Opportunities of good practices are pointed out by remarking some ASGM conditions found in Brazil.

UNDP has also captured the opportunities on ASGM highlighting “existing best practices in the region, the availability of mercury free and mercury recycling techniques, and both governments and miners associations that are motivated to change the SSGM sector into a more environmentally and socially responsible sector" (UNEP, 2011, p. 4). The conclusion from table 2 is another question: what is missing in Brazilian ASGM sector to have more effective practices set, as per comparison with those countries where the same LSMs operating in Brazil have reported the implementation of actions? Further research could attempt to answer the reason why actions of cooperation between LSM and ASGM in Brazil are scarce or poor in terms of impacts (Ribeiro-Duthie & Castilhos, 2016) when compared to those examples of actions reported by the same LSM companies in other countries. We have for now some brief hypothesis.

i) LSM targets GRI directions, as its topic MR8 states "Number (and percentage) of company operating sites where ASM takes place on, or adjacent to, the site; the associated risks and the actions taken to manage and mitigate these risks" (Company A Sustainability Report, 2013, p. 53). Whether Brazilian LSM mine sites scape from this target, actions are not addressed in the country. Hence, the location of ASGMs surrounding LSMs facilities in the country could be mapped and analysed in further studies.

ii) the nature of conflicts in Brazilian mine sites are not detected by the Heidelberg Conflict Barometer, so actions towards ASM would be misregarded in the country as some LSMs justify their actions considering this barometer. Further research could analyse closely those “conflict barometer” criteria.

iii) actions between LSM or MSM are underreported, as we actually found on field work some larger companies with practices of coexistence with ASGM in Brazil. Further analysis could better inform the actual scale of these companies and the nature of these relations.

In some cases, there is the comprehensive risk to the LSM operations and the proximity with facilities that may turn the actions towards ASGM a high priority in some localities. However, would that encompasse everything? Further research perhaps could clarify these initial hypothesis. Examples of what is practiced worldwide work as guidance on what can be done, but the context of each country must always be considered. We believe that the single comparison in table 2 can demonstrate similarities and opportunities for good practices that could improve relations between LSMs and ASMs in Brazilian gold mining industry. And we know that, in a globallized economy, good practices surpasse geographical frontiers and have a spill-over effect.

## CONCLUSIONS

Beyond the reasons for the scarcity of practices between LSM and ASM in Brazil demonstrated through our methodological approach, it is clear that there is room to improve on actions and good practices in the Brazilian gold mining industry, and published international examples are perhaps a guide to start changes. What matters from our findings in this initial research is the fact that there are ASGMs in Brazil interested in doing right despite the rare support they count upon to attend requirements for better HSE performance and legal compliance. There are actions undertaken in other countries that could also benefit the Brazilian small-scale gold sector and therefore address the health-safety-environmental and socioeconomic impacts caused by ASGM. Practices related to Brazilian ASGMs was limited, but what did not appear through reports was found through field work. Thus, it would be worth to make a further comparison between larger and medium-sized companies practices towards ASGM including the empirical component.

We saw in field research that there is not much in clean technoology available to the small scale subsector of the gold mining in Brazil, even when there are some ASGM miners interested in stop being the 'villains' of the environment. UNEP and the Artisanal Gold Council (AGC) already published potential Mercury free methods for gold mining. According to UNEP and AGC, concentration methods applicable to ASGM are for example panning; sluicing; shaking tables; spiral concentrators; vortex concentrators; centrifuges (UNEP & AGC, 2012). In the case of Brazil, some of the equipments were seen in use and they were developed almost artisanally by former ASGM miners, but there was no monitoring in place to assess its efficacy; or a systematic surveillance to tackle barriers for the effective use of new technology when available (Souza, Castilhos & Araujo, 2015). By approaching the sector challenges, opportunities to develop better practices may appear. CETEM (Brazilian Center for Mineral Technology) has already addressed some technological challenges of the small-scale gold mining subsector and programs need support for continued development.

In conclusion, it was seen through field work that there is motivation to embrace sustainability practices in this subsector and what also needs to be asssessed is whether there is interest in having successful partnership with ASGMs. Sometimes one case of success can go a long way to bring about changes of behaviour, organisational culture and market practices.

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# KAOLIN AND GRANITE RESIDUES UTILIZATION IN FORMULATION CERAMIC MASSES TO PORCELAIN STONEWARE FABRICATION

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# KAOLIN AND GRANITE RESIDUES UTILIZATION IN FORMULATION CERAMIC MASSES TO PORCELAIN STONEWARE FABRICATION


## ABSTRACT

In recent years, mining companies mainly beneficiation of kaolin and granite have been cited by environmentalists as sources of contamination and/ or pollution of the environment due to the huge amount of waste generated and often dumped directly into ecosystems, without a treatment process to eliminate or reduce the constituents present. This work aims to evaluate the potential of using residues of kaolin and granite, for their application as ceramic raw materials in the production of porcelain stoneware. The formulations studied, F1, F2, F3, F4, F5, F6, F7 and F8 were prepared from the raw clay, kaolin residues and residues of granite. The raw materials were characterized by X-ray fluorescence (XRF), X-ray diffraction (XRD) and thermal analysis (TG/DSC/ADT). Technological properties of the material were analyzed by tests of water absorption (AA%), apparent porosity (% PA), linear retraction (% RT), bulk density (BD), loss on ignition (% PF) and flexural strength at three points (TRF) of the samples sintered at temperatures of 1175, 1200, 1225 and 1250° C with a level of 60 minutes and heating rate of 5°C/ min. Microstructural characterization of the samples was performed using scanning electron microscopy (SEM). The F6 and F8 formulations showed better physical and mechanical properties for the production of porcelain stoneware being can replace the use of conventional materials by residues. The adoption of alternative utilization of these residues may not only reduce the environmental impact of mining kaolin and granite, but also enable the aggregation of value to this material, mainly for industrial use in porcelain-stoneware.



## KEYWORDS

Residues of kaolin. Residues of granite. Porcelain stoneware.


## INTRODUCTION

The pegmatitic Province of Borborema precisely in the municipalities of Equador and Parelhas, Rio Grande do Norte (RN), Brazil, has a significant mineralogical potential. However, the processing and extraction processes kaolin and granite mines of Caulise and Coto (Figure 1), respectively, are still rudimentary, not respecting the relationship between man versus nature. The mineral residues use of granite and kaolin, from the beneficiation process and extraction of mining Caulise and Coto, respectively, located in the municipalities of Equador and Parelhas, Rio Grande do Norte, possible alternatives to create formulations for the production of porcelain stoneware from the addition these residues, greatly increasing the lifetime of the deposits, reducing the social and environmental impacts caused by mining activity.

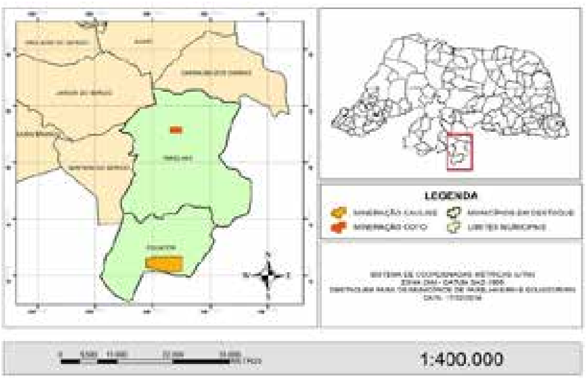

Figure 1 – Localization map of Coto (Parelhas, RN, Brazil) and Caulise (Equador, RN, Brazil) mines

This present study attempts to create alternatives to the use of mineral residues from inefficient process of extraction and processing generated by Caulise and Coto mining companies of Equador and Parelhas, RN cities. Well as to assess the potential addition of kaolin and granite residues from the extraction and processing of the same, the mining companies Caulise and Coto, located in those cities, as raw material for the formulation of masses ceramics for porcelain stoneware. In order to characterize residues of granite and kaolin from the extraction and processing, respectively; to measure the potential of adding kaolin and granite residues generated by already mentioned mining companies on the porcelain processing features used in the manufacture of porcelain stoneware; to analyze the chemical, mineralogical and microstructural parts obtained with the addition of waste; and finally, to evaluate the technological properties of the parts obtained according to the percentage of residues.

## METHODOLOGIES AND EXPERIMENTAL PROCEDIMENTS

The experimental procedures were performed according to the scheme shown in the flowchart (Figure 2). Basically, the experimental procedure was developed from the collection of raw materials (clay, kaolin residues and granite residues), soon after, there was the comminution (crushing and grinding), screening (size classification), drying, characterization (X-ray Fluorescence - XRF, Scanning Electron Microscopy - SEM, X-ray Diffraction - XRD, thermogravimetry - TG, differential thermal - ADT and differential scanning calorimetry - DSC), formulation of the masses, pressing, drying, sintering and the tests applied to ceramic piece produced for characterization (linear firing shrinkage, water absorption, apparent porosity, bulk density and flexural modulus).

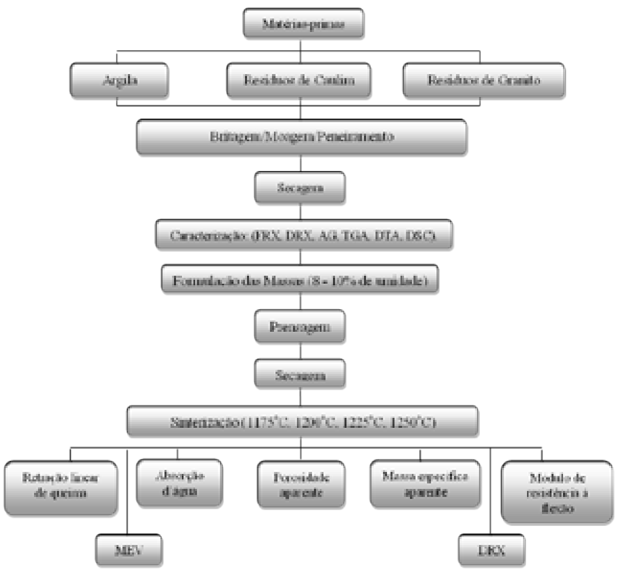


Figure 2 – Flowchart of experimental procedures

The materials were used in the eight tested formulations. F1 (Formulation No. 1) was 50% clay, 10% of kaolin residues, 40% granite residues. In F2, respectively, 50%, 15% and 35%. For F4, 50%, 25% and 25%. F5: 45%, 15% and 40%. F6: 45%, 20% and 35%. F7: 45%, 25% and 30%. As for F8, 45% for clay, granite residues, and 10% of kaolin residues.

The methods set out with the comminution of the material (crushing and grinding), proceeded with the size analysis (laser and screening), with compression of the test specimens, chemical characterization by XRF, mineralogical characterization XRD and SEM, thermal analysis (TG, ADT, DSC), sintering of the test specimens, characterization of the specimens (linear shrinkage - LS, water absorption - WA, apparent porosity - AP, bulk density - BD, bending resistance module - BRM).

## RESULTS AND DISCUSSIONS

### Evaluation of plasticity

Based upon a characterization of the raw materials by analysis by X-ray fluorescence was obtained from the percentage concentrations by weight of each oxide (Figure 3). By means of characterization can evaluate the plasticity of the material. The clay used has a high $SiO_2$ content (51.8%) related to the presence of kaolinite, mica, feldspar and quartz, and a $Al_2O_3$ content (20.3%), related to the presence of kaolinite and feldspar; giving this PI (Plasticity Index) median clay (9.4%). The major compound presented both as the kaolin clay residues, granite has silica ($SiO_2$), indicating compounds such as quartz, mica and feldspar in composition. The high $SiO_2$ indicate the presence of silicates and free silica. The free silica corresponds to quartz and derivatives, which provides a reduction in the plasticity of the ceramic material. The silicates are clay minerals, mica and feldspar. Typically, a high content of $SiO_2$ and $Al_2O_3$ indicate the case of the chemical composition of starting materials and clay minerals (quartz, feldspar and mica group minerals) (Morais, 2007).

| | Concentrações em Peso (%) | | |
|---|---|---|---|
| Óxidos Presentes | Argila | Resíduos de Caulim | Resíduos de Granito |
| $SiO_2$ | 51,848 | 48,182 | 60,700 |
| $Al_2O_3$ | 20,373 | 36,343 | 22,115 |
| $Fe_2O_3$ | 3,583 | 1,186 | 0,942 |
| $K_2O$ | 1,019 | 1,318 | 9,067 |
| $TiO_2$ | 0,931 | 0,098 | - |
| BaO | 0,391 | - | - |
| $SO_3$ | 0,367 | 0,072 | 0,215 |
| CaO | 0,250 | - | 0,874 |
| $ZrO_2$ | 0,066 | 0,007 | 0,012 |
| $Cr_2O_3$ | 0,021 | - | - |
| MnO | 0,020 | 0,075 | 0,157 |
| SrO | 0,011 | 0,008 | - |
| ZnO | 0,010 | - | - |
| $Rb_2O$ | 0,007 | 0.013 | 0,060 |
| NbO | 0,006 | - | - |
| MgO | - | 0,736 | 0,482 |
| $Ta_2O_5$ | - | 0,032 | - |
| PbO | - | 0,013 | - |
| $Ir_2O_3$ | - | 0,012 | - |
| $Y_2O_3$ | - | 0,006 | 0,006 |
| $Na_2O$ | - | - | 3,071 |
| Perda ao Fogo - PF | 21,100 | 6,171 | 1,157 |

Figure 3 – Percentage concentrations by weight of each oxide by X-Ray Fluorescence analysis

The $Fe_2O_3$ incorporated in the ceramic masses reduces the plasticity, but also reduces the firing shrinkage and facilitates drying of the masses, reducing the mechanical strength, however, the some that melt during sintering provides hardness to the ceramic bodies (Vieira, 2004). The concentrations of potassium oxides - $K_2O$ in the clay and residues, with a higher percentage in granite residue (9.067%) can be derived from fluxing agents, so agents which act in the sintering process, to fill the pores in bodies ceramic (Silva et al., 2005).

The clay used had PI greater than 9.0% is characterized as median plasticity material (5% <PI <15%). Kaolin residue presented IP around 14,5%, characterizing it with a median plasticity, tending to very plastic (PI> 15). The granite residues were presented as non-plastic material.

**Granulometric analysis**

Figure 4 is a graph relating clay granulometry and shows that there is a modal distribution with a particle percentage (about 90%) with a diameter of up to 38.44 µm. The mean diameter of 16.59 µm. The clay curve showed particles with diameters up to 12.24 µm 50% of the population and diameter of up to 1.40 µm by 10%.

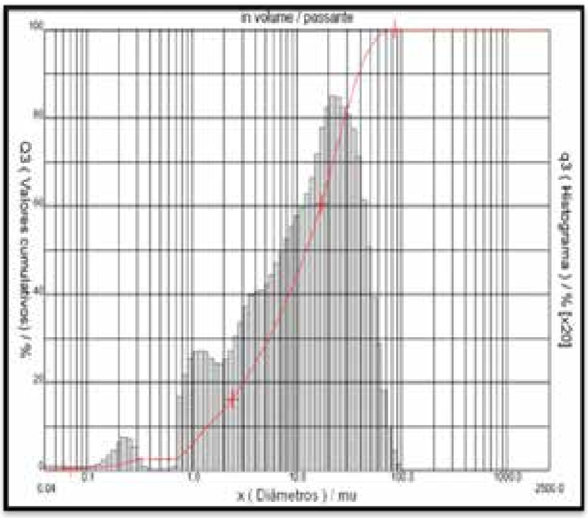


Figure 4 – The graph on the particle size of the clay

The graph of Figure 5 is related to particle size of kaolin residues and shows that the residue has a bimodal distribution, with the particle percentage (about 90%) with a diameter of up to 1970.90 µm. The average diameter obtained was 1082.90 µm. The curve has particles with diameter of up to 1050.43 µm 50% of the population and diameter of up to 48.01% at 10 µm.

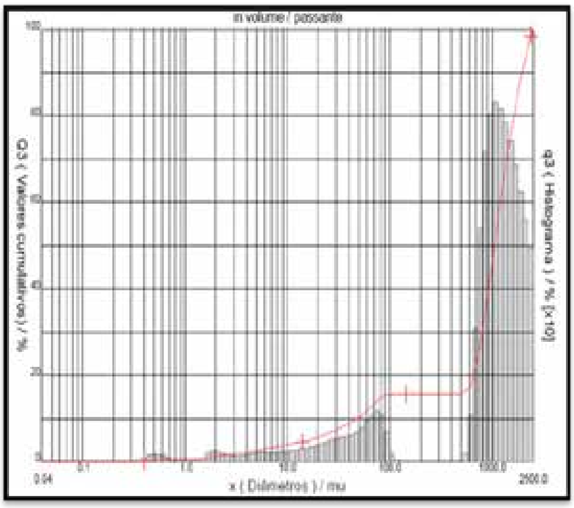


Figure 5 – The graph on the particle size of the kaolin residues

Figure 6 shows the graph on the granulometry of granite residues and shows that the residue has modal distribution with a particle percentage (about 90%) with a diameter of up to 67.12 µm. The mean diameter of 36.55 µm. In granulometric curve is observed particle diameter of up to 35.52 µm 50% of the population and diameter up to 6.06 µm by 10%.

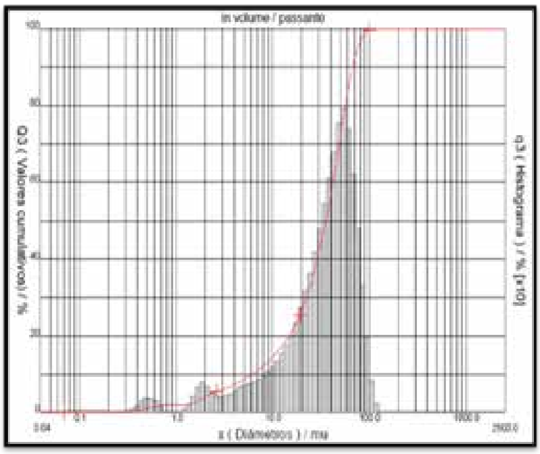

Figure 6 – The graph on the particle size of the granite residues

**Mineralogical analysis**

The graphs of Figures 7, 8 and 9 show, in respective way the mineralogical analysis results obtained by X-ray Diffraction (XRD) of clay, the kaolin residue and granite residue.

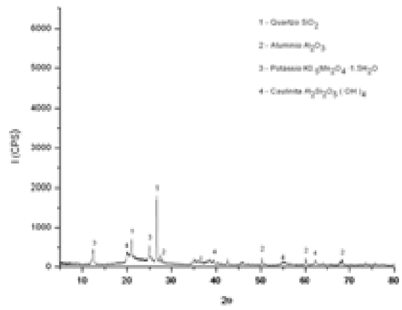

Figure 7 – The graph shows mineralogical analysis obtained by X-ray Diffraction (XRD) of Clay

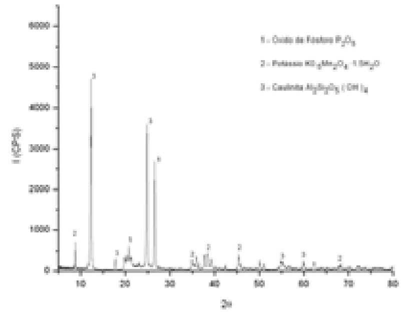

Figure 8 – The graph shows mineralogical analysis obtained by X-ray Diffraction (XRD) of kaolin residues

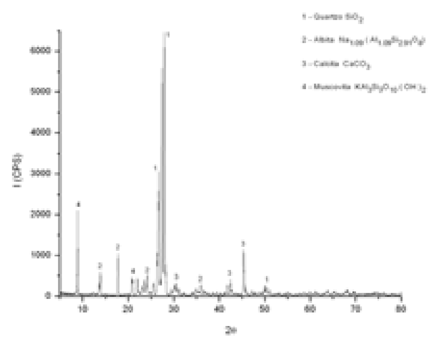

Figure 9 – The graph shows mineralogical analysis obtained by X-ray Diffraction (XRD) of granite residues

**Thermal analysis**

Since the graphs of Figures 10, 11 and 12 show respectively the results of thermal analysis (TG/DSC) of clay, the kaolin residue and granite residue.

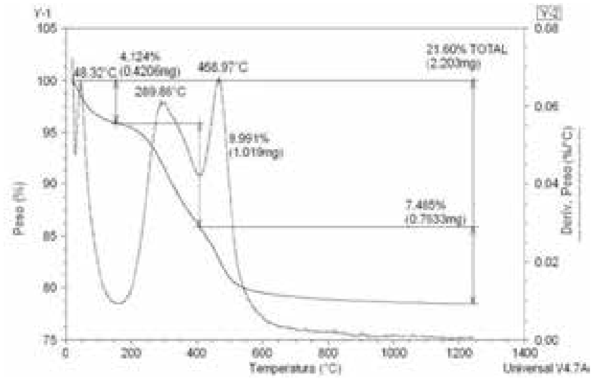


Figure 10 – The graph shows thermal analysis (TG/DSC) of Clay

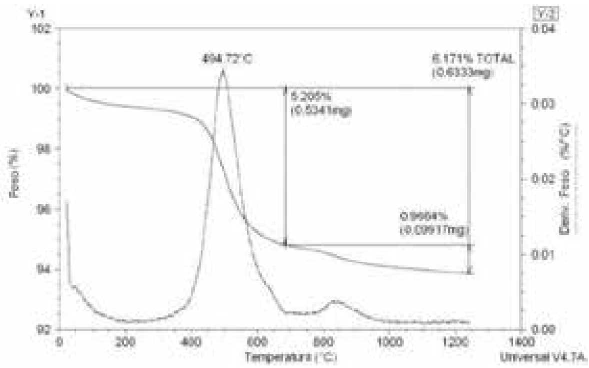


Figure 11 – The graph shows thermal analysis (TG/DSC) of kaolin residues

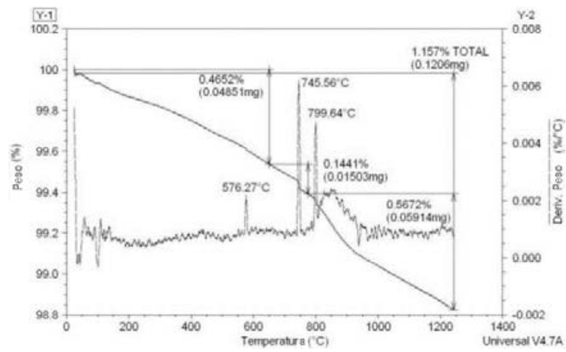

Figure 12 – The graph shows thermal analysis (TG/DSC) of granite residues

**Technological essays of the formulations**

Linear shrinkage

All formulations exhibit a substantial rise of the linear firing shrinkage with increased 1175 °C sintering temperature to 1250 °C. This increase in linear shrinkage can associated to the reactions of reduction occurring during sintering, causing the expansion of the bodies of the test piece, this due to the entrapment released from the inner gas of the bodies of the test piece during reactions, being detrimental to mechanical strength and water absorption of the material. It is observed that the F4 and F7 formulations suffered minor shrinkage in sintering temperatures. Believed to have this occurred because both mixtures contain lower levels of granite waste and larger kaolin residues, as well as the presence of amorphous aluminosilicate which also act on refractoriness, stabilizing the dimensions of the bodies of the test piece.

Water absorption

We observe that the bodies of the test piece sintered at 1250 °C showed a variation of water absorption of 0.29% (F8) and 2.77% (F3), confirming the strong effect of temperature in lower absorption of water. The ceramic bodies of the formulations F1 (1.53%), F2 (1.85%), F3 (2.77%), F4 (2.07%) and F7 (1.03%) sintering temperature characterized in that as sandstone (BIb group; 0.5% <Water Absorption - WA<3.0%), since the formulations F5 (0.49%), F6 (0.36%) and F8 (0.29%) were enquandram in BIa group (WA<0.5%) as a product of porcelain stoneware.

Apparent porosity

The results of the apparent porosity test are consistent with the results of water absorption and linear firing shrinkage. There is, in general, a reduction in porosity with increasing firing temperature.

The porosity of the bodies of the test piece sintered at 1250 ° C ranged from 5.42% (F8) and 8.19% (F3), showing a trend of reduction in porosity with increasing temperature, and justified by rounding and partial closure of the pores of the ceramic bodies due to coalescence by thermal diffusion and, consequently, reducing the porosity of the ceramic bodies.

Bulk density

Any formulations analyzed showed an increase in bulk density with increasing temperature. In diffusion sintering processes in solid and liquid phase formation there fill the pores, it becomes ceramics with higher density. The results are consistent with literature and demonstrate the densification behavior of the samples with increasing sintering temperature. The higher the sintering temperature, the larger the amount of glassy phase penetrating and filling pores while in the liquid phase during sintering. Thus, the higher the density of the ceramic bodies (Morais, 2007; Menezes et al., 2002). The European standard (EN 87) requires that the bulk density is greater than 2.0 g/cm³ for porcelain tile, be in compliance with all formulations.

Flexural strength in three points

We observe that the bodies of the test piece sintered at 1175 °C temperature variation on the resistance to bending modulus of 19.11 MPa (F1) and 23.92 MPa (F8). In the temperature 1200 ° C, the bodies of the test piece sinterized exhibited variation between 20.94 MPa (F4) and 28.57 MPa (F8). As the technological testing of linear shrinkage, water absorption, porosity and bulk density, to note an increase in the flexural strength modulus of all formulations with increasing sintering temperature. The bodies of the test piece sintered at temperature 1225 °C showed a range from 23.03 MPa (F4) and 29.90 MPa (F8), showing the influence of temperature on the densification and the flexural strength of bodies ceramic.

In the temperature 1250 °C, ceramic bodies exhibit a variation of the flexural strength modulus of 26.99 MPa (F2) and 33.80 MPa (F6), with higher values compared to the modules of the sintered specimens at 1175, 1200 and 1225 °C. All the formulations showed a substantial increase in flexural strength with increasing the sintering temperature from 1175 °C to 1250 °C, especially of formulations F6 (33.80 MPa) and F8 (31.88 MPa) sinterized at 1250 °C.

Microstructural analysis

The micrographs corroborate the values of apparent porosity of formulations F6 (6.83%) and F8 (6.88%) and water absorption, F6 (0.94%) and F8 (0.98%) being justified by the expansion of the liquid phase by virtually the entire body of the test piece, however the F5 formulations, F6 and F7 showed no vitreous phase at that temperature, with regions that were not fully sintered. Less sintered layers are characterized as regions of low heat diffusion, in which there is a lower rate of thermal coalescence caused by the presence of higher concentrations of plastic materials (mainly clay) and less fluxes (non-plastics materials) in which case features If the waste granite. The thermal coalescence is also known for neck training, responsible for the union of grain.

## CONCLUSION

The chemical and mineralogical composition of the raw materials clay, kaolin residues and granite residues influenced decisively in the technological properties of the ceramic material formulations for the production of porcelain stoneware. It appears that there is a relative change in the water absorption and the linear shrinkage in the formulations, to the sintering temperature to 1225 °C. The formulation F8 showed the lowest water absorption and is suitable for the production of porcelain stoneware, as well as the formulations F5, F6 and F8 at a temperature of 1250 °C, at which had water absorption of less than 0.5%.

The F6 and F8 formulations showed lower porosity of the specimens at all sintering temperatures, which is important characteristic for the production of porcelain stoneware. The F6 and F8 formulations showed higher bulk density values, with values greater than 2.0 g/cm³ reaching the values set by the European Norm (EN 100) for porcelain stoneware. The bodies of the test piece F8 formulation showed higher flexural resistance at temperatures modules 1175, 1200 and 1225 °C, as well as F6 formulation showed satisfactory values of flexural strength at 1250 °C for the production of porcelain stoneware. The formulations F6 and F8, respectively, are most appropriate for the production of porcelain stoneware having a percentage of 45% clay, kaolin residues 10 or 20% and granite residues 35 or 45%. The use of kaolin and granite residues in ceramic bodies are presented as excellent potential for the production of porcelain stoneware.

Based on what has been studied ascertains become necessary in future studies can be revised the influence caused by higher levels at temperatures of 1225 and 1250 ºC, with 30 and 45 minutes, thereby determining whether there is improvement or loss of porcelain stoneware properties with respect to level of 60 minutes. Similarly, glazes embed the surface, testing the staining resistance properties, chemical attack, abrasion, surface hardness. Likewise, the accomplishment of tests with a higher content of plastic materials, thus seeking to improve the properties obtained during sintering; Tests using the atomization process and varying the viscosity of the slip and moisture of the ceramic material; stoneware porcelain production using mineral residues of kaolin and scheelite; And finally, the production of porcelain stoneware with the intermediate firing level, analyzing the improvement in mechanical properties by using mineral waste kaolin and quartzite.

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# LATERITIC TERRAINS AND THE EVOLUTION OF PSEUDOKARSTIC FEATURES – CASE STUDY IN THE IRON ORE MINE N4E, CARAJÁS REGION – PARA, BRAZIL

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# LATERITIC TERRAINS AND THE EVOLUTION OF PSEUDOKARSTIC FEATURES – CASE STUDY IN THE IRON ORE MINE N4E, CARAJÁS REGION – PARA, BRAZIL


## ABSTRACT

The Carajás region is located in the southeastern portion of Pará State and is part of the geomorphological unit called Dissected Plateau of South Pará, represented by a set of plateaus with flat top, with topographic levels ranging from 500 to 850m, surrounded by large flattened areas, whose levels range 250-350 m. These plateaus are relicts of the original South American Surface, developed between the Cretaceous and the UpperTertiary, especially the so-called Ridges; Norte, Sul, Leste, Bocaina and Tarzan. These ridges are sustained by a lateritic profile, about 20m thick, developed on basalts and banded iron formations of Grão Pará Group. This lateritic profile displays pseudokarstic features in the interface with the underlying horizons, where there are occurrences of caves in upper and middle slopes, as well as in low level slopes, commonly associated with colluvial and talus deposits. Geological studies of systematic mapping in these caves and surrounding area allowed the definition of three typical horizons of lateritic profile of the region, associating them to the underlying bed rock: *Lateritic Crust* (with ferruginous composition when in ferriferous rocks domain and with aluminous composition when in mafic rocks domain), *Transition Horizon*, and *Saprolite Horizon*. This paper presents an analysis of these three typical horizons studied in N4E iron ore mine, located in Norte Ridge and their relationship with the development/evolution of natural caves, based on field data. The results contribute to the understanding of ancient speleogenetics processes that nowadays still persist in this environment.



## KEYWORDS

Lateritic profile, Pseudokarstic features, Caves, Lateritic crust, Carajás


## INTRODUCTION

The Carajás ridge corresponds to one of the great geomorphological contrasts in southern state of Pará landscape, with a set of top flattened hills (plateaus) with an average elevation of 650 meters stands out in devastated areas in its surroundings with the height differences reaching 500 m. Boaventura (1974) identified two significant geomorphic units according to morphostructural and morphoclimatic characteristics, they are: Dissected Plateau of South Pará and Peripheral Depression of South Pará. The region is therefore a residual feature of Dissected Plateau of South Pará sustained by a lateritic cover resistant to erosive process that promotes the retreat of slopes. The Carajás ridge is also correlated as part of the South American Surface defined by King (1956) and reported in various publications. In contrast, the base of these plateaus would be related to the recent flattening, "Velhas Surface", King (1956) or intermediate stages of recovery of erosive cycles.

The current relief of the region is structured in a significant regional direction towards W-NW and E-SE, mainly over archean volcano sedimentary rocks of the Grão Pará Group. In the basal portion occur basic and intermediate cloritized volcanic rocks of Parauapebas Formation followed by the Carajás Formation with banded iron formation domain. To the top, another basic volcanic rocks sequence of Igarapé Cigarra Formation occurs, covered by sandstones and siltstone from Águas Claras Formation (Macambira, 2003; Zuchetti, 2007).

The region is also interpreted as remains of a Pliocene superimposed pediplanation on an extensive old flattened terrain, possibly of Cretaceous or pre-Cretaceous age (Boaventura, 1974). Ab'Sáber (1986) explains that the Carajas massive represents remaining features of an extensive ancient erosion plain terrain that suffered regional and discontinuous uplift as a result of epeirogeny after the erosion phase of the region. He still admits the latter stages of this movement were the cause of alveolarization of valley's highest topographic surface, with interference in the subsurface and underground drainages in lateritic terrain, resulting in a series of pseudokarstic features.

The Amazon region presents several examples of laterite landscapes in dissected reliefs and covered by hardened ferruginous covers (Piriá ridge, Maicuru ridge, Trucará ridge, Seis Lagos hill, among others). In these ridges, it is common the occurrence of caves in cornices and / or cliff of plateaus. An extensive list of references on pseudokarstic features in lateritic terrain from various countries distributed in the tropical zone was cited by Maurity (1995). In the context of pseudokarstic features in lateritic terrain, Carajás region stands out for presenting a significant occurrence of caves. Geological characterization studies were performed in three representative profiles in the northern portion of N4E iron ore mine in a basic volcanic rocks domains of Igarapé Cigarra Formation. Two profiles were exposed in the mining area, and one on the slope near cave N4E- 0026 (Figure 1). The studies aimed to individualize each horizon to thereby contribute to the evolution of knowledge about the origin of these pseudokarstic environment as well as its caves.

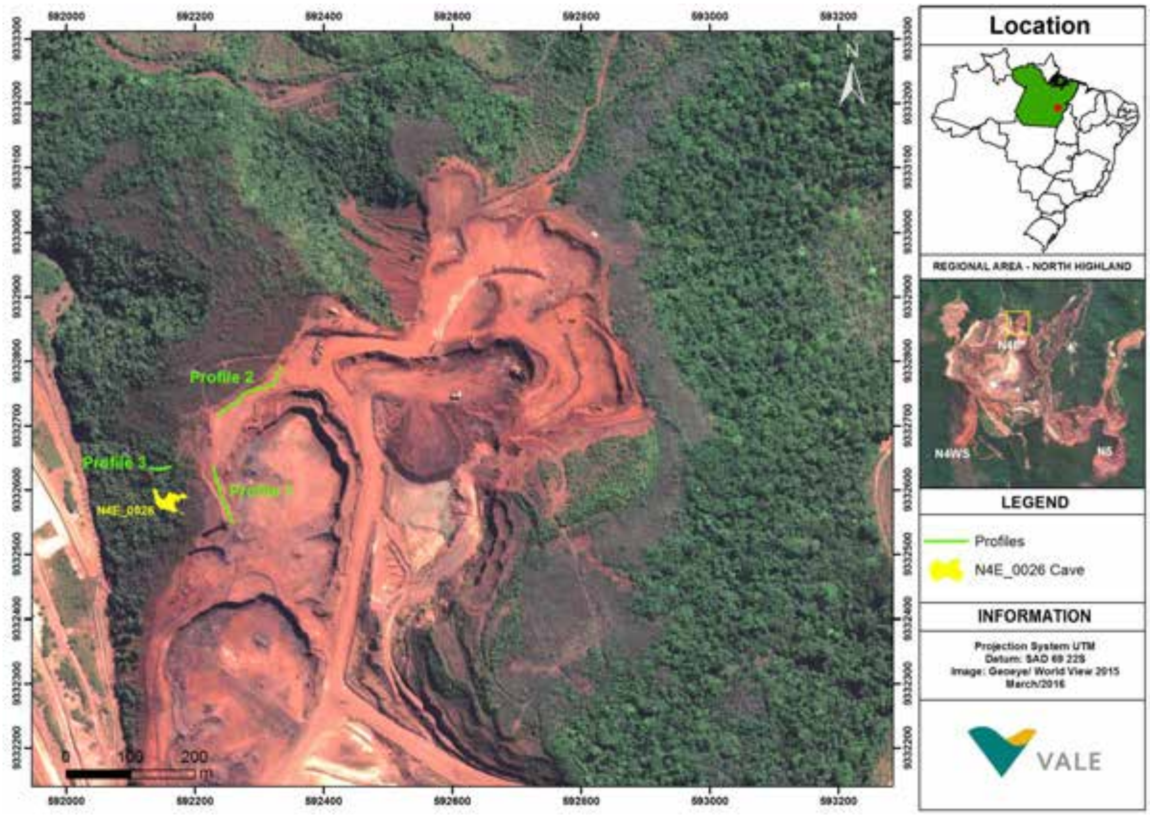


Figure 1- Northern part of N4E iron ore mine with location of the studied lateritic profiles

## LATERITIC PROFILES

The lateritic profiles generally do not develop soil horizon, and are characterized by presenting three major horizons of weathering, above the dominant volcano sedimentary rocks of the region. From the top of the profile, there is a hardened Lateritic Crust also known as "duricrust" consisting of centimetric fragments and angular iron ore clasts, dominating hematite with reliquiar jaspilite texture, as well as volcanic mafic weathered rocks, all cemented by iron oxides / hydroxides. The Transition Horizon shows variable thickness and may have specific textural features both in the top of the profile, as in the underlying rock. Usually has porous / cavernous appearance in fine clayey ferruginous matrix. The basal horizon is represented by Saprolite, in dark brown to reddish clay, sometimes containing kaolinic whitish to yellowish spots, and even partially immersed blocks of weathered volcanic rocks (Figure 2).

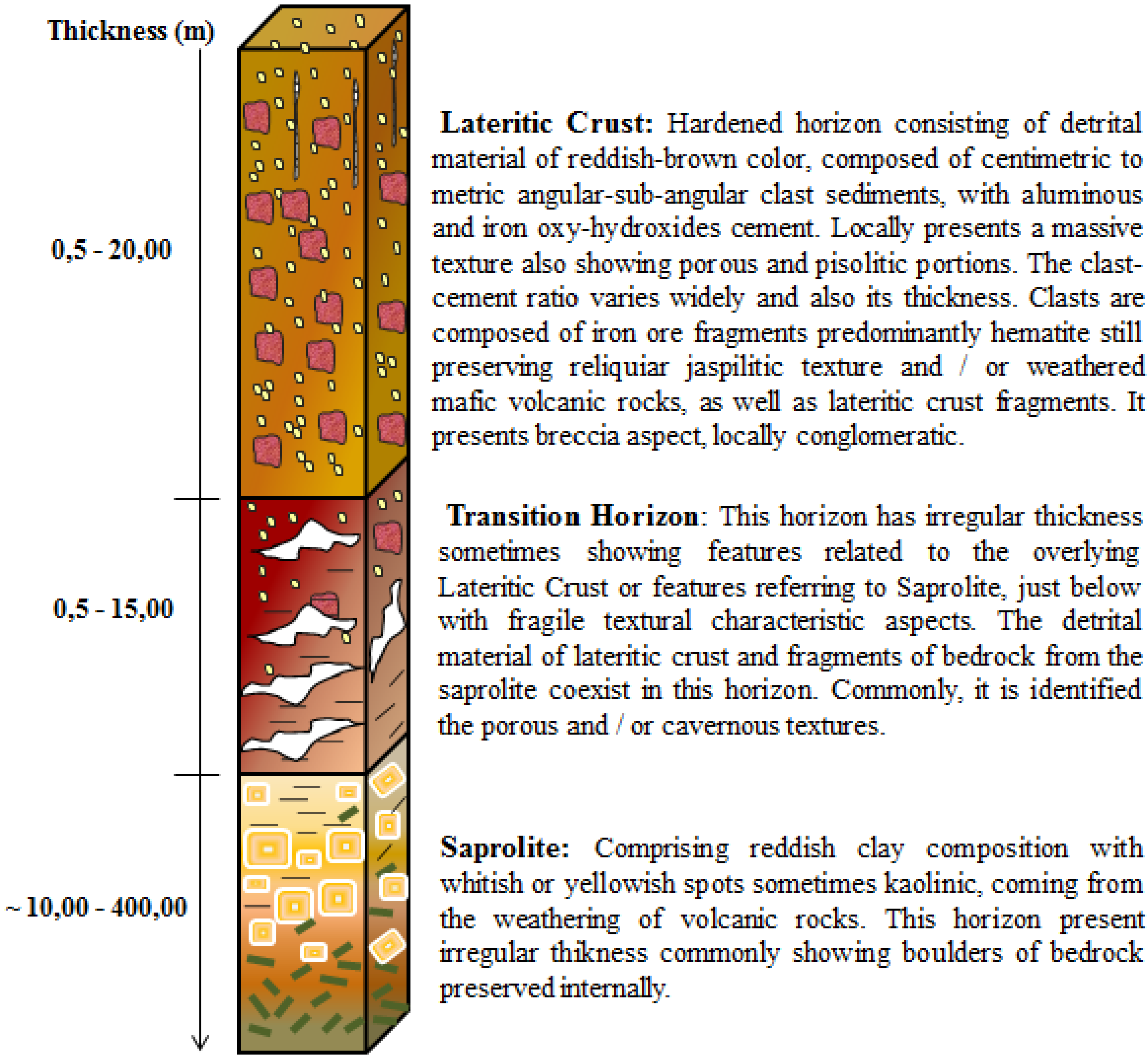


Figure 2- Tipical lateritic profile from iron ore mine N4E

**Lateritic Crust ("duricrust")**

The Lateritic Crust lies discordantly on the Transition Horizon (Figure 3A) and consists of material composed of milimetric ferruginous spherulites. Shows detrital portions composed of hematite sub-angular to angular clasts, cemented by aluminium and/or iron oxy-hydroxides. In addition, restricted centimetric portions are dominated by goethite. This goethite presents itself in two forms in grayish shades with metallic luster and yellowish and earthy appearance (Figure 3B). Portions were also observed where there is porous texture with centimetric ferruginous pisolites (Figure 3C). Locally there are still verticalized dark-gray features produced by roots ("ferruginous tubes").

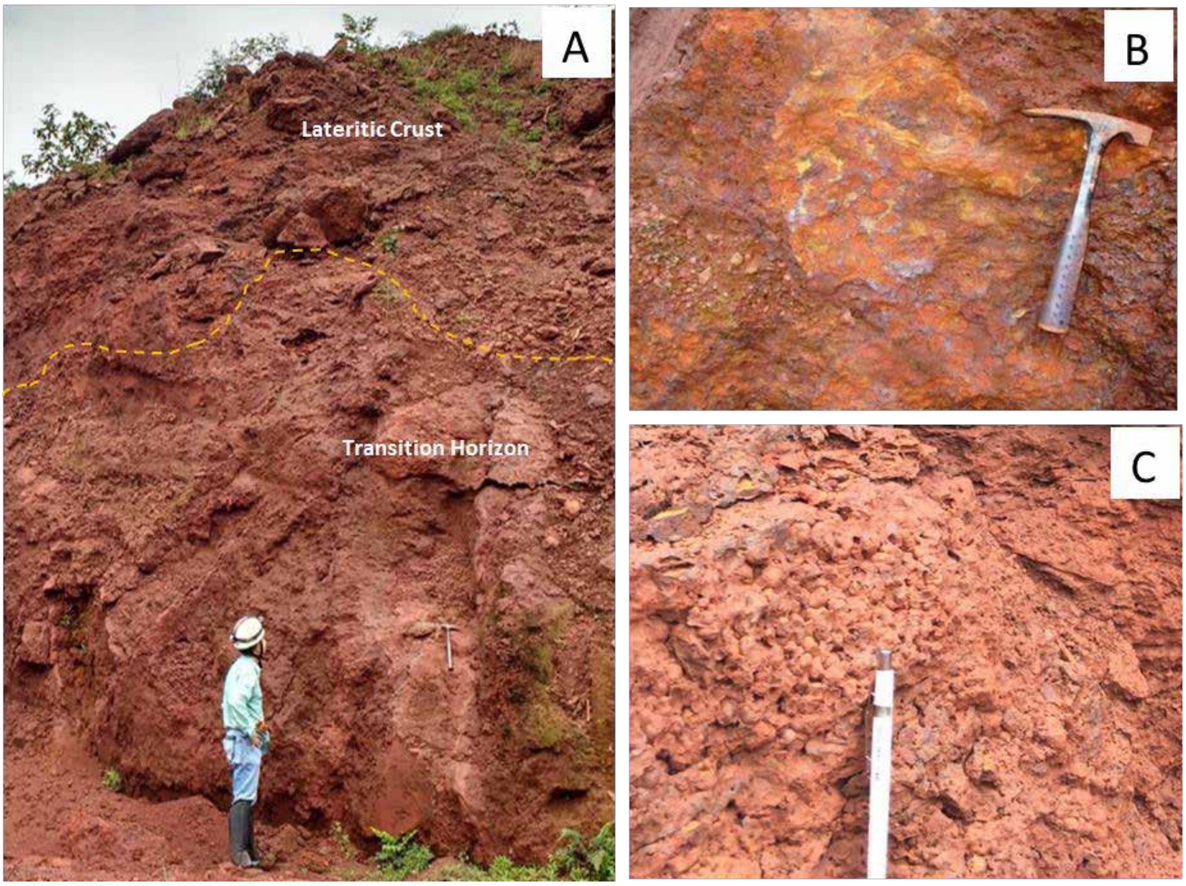


Figura 3 – Profile 2. A – General aspect of the irregular geological contact among Lateritic Crust and the Transition Horizon. B – Lateritic Crust showing centimetric zones dominated by goethite. C- Lateritic Crust showing porous texture with centimetric pisolites.

In the profile 3, located in the slope near cave N4E-0026 the study included the cave interior itself, where the Lateritic Crust occurs in the ceiling. The Lateritic Crust displays porous, (Figures 4A and 4B), and detrital appearance (Figure 4C), where elongated clasts, centimetric-shaped hematite platelet occur cemented by aluminium and/or iron oxy-hydroxides. It is also possible to identify cavernous texture portions near the base of the cave wall (Figure 4D).

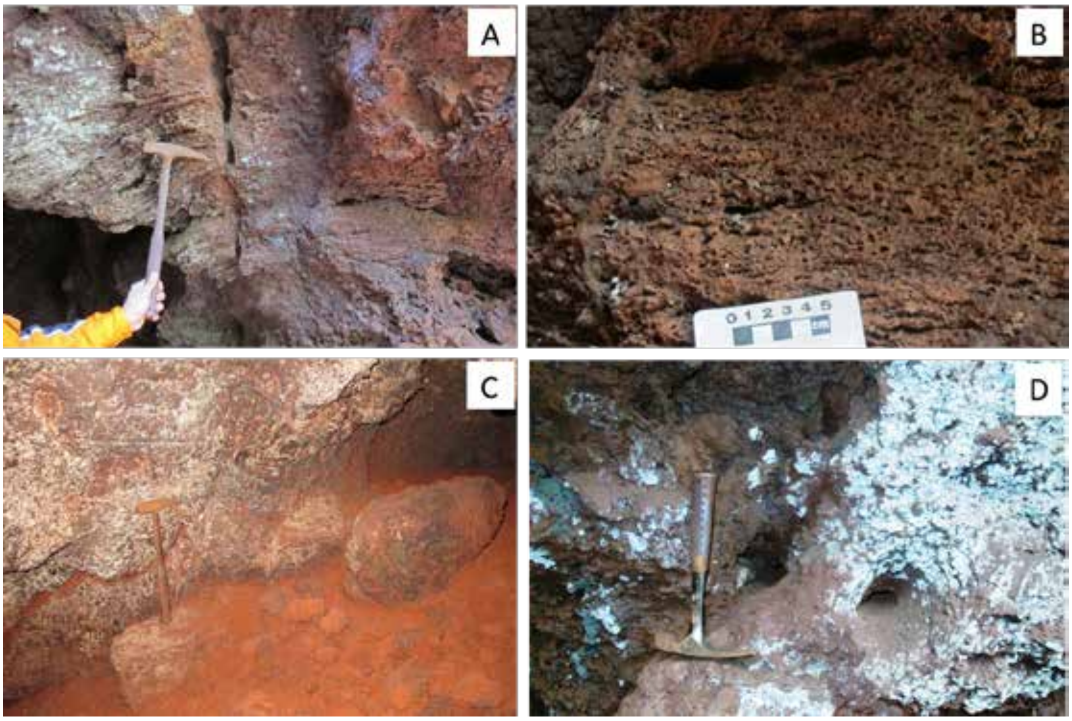


Figura 4 – Profile 3. A – Porous texture of Lateritic Crust on cave entrance, also identified on the cave ceiling. B – Porous texture detail of Lateritic Crust. C- Detrital aspect of the Lateritic Crust. D- Cavernous texture on the base of the cave wall near de floor.

**Transition Horizon**

Among the Saprolite Horizon and the hardened capping (Lateritic Crust), there is a horizon of irregular thickness called Transition Horizon (also known as Transition Zone), with poor geotechnical conditions, high perm porosity and fragile structural and textural aspects that without the hardened crust capping protection would easily eroded, resulting in the rapid denudation of the area in a short period of geological time. This horizon is composed of a frame comprising aluminium and/or iron oxy-hydroxides. Locally shows porous and / or cavernous textures. In this perspective, subvertical fractures were identified that slice up the entire horizon, as well as cavernous texture portions formerly called "Low Density Zones" (Figures 6B and 6C) (Maurity, 1995). This horizon was considered as the main horizon where there is the development of voids by enabling, through their fragile structure, the percolation of water in the vadose system causing erosion and evolution for underground caves (Maurity, 1995). In profile 3, located near N4E-0026 cave and in its interior were also observed the "Low Density Zones" in this horizon.

The contact of the transition horizon with overlying Lateritic Crust is irregular and sometimes confused (Figures 5 and 3A).


Figure 5 – Profile 2 (Panoramic view). General aspect of the irregular geological contact among Lateritic Crust and Transition Horizon.

**Saprolite**

Among the bedrock and the Transition Horizon generally have a thick layer of Saprolite with poor geotechnical resistence. This horizon can reach thicknesses of up to 500 m depending on the base level differences of 400 meters or more. Depending on the type of bedrock, its mineralogical matrix composition may consist of clays, in the case of volcanic rocks and hematite iron ore in case of jaspilites. The Saprolite Horizon is irregular and may contain large blocks of bedrock partially weathered, preserving its original texture internally and often visible in the iron mine area. In the studied profiles in N4E Mine, this horizon consists of yellowish to off-white material, clayey constitution, kaolinitic, with contribution of aluminium and/or iron oxy-hydroxides. It is common metric blocks featuring relict textures of volcanic rocks in the area (Figure 6A). Subvertical fractures occur by cutting this horizon, and are filled by iron oxy-hydroxides. The geological contact of this horizon with the Transitional Horizon above is abrupt and quite irregular (Figure 6A).

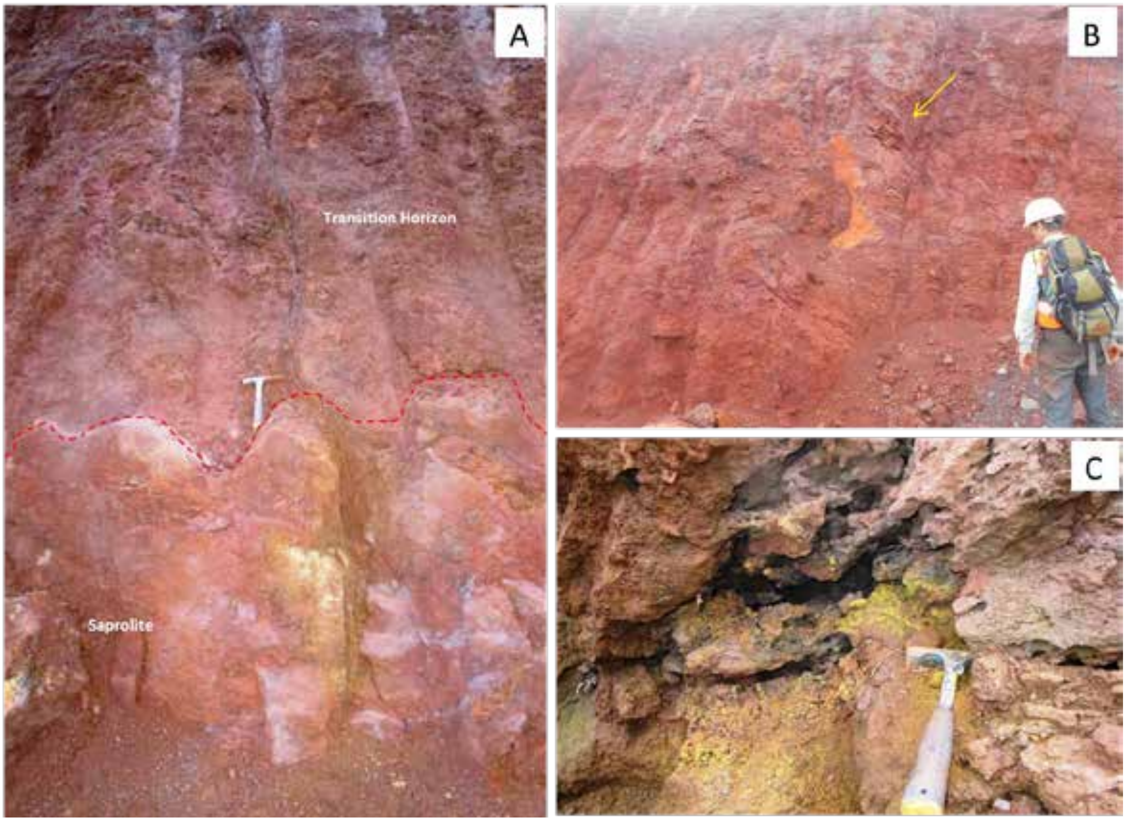


Figure 6 – Profile 1. A – Irregular geological contact of Saprolite and the Transitional Horizon. Notice kaolinitic blocks in the Saprolite and subvertical fracture cutting both horizons. B – "Low Density Zone" occuring on the Transitional Horizon (yellow arrow), identified by the higly cavernous texture. C – Detail of photo B showing the highly cavernous texture.

## DISCUSSIONS AND CONCLUSIONS

The profiles studied in N4E iron ore mine represents characteristic examples of mature lateritic terrains where the horizons can be clearly individualized and correlated to other mature profiles studied in the Amazon according to Costa (1991). The Saprolite and Transition Horizons show autochthonous elements developed at the expense of chemical weathering of volcanic rocks that occur in this area. This is supported by the intrinsic characteristics of very clayey saprolite and still partially preserving the original features of the bedrock, as well as the porous framework of iron oxy-hydroxides and the occurrence of cavernous portions located in the Transitional Horizon, related to the early beginning of speleogenesis. These aspects reinforce the hypothesis that more vulnerable horizons occurred in the past with structures mores susceptible to weathering action.

The Lateritic Crust, may be related to allochthonous detrital of sedimentary origin. This material would possibly developed by erosion of ancient lateritic profiles and, commonly form alluvial fans type deposits on middle slope. After the restarting of lateritization process, debris deposits become hardened by the penetration of rich iron solutions precipitated and crystallized in the form of goethite, allowing hardening of the crust. In the inner portions of the plateau at the top of the hills, the Lateritic Crust shows relict textures especially when arranged over banded iron formation. The hardened crust has an important role in sustaining the surface of the plateaus and ceiling support of the caves during the deepening of the valleys.

Speleogenetic processes over lateritic terrains in Carajás Ridge have been previously discussed in the 80's and 90's in several studies regarding proposals for an evolutionary model for the laterite profile and definition of pseudokarstic forms in the region (Pinheiro et al 1985; Pinheiro & Maurity 1988; Maurity & Kotschoubey 1995, Maurity 1995). Recently there has been published a number of articles and reports dealing with speleological surveys to meet the environmental constraints in the implementation of exploitation in iron ore projects (Atzingen & Crescêncio 1999; Piló & Auler 2009; Atzingen et al 2009; Piló et al 2010; Calux 2011; Souza et al 2012; Piló et al 2014, among others).

At the bottom of the geomorphological unit - Dissected Plateau of South Pará, there are less significant lateritization terrains belonging to other unit - Peripheral Depression of Southern Pará (Boaventura, 1974) correlated to the most recent pediplanation event possibly attributed to Velhas Surface from King (1956). These lateritization terrains also have caves developed in the Transition Horizon, although in smaller quantities and expression. Some evidence about the pediplanation processes of Velhas Surface are not clear due to the presence of other lower levels of pediplains represented by other lateritic spots dismantled with different levels lower than 10 meters, for example, the features found in Arqueada Ridge (Maurity, 2015).

Generally such lateritic terrains occur in topographic levels between 450-300 m, cut by streams whose headwaters are positioned in the middle part of the highlands. The occurrence of caves is related to the installation of the drainage system responsible for dissecting and dismantling the plateaus edges in the recent lateritization cycles. Resurgences of watercourses under the crust cause, in part, erosion and transport of this base material and the Transition Horizon as well. Speleological surveys identified caves in these land-based lateritic terrains in the surrounding area as Arqueada ridge, Bocaina ridge ( locality of Agua Boa), Sul ridge (S11D) and Plateaus V1 and V2 mainly.

Finally, the occurrence of caves in lateritic terrains is related to the whole lateritic profile resistance, where hardened Lateritic Crust horizons (duricrust) on the ground surface resists from erosion processes by reducing the indentation of the edges of the plateaus, while the Transition Horizon right below is subjected to eluviation and leaching processes. In contrast to the erosive effects, the Transition Horizon remains being dismantled in the current period.

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# LIFE CYCLE MANAGEMENT FOR BRAZILIAN MINING: A CASE STUDY

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# LIFE CYCLE MANAGEMENT FOR BRAZILIAN MINING: A CASE STUDY


## ABSTRACT

Several approaches addresses practices and their improvements in mining aimed at sustainable development, but the total resource consumption and environmental impact continue to increase. This could partially be understood when developing comprehensive sustainability strategies that address the entire product life cycle, especially focusing on resource extraction. This paper aims to discuss how mining activities can contribute for product environmental performance and what are the opportunities for improvement in a value chain. Throughout a case study of concrete for highways, a life cycle assessment measures impacts such as Climate Change, Photochemical Ozone Formation Potential, Ozone Layer Depletion Potential, Acidification Potential, Eutrophication Potential, Consumptive Water Consumption, Abiotic Resource Consumption, Land Use and Human Toxicity Potential. This study analyzed the stages of construction and maintenance of a road (11,200.00 m2) with standard volume of daily traffic of 10,000 vehicles. From the analysis results, it is possible to identify causes and suggest improvements for the environmental performance in mining activities. Considering only the reduction of 1% of diesel consumption, the environmental benefits are significant. Monitoring the consumption of water and fuels is important to track progress. We believe that is possible to demonstrate how this life cycle thinking approach is needed to handle holistic dimension of natural resources consumption. The case study establish that environmental information as well as project and technology data should be available in the mining industry for life cycle management. Following the outcomes, it is recommended that guidelines should be developed so it can be used during project and technology management. It is envisaged that such guidelines would improve the availability of quantitative life cycle data along time, and would therefore make the benchmarking procedures more practical in the future (Environmental Product Declarations, for instance).



## KEYWORDS

Life Cycle Management, Monitoring and evaluation, Product environmental performance, Concrete Highway, Mining Sustainability.


## INTRODUCTION

Although many have defined and applied the concept differently, Sustainable Development, generally, is the combination of enhanced socioeconomic growth, improved environmental protection and pollution prevention. Hilson & Murck (2000) comment that the literature on this subject contains a wide-range of interpretations, and increasingly it is becoming unclear how exactly mining activities can contribute to sustainable development. The authors point out for a mine contribute to sustainable development, at least from an environmental perspective, its managers and employees must determine not only what set of cleaner production activities should be adopted as a corporate environmental strategy, but also promote integration of the necessary environmental management tools into operations. In order to incorporate a systemic vision, a mine must take into consideration the environmental impacts throughout its lifecycle, from exploration, through extraction, beneficiation, to land reclamation.

Life Cycle Assessment (LCA) is the environmental management tool that applies this life cycle approach, and can be used to support understand damage to the environment, for mines and their products. According to Suppen et al. (2006), LCA is an analytical tool used to quantify environmental impacts of products, processes and services; it comprises a life cycle inventory phase (LCI), life cycle impact assessment and an interpretation stage. The use of LCA has also evolved in the development of different approaches based on the concept of Life Cycle Thinking that is accounting impacts and effects in all the phases of the life cycle. Such approaches include life cycle cost analysis and life cycle design, among many others.

On a life cycle perspective, every mining product is an input for another industry. For example, in the paving industry, where limestone and clay are used in the concrete production process for rigid pavement. Despite having one of the largest road infrastructure across the world, when it comes to paved roads, Brazil is still behind compared to other major economies, with only 13% of all roads being paved. Poor road conditions are a drawback that, ultimately, leads to higher truck operating costs. In this situation, vehicles need to reduce speed, which decreases the possible number of trips per day, and consequently increases the cost per trip due to variable costs such as fuel, spare parts, tires, lubrication and washing (REIS, 2011).

In recent years, LCA has been used by many industries as a powerful tool, regarding the evaluation of environmental impacts, implementation of eco-design strategies and as an important requirement for ecolabels or environmental declarations. By means of a LCA performed to concrete for highways, this paper aims to discuss how mining activities contribute to product environmental performance and what are the opportunities for improvement taking into consideration the whole value chain.

## METHOD

The LCA followed the ISO 14.040 (2006) and ISO 14.044 (2006) standards and analyzed the stages of construction and maintenance of a concrete road pavement (functional unit (FU): 11,200.00 $m^2$, equivalent to 1 km long drivable road) with a standard daily volume traffic of 10,000 vehicles (bidirectionally) over 20 years in surfaces suitable for traffic.

As shown in Figure 1, the system product model comprises a life cycle from raw material extraction to end of life. It also includes production of primary raw materials and intermediates (e.g. clinker and cement), utilities (as thermal energy), end products; followed by road construction and maintenance, and the corresponding logistics stages. Concrete, to this model, is the result of mixing only cement, water, stone and sand. When hydrated by water, cements forms a tough and adherent paste into the pulp aggregate fragments (sand and stone), forming a monolithic block, functioning based on a cradle-to-grave approach.

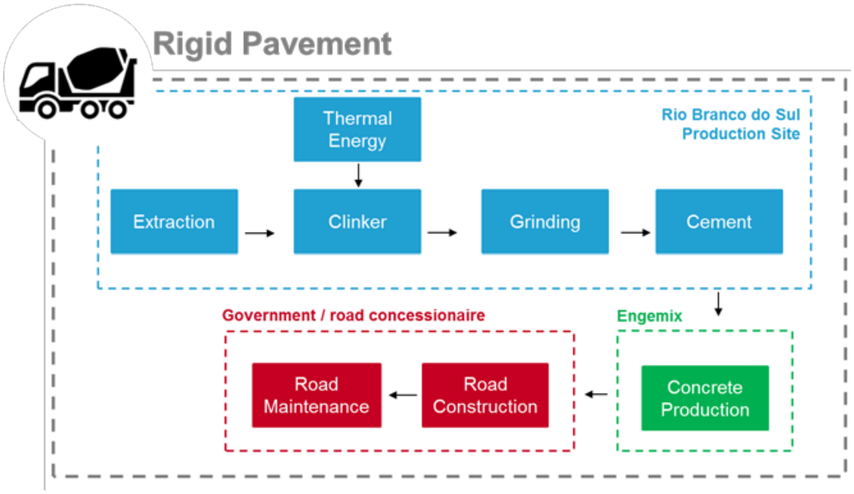


Figure 1: Concrete/Rigid Pavement System Product

Data availability is a major concern for any LCA, especially when the majority of high quality data necessary for the study is confidential to companies (Durucan, S. et al., 2005). As data quality guideline for this study, it was established that the Life Cycle Inventory (LCI) should reflect the reality of the production systems, therefore, to better reflect the environmental aspects: primary data should come from unit processes regarding Votorantim Cimentos' operation in Rio Branco do Sul, (Parana State, Brazil), which comprises from extraction of raw materials to cement production. Moreover, as for the concrete, it is represented by secondary data from a major concrete company in Brazil (Engemix). Likewise, construction and maintenance data are from secondary data from reports published by Government and Road Concessionaries responsible for highways in Brazil. In terms of temporal coverage, the data reflects the reality of production for the full year of 2014.

The data regarding the extraction of limestone and clay (raw materials) reflects the operation within the mines of Votorantim Cimentos. For instance, as inputs related to the FU, there is a consumption of 200 kg of explosives, 43,318 L of diesel and 13,588.00 MJ of electricity. The transport stage for limestone (mostly by road), performed by ski lifts and conveyor belts, demands 13,556.00 MJ of energy in the form of fuels.

Having completed the LCI, a Life Cycle Impact Assessment (LCIA) was conducted, which correlates the various aspects collected in the LCI to their respective potential environmental impacts. The application of eco-efficiency analysis method (NSF, 2013) was chosen to this generate the results. This method determines the procedures needed for grouping the several impact categories, as well as the criteria used (and their explanations) for normalization and weighting. Such procedure possibilities calculate a single indicator for environmental performance (related to the assessed product performing its function) and the respective contributions from each impact category selected. The grouping procedures are in line with the EU PEF Manual – European Union Product Environmental Footprint (EU, 2013).

The respective contribution of each impact category to the overall result are called "Relevance Check". These values, obtained through referenced method, presents the impacts contribution ratio from an environmental point of view. Major contributions can be interpreted as issues which can be managed for better environmental performance (ex: In case GWP – carbon footprint – is identified as an issue, fossil fuel consumptions, such from trucks or explosives, biofuels can be an alternative for lower carbon emissions).

Therefore, all assessed environmental impacts values can develop an action plan or strategy, and the respective urgency can be determined according to the relevance check factor. From rigid pavement LCIA results, mine managers and employees can understand the main contributions for mining operation.

## RESULTS AND DISCUSSION

Environmental Relevance Check (Table 1) shows the contributions for the ten impact categories related to rigid pavement life cycle, according to the ecoefficiency reference method: Global Warming Potential (GWP), Photochemical Ozone Potential (POCP), Ozone Layer Depletion Potential (ODP), Acidification Potential (AP), Freshwater and Marine Eutrophication Potential, Human Toxicity, Water and Abiotic Resource Consumption, and Land Use.

Table 1: Environmental Relevance Check for Rigid Pavement life cycle performance

| EEA10 impact categories | Rigid Pavement |
|---|---|
| GWP | 23,06% |
| POCP | 20,21% |
| ODP | 0,01% |
| AP | 18,68% |
| Eutrophication Mar. | 13,58% |
| Eutrophication Fresh | 0,55% |
| Human Tox overall | 23,15% |
| Resource Depletion (water) | 0,09% |
| Resource Depletion (Total) | 0,34% |
| Land use (total) | 0,34% |
| Sum | 100,00% |

Due to smelting and transportation air emissions (mainly from combustion) are indicated on Table 1 as relevant environmental impact categories; and due to water emissions (like heavy metals overloading), toxic substances threaten human health. Therefore, considering only consumptions and generations coming from the mining activities, Human Toxicity, GWP, POCP, AP impact contributions have opportunity for improvement related to the management of mine operations.

Literature unveils that "every industry, in addition to generic environmental complications, faces industry specific challenges that require careful planning, tactical investment, and strategic management to overcome" (Hilson & Murck, 2000). Hence, mine management should not focus only on attending environmental legislation, since sustainability calls for a more proactive environmental management, which demands a requirement to perform beyond regulatory obligations. Several publications advocate that Cleaner Production require "integrating a number of highly effective environmental management tools such as audits, reviews, monitoring practices, environmental management system, and reporting systems" (Ny, H. et al, 2006) into operations, what can also be interpreted as Life Cycle Management. The application of this integration of tools, within a long-term perspective, are likely to help mine managers and workers to better anticipate problems with not only wastes, but also to handle other environmental problems when they occur.

Evermore, improved waste management and implementation of cleaner technology, such as scrubbers, flash smelting, water treatment plants, industrial wetlands/tailings ponds and bio-detoxification technologies can represent practical solutions for a better mining environmental performance. For the life cycle management success, it is also recommended the establishment of sustainability partnerships throughout the value chain, focusing on staff training, which ultimately benefits the completely mining products.

## CONCLUSION

As the literature and this case study shows, mining leads to environmental problems in several areas, such as: upon air (due to smelting and transportation emissions); water resources (due to water emissions like heavy metals overloading); soil and land (due to mineral extraction); and human health (due different emissions). For mining operation, cleaner technologies should be integrated so the process itself would generate less waste and or best treat other pollutant streams. It is recommended to plan engagement effort through stakeholders and coworkers along mining products value chains for the life cycle strategy be succeed.

The case study unveil that environmental information as well as project and technology data should be made available in the mining industry in order to put in practice the life cycle management. Another outcome from this exercise is that guidelines should be developed so it can be later used during project and technology life cycle management practices. Such guidelines would improve the availability of quantitative data along time to come, and therefore would make the benchmarking procedure more practical in the future.

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# MINERAL BUSINESS: ASYMMETRIES OF THE SUSTAINABILITY

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# MINERAL BUSINESS: ASYMMETRIES OF THE SUSTAINABILITY

## ABSTRACT

Regarding the growing awareness of global society, produced by convergence based qualitative procedures in <paradigm of sustainability>, policy makers still face major dilemmas — always associated with overcoming challenges posed by the size of <growth limits> —, from utilitarian relationship progressively asymmetrical man and nature.

Indeed, it is proposed to broaden the discussion on the <asymmetries of geoeconomic information> associated with the <boom and bust cycle phenomenon>, in order to define axes of reflections under the aegis of <strategic planning> and <strategic management> the use of mineral resources, in order to identify competitive archetypes, its legitimacy before their stakeholders and sustainability of mineral Business in Brazil.

Therefore, the great challenge of the academy is to understand and explain: What determines such booms and busts? Was the last boom exceptional? Where are prices today relative to long-run trends? And the big question – where are prices likely to go from here? In this perspective, by examining ─ by way of illustration summary ─ the <architecture sustainability>, you can identify dependency links and vulnerability in <Global Mining Economy>.

## KEYWORDS

Mineral business, sustainability asymmetry, boom and bust,

## INTRODUCTION

The minerals boom of the 1970-80s led to an aggressive expansion of mine development in greenfield areas, many of them the domains of indigenous communities. Indeed, under considerable pressure, the scope for an sustainability of mining has been dramatically transformed since the publication of the Brundtland Commission's Report, Our Common Future.

The first decade of the 21st century experienced the dramatic growth in mining activity in many developing countries. Although the mining industry is a relatively small industry compared to the global economy ─ involving the order of 30 million people involved in large-scale mining, and 13 million more involved in small-scale mining ─ the mining industry represents an important part of employment and GDP for some countries in Latin America, Africa and Asia, including Brazil, China, Australia.

In this perspective, it is proposed in this paper contribute to a better understanding of the dimensions and polysemic concept of asymmetries of sustainability and overcoming the challenge of incorporating the hierarchical combination of economic mineral efficiency, ecological responsibility and social welfare to the mineral business in Brazil.

Despite the economic theory demonstrate the superiority of market-based instruments on command and control measures in terms of efficiency, it is accepted as an aggravating factor the asymmetry of information and disparate interests between social actors (voters, politicians, producers, bureaucracies and groups of traditional and green interest). But, for an industry accustomed to volatility, what defines "sustainability"? How can the Mineral Business sector shape the agenda on this issue rather than react to it?

This approach proposes assessing some broader empirical questions

- What are the macro and micro-economic drivers and prospective effects on the sustainability of Mineral Country Business?

● Analyze the impact of policy issues, environmental economic impacting the strategic business model of mining in Brazil.

**BALANCE OF ENVIRONMENTAL LITERATURE**

Pre-paradigmatic sustainability phase started with discussions on the "limits to growth" from an articulated movement of the group of companies called "Club of Rome", in order to discuss the possibility of depletion of natural resources, whose results were consolidated in the Meadows Report, (1972), by scientists at the Massachusetts Institute of Technology (MIT). is assigned to this report the dissemination of a critical view of the ideology of -growth without limits and ecological-environmental vulnerability, given population growth and physical limits of the Earth. Anyway, warned of possible problems associated with the development without limits and collapse risk of mankind if the population growth did not change.

The paradigmatic phase established itself with the creation of the World Commission on Environment and Development (WCED, 1987) by the UN General Assembly, which resulted in the Brundtland Report, also known as "Our Common Future", consolidating the historical and promoting the concept of broadcasting that "*sustainable development is development that meets present needs without compromising the ability of future generations to meet their own needs*." In this perspective, the Johannesburg Declaration on Sustainable Development (2002), recognized the dual goal of eradicating poverty and transforming consumption and production patterns. The protection and management of natural resources for economic and social development remain as common goals, although the prevalence of the last over nature. Therefore, to reaffirm the commitment to sustainable development, taking account of the model of three pillars of sustainability ─ economy, natural resources and society ─ advocates to collective responsibility to advance and strengthen the interdependent and mutually reinforcing pillars supported sustainability economic, social and environmental protection.

At the national level, it is necessary to understand the constitutional axiological dimension (art. 3, III; the CF-1988), given that sustainable development emerges among the fundamental objectives of the Republic. Indeed, it is assumed the assumption that sustainable development is a constitutional principle in the context of universal respect for multidimensional conditions of quality of life, in that it requires the guarantee of biodiversity and requires greatly, the compatibility of the requirements of efficiency and equity between generations. It emphasized that the constitutionalization of environmental sustainability function features very advanced progressive norms and protective of the environment, with its own instruments to his tutelage (art. 5, LXXIII; the CF-1988). In a systemic view, it is worth to highlight the following structural environmental standards:

a) Protection of the environment is the duty of the state and society;

b) The state can and should impose restrictions on the exercise of fundamental rights to protect the environment;

c) The right to an adequate environment is a fundamental right and must be guaranteed by the State; and

d) Economic development should be linked and associated with environmental sustainability.

Although the Brazilian Constitution under Art. 225 of the Federal Constitution, "*everyone has the right to an ecologically balanced environment and of common use and essential to a healthy quality of life, imposing to the government and society the duty to defend it and preserved it for present and future generations.* " Therefore, the assumption of the theme in the Brazilian legislation transversal the protection of the environment to the established economic order, requiring the observance of the principle of protection of the environment, including by differential treatment as the environmental impact of products and services. It is remarkable that even in despite of Art. 176 (CF-1988) there set up proper legal dichotomy between the rights of soil and subsoil properties (surface rights and mineral resources), mineral property undergoes of public ownership regime. Therefore, the current mining system in Brazil attaches to the granting of mining - which is true res in commerce - negotiating character and content of economic-financial nature.

In this context, considering the polysemy and the dynamic associated with the affirmation of a given paradigm, it must recognize the broader dimensions of Geodiversity, Biodiversity and Sociodiversity, always from the perspective of depreciation and marketability of the Mineral Capital. Indeed, it is assumed that the imperative challenge is to expand this notion of sustainable development for the Mineral Business, the hierarchical combination of economic mineral efficiency, ecological responsibility and social environmental function of the related goods and services to Natural Capital.

## DIMENSIONS AND ASYMMETRIES OF THE SUSTAINABILITY

In this perspective, by examining ─ by way of illustration summary ─ the <architecture sustainability>, you can identify dependency links and vulnerability in <Mineral Global Business>: Given the assumption that the strategic moves geopolitical and geoeconomic not exist in isolation - to the extent that bolster the articulation of the new world political order - is observed that the global mineral economy is organized based on a <flexible geometry> incorporating the physical and virtual dimensions of capital flows (FDI), in which the investment decision considers the <risk offer> conventional elements and high-techs, aggravated by the nationalization of resources movements.

In study "Super-Cycles of Commodity Prices Since the Mid-Nineteenth Century," economists Erten and Ocampo (2012) confirm that the commodity price increases in the first decade of this century were the result of a super-cycle upswing. The cycles they identify ran from 1894 to 1932, peaking in 1917; from 1932 to 1971, peaking in 1951; from 1971 to 1999, peaking in 1973; and the post-1999 episode, which is ongoing. They claim that the increases in commodity prices during these cycles are driven largely by increases in demand arising from strong periods of industrialization and urbanization, such as those experienced by Great Britain, Germany, and the United States in the 19th century, by Japan in the 20th century, and by China and other emerging economies at the beginning of the 21st century.

Stuermer, M. (2014), in turn, tries to account for trends in commodities by looking at how prices have evolved for four minerals—copper, lead, tin, and zinc— since 1840, in search of answer to the question: What Drives Mineral Commodity Prices? Concludes that commodity price increases are driven by demand shocks rather than by supply shocks and that the price surges caused by rapid industrialization are a recurrent phenomenon throughout history. Warns warns finally that mineral commodity prices return to their declining or stable trends in the long run.

### Geopolitic and Geodiversity Dimensions

In the globalized economy dependent on scarce natural resources and increasingly threatened by regional instabilities changes, power struggles for access to resources are playing an increasingly crucial role behind the scenes, often covered by diplomatic rhetoric in perspective forging strategic partnerships between nations. The <radar business risks> Ernst & Young (2015) for the mining sector shows the <resource nationalism> among the top ten. This phenomenon is characterized by the state's tendency to assume the direct control of economic activity in the fields of natural resources, traditionally understood as an effect of commodity price curves up, or a reaction against former colonial masters, under the political-strategic pretext to ensure investments built on the of revenues from natural resources.

These movements, historically associated with the oil industry (Russia, Mexico and Venezuela), may very well be characterized in conventional mining of metal and fertilizer. In this context, it is worth mentioning the recent announcement of British SRE Minerals Limited on the discovery of reserves of about 216.2 Mt REEs (≈US $ 4.7 trillion) in Jongju City in North Korea, in 2013 ─ that means more than double the global resources estimated rare earth ─ with recognized potential IEDs catalyst, can encapsulate other type of resource nationalism and radically change the geopolitics of the region.

**Economic and Financial Dimensions**

In the <Economic Dimension>, it is assumed that the Global Financial Crisis (GFC) of 2008 was the main agent catalyst volatility price of mineral commodities, as contributing to the shift in the balance between supply and demand, influencing the availability credit and reduced investments, strongly impacting the sustainability of the mineral world business. Admitting the assumptions: a) the structural crisis of the capitalist world-system dates back 40 years ago; b), which should continue for another 20-40 years (mean duration of structural crisis), it is reasonable to bet on the game worsening in the geopolitical arena, in a situation where none of these areas (*loci*) of geopolitical power will be in a position to dictate the inter-state rules, making it even more unstable economic system.

In this perspective, it is a truism to state that short-term forecasts ─ considering the risks and uncertainties associated with a series of chaotic fluctuations and unpredictable changes in the real political, and economic world ─ they are mere conjectures, devoid of any economic significance. However, even despite the aggravating factor of <dissymmetry of geoeconomic information>, combined with <phenomenon of boom-bust cycle>, seeks to overcome these challenges from the construction of economic scenarios for medium and long term, based on a structure theoretical praxeological adequate, combined with a solid empirical analysis of global market trends of commodities. The diagrams below suggest that the closest to the radar center risks are those with the greatest challenges in the mining sector in 2014.

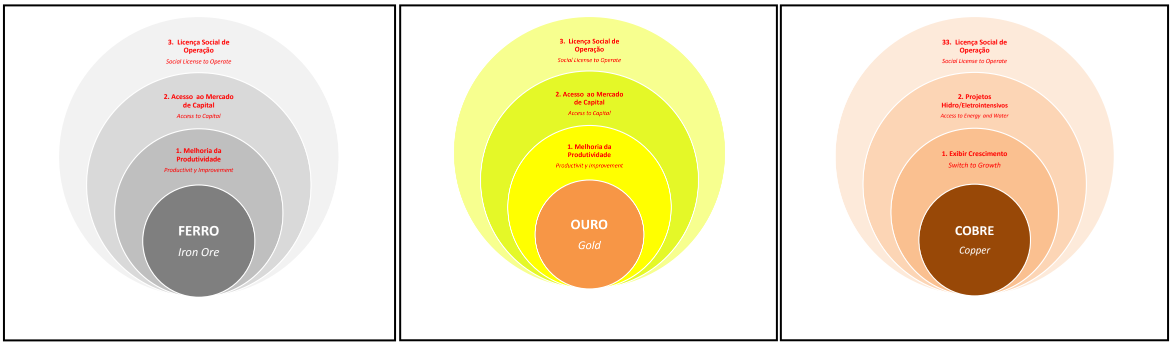


Figure 1 – Radar-Risk for Iron-Ore, Gold and Copper (E&Y, 2015).

The decade-long commodity-price boom has come to an end, with serious implications for global GDP growth, the main aggravating factor for developing countries. And, although economic patterns do not reproduce themselves exactly the end of the upward phase of the super-cycle that the world has experienced since the early 2000's commodity dims Developing Countries' prospects for continued rapid catch-up to advanced-country income levels. Historically, this is not surprising, given ample evidence literary on the super-cycle commodities, noting that, since the late nineteenth century, commodity prices have undergone three long-term cycles and the upward phase of the quarter, mainly driven by changes in global demand. It is assumed that the first two cycles are relatively long (about four decades), and the third was lower (28 years).

Forward looking commodity prices respond to the probabilities of future supply/demand events. Demand shocks may provoke high correlations across commodities, whereas supply shocks tend to be more idiosyncratic. The upward phases of all four super-cycles were led by major increases in demand, each from a different source. During the current cycle, China’s rapid economic growth provided this impetus, exemplified by the country’s rising share of global metals consumption.

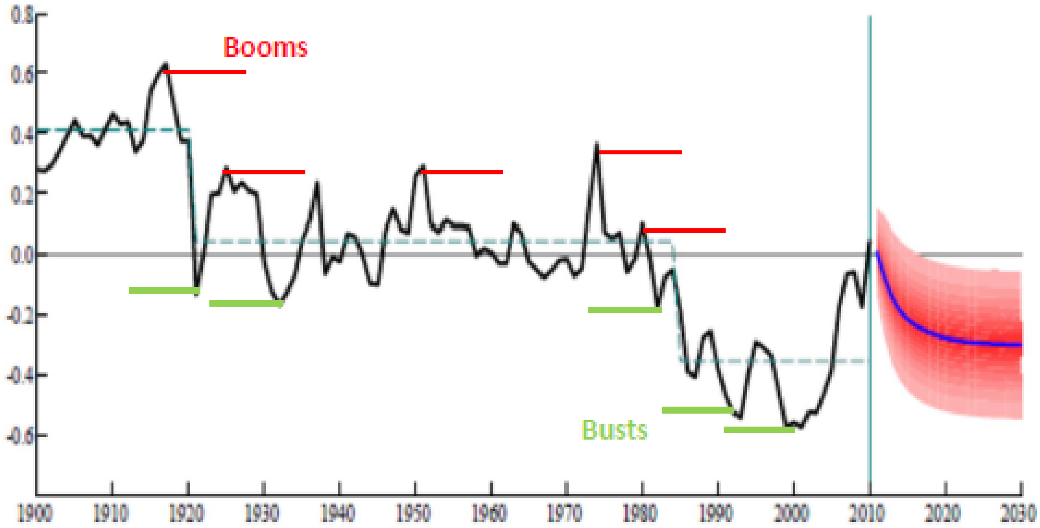


Figure 2 – Real (non-oil) commodity prices since 1900 and a naive projection (*apud* Powell (2015).

Econometric exercises performed by Erten and Ocampo (2012) on the decomposition of real commodity prices suggests four super-cycles during 1865-2009 ranging between 30-40 years with amplitudes 20-40 % higher or lower than the long-run trend. Economists also say the ascending phases of all four super-cycles were driven by large increases in demand, each from a different source, and that the recent boom in commodity prices is closely linked to China's rapid economic growth, exemplified particularly the growing consumption of metals. It is in this environment that recognizes the vocation of Geodiversity of a country trying to resist the global economic crisis. The high dependence on trade balance Primary Sector Economy (metals and grains) certainly has ensured an exportable surplus condition, despite the impact of expansion and contraction in the first decade of this century. But unfortunately, it seems inevitable economic recession Brazil in the coming years.

**Social and Environmental Dimensions**

In the <Social and Environmental Dimensions>, even despite the underlying idea of <sustainable development> be as resonant today, policymakers still face major dilemmas — always associated with overcoming challenges posed by <growth limit Planet>, given the increasingly distorted man-nature relationship — face the utilitarians asymmetries relations of mineral resources, an economic perspective, technological and socio-ecological.

The emblematic <SAMARCO's Case> refers to the consideration of the proposal by British economist Ronald Coase, who suggested that "*the polluter and the victim can negotiate with each other to achieve an efficient solution*". Nobel Prize winner in economics, particularly the authorship of the "Coase Theorem", according to which all must come together and decide the efficient levels of pollution and environmental deterioration. Indeed, the recent <Mariana Tragedy> comes distort 'Coase' ─ paradigm even despite hypothetically be applied in small-scale situations ─ in that it is hard to imagine that it is applicable in cases of large-scale externalities (irreversible), valuation and cost of exponential environmental repair.

Conclusively, despite large portion of conventions, international reports and national and international environmental legal doctrines always seek a definition for sustainable development, not managed to converge to standardization of a polysemic concept, to the extent that the multifaceted nature of sustainability is based on three pillars or more incompletely balanced elements ─ economic efficiency, environmental compliance and social function ─ in view of the large dimensions of Geodiversity, Biodiversity and Sociodiversity. At the same time, the theory of sustainable development has expanded and strengthened; however, very focused on economic rationality, in practice, it turned out to disregard the unequal distribution of environmental costs and the social marginalization.

### DESIGN OF SUSTAINABILIRY IN ARCHITETURE BRAZIL MINING

It is now a truism to state that the intensity of the work and the techniques used in Mineral Exploration Phase vary depending on the search target object, always associated with metallogeny and the areas of regional Geodiversity, whose degree of environmental impact, can be considered relatively low. In Brazil, the analysis of the impact of mineral and environmental policy frameworks in the strategic model of the mining business, it is observed that the Authorizations Research (Fig. 3) granted by the Federal Government (National Department of Mineral Production -DNPM) make up an area of 69.96 million hectares (Mha), representing 12.43% territory of the country's surface: 851.58 Mha (DNPM, 2016).

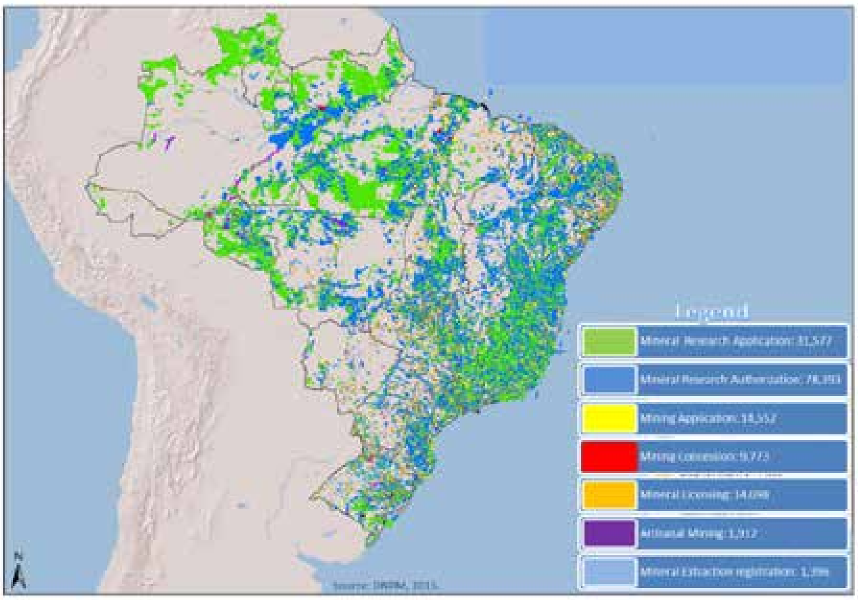


Figure 3 – Distribution of areas for Mineral Exploration and Mining (to 31dez2015; DNPM, 2016).

In this perspective, even despite the areas of index encumbered for Mineral Exploration purposes in Brazil (Table 1), reaching the order of 8.21% of the total area of the country, it is assumed that the human intervention level is insignificant, negligible. Moreover, it is appropriate to warn that the Amazon region, these areas can reach the order of 10,000 ha, which does not mean that the whole area will be searched, but only those pre-selected geological targets, always in compliance with the technical efficiency and minimization costs of preliminary work field for subsequent definition of density targets of mineral exploration with much smaller areas. Admitting that the stages of development of a mining project are closely associated with progressively demanded investment flows, meaning points of decision-making on whether to proceed with the project, before the assessment of uncertainties and market risks, if positive, advances for mine development. At this stage, yes, human impacts on infrastructure and operational works are significant, saving a difference in the type of mining: the surface or underground.

Table 1 – Brazil: areas of mineral exploration and mining.

| BRAZIL | | North | Northeast | Midwest | Southeast | South |
|---|---|---|---|---|---|---|
| MEA[1] | 69.956.725 | 32.500.190 | 24.598.065 | 8.783.273 | 17.121.466 | 4.075.197 |
| Δ% BR | 8,21 | 8,43 | 15,83 | 5,47 | 18,52 | 7,07 |
| MC[2] | 3.668.187 | 1.914.640 | 624.699 | 572.586 | 1.217.376 | 556.262 |
| Δ% BR | 0,43 | 0,50 | 0,40 | 0,36 | 1,32 | 0,96 |

Souce: DNPM, 2016.

Notes: [1]Mineral Exploration Authorization (MEA)
[2]Mining Concessions (MC)

Returning to the analysis of the areas available for mining (MC) in Brazil, despite the assumption of the environmental impact, it is observed that the index in mineral exploration stage (MEA) by lifting the order of 8.21%, drops to only 0:43% of the national territory occupation (Table 01). Unfolding the analysis for macro-regions of the country, the following indicators are obtained (Fig. 4): North (MEA: 8.23%; H: 12.50%), Northeast (15.47%; 0.40%), Midwest (5.47%; 0.36%), Southeast (18.52; 1.32%) and South (7.07%, 0.96%). Conclusively, arguing about the empirical data of the DNPM, it is stated that the national land use indicators demystifying the pejorative labeling attributed to mining <environmental gran-villain>.

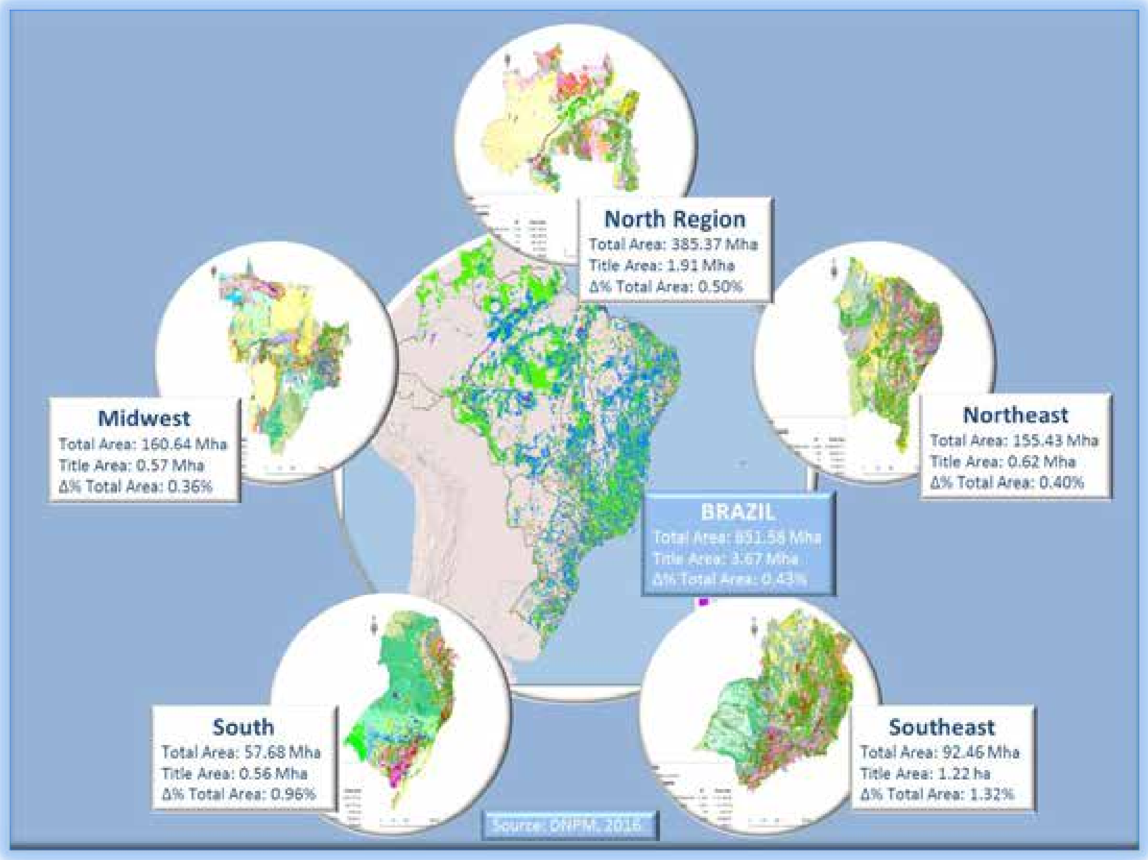


Figure 4 – Brazil: Mineral Exploration and Mining by Macro-regions (to 31dez2015).
Source: DNPM, 2016.

The angle of the mineral economy, or mineral business showed increased participation in foreign trade, contributing significantly in the trade balance composition. It warned that despite the surplus still be the result of a larger decrease of imports than exports, the behavior of the two movements has obvious asymmetries. Therefore, considering the period from January-Nov / 2015 on the export side, it notes that the reduction is the result solely of falling prices of exported products (-21.8%). Export volumes, however, increased by 9.3%. Moreover, this increase is triple the growth forecast by the IMF for world exports for 2015 (3.1%). It is in this context of global crisis which is observed about 70% of the decrease in revenues from exports is concentrated in three product groups: 1) iron ore; 2) oil and oil products and 3) soy complex - which however, had a significant increase in volume. (MDIC, 2015).

- Iron ore: + 7.8% Quantum / -49.5% price (lowest since April / 2005);
- Complex Soybean: + 13.4% quantum / -23.8% price (lowest since 2010 for soybeans);
- Oil crude: + 47.3% quantum / -49.7% price (lowest since 2009).

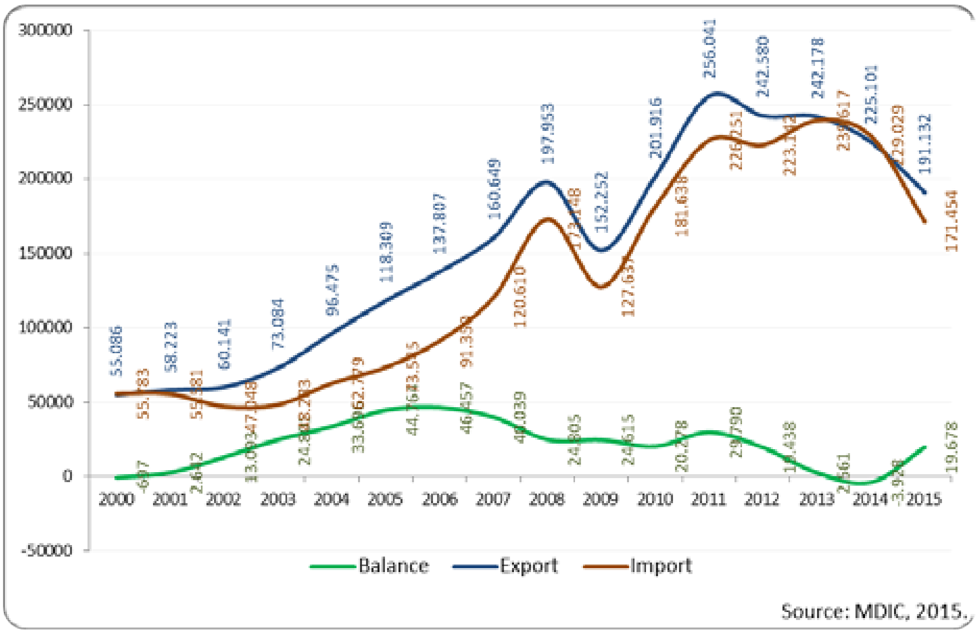

Figure 5 – BRAZIL: Trade Balance 2000-2015.

The latest World Exploration Trends report reveals that the global exploration sector a 19% decline in worldwide nonferrous metals exploration budgets in 2015, compared with the previous year. Therefore, In the 26th edition of its Corporate Exploration Strategies report, SNL Metals & Mining calculated that the mining industry's total budget for nonferrous metals exploration in 2015 was US$9.2 billion, less than half the record US$21.5 billion budgeted in 2012, assigning a relative participation of Brazil in the order of 3%.
The database of the Mineral Department of Mineral Production (DNPM), makes evident the growing trend of the mining share (excluding oil and gas) in GDP-Brazil. The influence of the boom-bust cycle of metal commodities (2003-2015), it is quite the asymmetric inflections of the curve in the graph below.

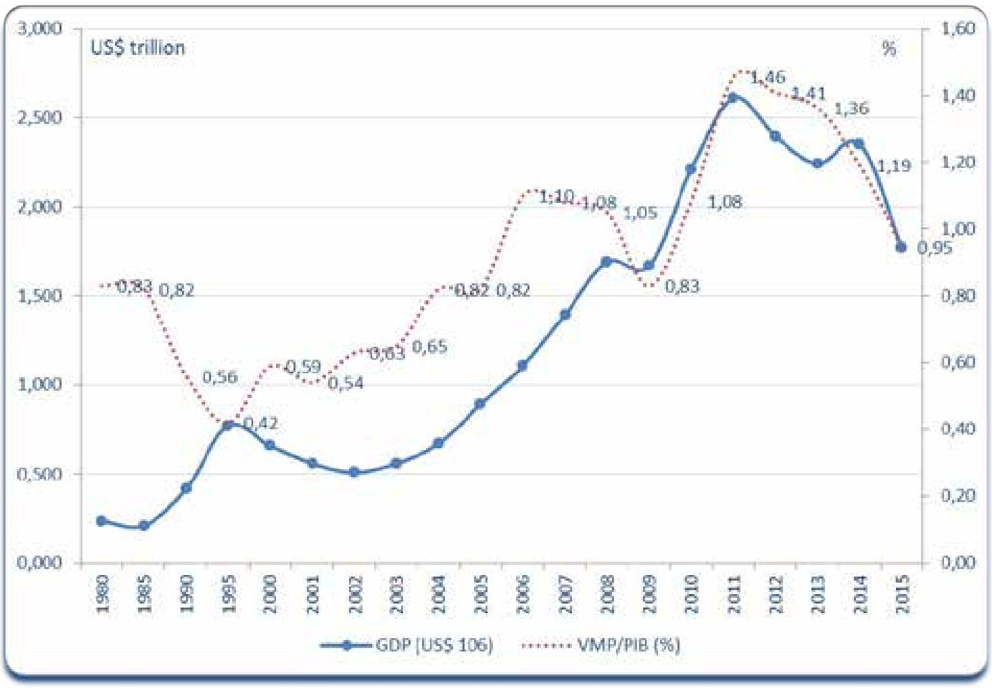

Figure 6 – Mineral Production Value (MPV) in GDP-Brazil: 1970-2015.

## CONCLUSION

A global economy dependent on natural resources, exacerbated by changes in international production standards arising from globalization, from 1980, forced the hegemonic powers to redefine its geopolitical strategies to ensure the areas in rich regions in energy sources and minerals. The commodity boom in the early twenty-first century, in turn, to intensify the competition between developed and underdeveloped countries, encapsulated another type of resource nationalism, redefined the long-term economic prospects of countries and radically changed the geopolitical regions, face the assumption that the relationship between ownership (control) and production (management) is a power relationship, the core of asymmetry.

In the <Economic Dimension>, it is assumed that the global financial crisis of 2008 was the main agent catalyst volatility price of mineral commodities, as contributing to the shift in the balance between supply and demand, influencing the availability credit and reduced investments, strongly impacting the sustainability of the mineral world business.

Despite the recognized universal concept of sustainable development ─ very focused on economic rationality and ignoring the unequal distribution of environmental costs and social marginalization ─ warm up that <trivialization sustainability>, as the main determinant of the development model of < risk society>, inspires reflection on the need for structural changes in the rules of mineral political and economic systems and emergency social and environmental values.

It is in this historical moment of transition paradigmatic stages to post-paradigmatic concept of sustainability that the Mineral Business needs to redefine the competitive conditions in the <Risk Society>, in that reflexivity implies rethinking market rules, in commitment to technological innovation and corporate responsibility with the communities surrounding the mine, always from the perspective of Social License.

Anyway, as a result of this closely linked approach the new era of reflexive modernity, considering the polysemy and the dynamics associated with post-paradigmatic statement of sustainability, we must recognize the dimensions and asymmetries in the fields of Geodiversity, Biodiversity and Sociodiversity, always in a depreciation perspective and fungibility of the Mineral Capital.

Indeed, it is assumed that the imperative challenge of a reflexive society is to expand this notion of sustainable development for the Mineral Business, the hierarchical combination of economic mineral efficiency, ecological responsibility and environmental function of the related goods and services to Natural Capital.

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# MINERS MUNICIPALITIES AND TERRITORIAL DEVELOPMENT: IN WHICH MEASURE MAJOR MINERALS PROJECTS CHANGES THE DYNAMICS OF MUNICIPALITIES AND PROMOTES THE SUSTAINABLE DEVELOPMENT OF TERRITORIES

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# MINERS MUNICIPALITIES AND TERRITORIAL DEVELOPMENT: IN WHICH MEASURE MAJOR MINERALS PROJECTS CHANGES THE DYNAMICS OF MUNICIPALITIES AND PROMOTES THE SUSTAINABLE DEVELOPMENT OF TERRITORIES


## ABSTRACT

Brazil is a major producer of minerals and, by the same token, the State of Pará, which nowadays represents the second mineral producer in the Country. The mining activity not only stands out because it is a basic industry, but also by its condition to foster new economic opportunities. In Pará, mining projects established a new sectorial provision in Pará economy, triggering changes in the state. This article aims to analyze the impact of the operation of the largest iron ore mining in the world - the Carajás Project, in the transformation of the territory, taking the municipality of Parauapebas, where the project are located, as reference, and its border towns, Canaã dos Carajás, Curionópolis, Tucumã, Água Azul do Norte, São Felix do Xingu and Marabá, by comparing financial and economic data with social and sanitation indicators in order to measure the improvement of life quality of the city dwellers.



## KEYWORDS

Mining, Parauapebas, CFEM, territorial development.


## INTRODUCTION

From the Latin word *Mineralis* (related to mining), the mining activity can be defined as the process of mineral extraction with economic value for the use of the mankind. The sector is characterized by being a primary industry extracted from the Earth's crust, including the ones from the oceans, lakes and rivers. The raw materials produced in this industry will be feedstock for the secondary industries. Brazil is a major producer of minerals. In 2014, the national production covered 200 substances, according to National Department of Mining Production (DNPM).

Table 1 – Brazil Position in the perspective of world production - Source: USGS 2015

| Exportador *Global Player* | Exporter | Self-Sufficiency | Importer/ Producer | External Dependence |
|---|---|---|---|---|
| Niobium (1st)<br>Iron Ore (3rd)<br>Vermiculite (3rd) | Tin<br>Nickel<br>Magnesite<br>Manganese | Limestone<br><br>Industrial Diamond | Copper<br>Sulphur<br>Titanium | Metallurgical Coal<br><br>Potassium |
| Graphite (3rd)<br>Bauxite (3rd)<br>Kaolim (5th) | Chromium<br>Gold<br>Ornamental Rocks | Talc<br>Tungsten | Diatomite<br>Phosphate<br>Zinc | Rare Earths |

The state of Pará, located at north region of Brazil, follows this pattern of diversity representing, nowadays, the second mineral producer in the Country, with 30% of national production, which corresponds to U$ 40 billion in 2014 (IBRAM, 2014).

However, being a pioneer industry, the mining sector can drive new economic opportunities. In Pará, major mining projects establish a new sectorial disposition in the state economy, highlighting economical and social changes in which can interfere in the macro and micro economy behavior of Pará.

But in which basis the territory's transformation occur? Taking the municipality of Parauapebas as a reference, where the operation of the largest iron ore mining in the world - the Carajás Project - is located and its border towns Canaã dos Carajás, Curionópolis, Tucumã, Água Azul do Norte, São Felix do Xingu and Marabá, the hypothesis of this article is built. Which effects a huge mine Project can cause in the amazon region? Which changes may occur in terms of infrastructure and socio economy after the mining implantation? What kind of learned lesson this experience may offer to the policies design in order to promote the sustainability of local and regional development based the mining industry?

## BRIEF HISTORY OF PARÁ SOUTHEAST OCCUPATION

The migration and occupation of Pará's Southeast area had an increment during 1960, and it is related to the mining projects and logistics implemented in the region. It was in that decade that researchers founded out the world major polimetalic province – Carajás and in 1968, the construction of PA-70 highway connected the region with Belém-Brasilia highway. The construction of this road constituted in fundamental factor for the penetration of migrants.

In 1981, the "Ferro Carajás" Project was started. In parallel, the Parauapebas Village, located in the River Parauaepebas Valley, began to be built. And, despite the inferior conditions in relation to the urban core standards designed in Carajás, it grew wildly. The village, once planned to attend 5000 persons, according to Brazilian Institute of Geography and Statistics – IBGE, already had around 20.000 persons.

In 1985, was launched the Carajás Railroad. Since that, the train becomes an important way of bringing people from all brazilian states to the region (Trindade, 2011).

## THE FORMATION OF THE ANALYZED MUNICIPALITIES

A brief summary about the formation of the municipalities is presented in order to contextualize the influence of the extractive industry projects on the socioeconomic dynamics of the region.

Marabá is one of the oldest municipalities in the southeast of Pará. Although this region has been explored by the Portuguese in the XVI century, the area still remained without permanent occupation for nearly 300 years. Only from 1892 it is that, in fact, the space was occupied by settlers. In 1929, the city was already lit by a wood burning plant and in 1935 the first plane landed at the newly opened airport in the city. During this period, the town consisted of 450 houses and 1.500 fixed inhabitants. With the opening of PA -70, in 1969, Marabá was connected to the Belém-Brasília highway. And in 1980 the city was beset by the biggest flood in its history. Already restored in 1988, start the preparations for the installation of the steel industry, for the production of pig iron, a deal that has brought great benefits and expansion to the county (Figure 1).


Figure 1- The State of Pará and their regional divisions - Source: Da Silva, 2006.

The municipality of Canaã dos Carajás started from an agricultural settlement. The Carajás Settlement Project was established in 1982 with the purpose to mitigate conflicts over land ownership in the region. The city possess an agricultural basis and it economy is related to the cultivation of rice, corn, beans, and livestock production. It's important to mention the copper ore extraction, in the Sossego Mine/Vale, installed in 2004, which has promoted noticeable changes in the socio-economic and cyclical structure of the city.

Curionópolis originated from the dismemberment of the city of Marabá and emerged from a cluster of people who in the late 70's was hoping to work with the implementation of the Carajás Iron Project, with the road construction or in search of gold , in the dozens of small artisanal mines that have proliferated in the region. With the occurrence of gold in Serra Pelada in the early 80's, Curionópolis consolidated to support this activity and as a place of residence of women and children of miners,

The area called Água Azul do Norte was linked to the municipality of Parauapebas until the early 1990. However, due to the distance of the municipal headquarters, 308 kilometers from the village, the population from Água Azul fought for the emancipation policy . The plebiscite was conducted in 1991 and it result left no doubt: Nearly 100 % of residents approved the village transformation in municipality.

The territory of the current municipality of São Felix do Xingu, located in the physiographic area of the same name, was inhabited originally by first nations. The district was separated from the municipality of Altamira, former Xingu. With the development of rice production in shell, rubber, syringe and corn, the town prospered, and in 1961, emancipated political administratively.

## THE CARAJÁS PROJECT

The Carajás Project, officially known as Carajás Great Program (PGC), is a Project of mining exploration, started in 1970, on the richest mineral province on Earth at that time. It extends over 900,000 square kilometers, an area corresponding to one tenth of the brazilian territory, crossed by rivers Xingu, Tocantins and Araguaia which includes the southeastern lands of Pará, northern Tocantins and southwest of Maranhão. It was created by the Brazilian company "Companhia Vale do Rio Doce (CVRD)".

The PGC, officially launched in 1982, had the objective to accomplish the integrated exploration of mineral resources from that province, plentiful of minerals, containing high content of iron ore, gold, tin, bauxite, manganese, nickel, copper, and others. The lifespan of iron reservoir, estimated in 1980 decade, were about 500 years.


Figure 2 – Iron ore mine in Carajás - Source: Google Earth

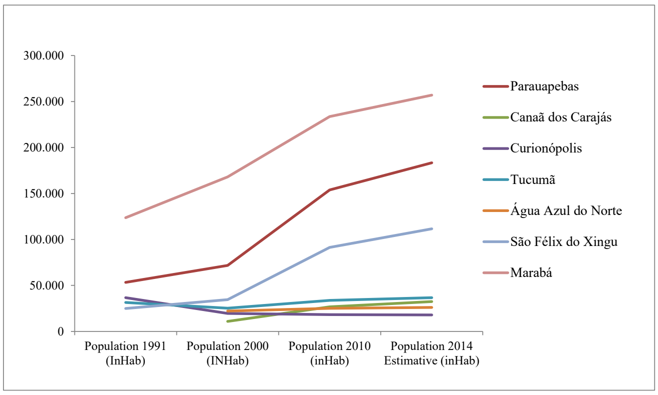
For the consolidation of this ambitious project, it was arranged a complete infrastructure system, that included the hydropower plant of Tucuruí, the Carajás Railroad and the Ponto da Madeira harbor located in Itaqui harbor, in São Luís/ MA.

Nowadays, the Carajás Project is one of the biggest areas of mining exploration in the world and their activities belong to VALE S.A, one of the major iron ore mining companies, that was privatized in 1997. Besides having the biggest reservoir of high content iron ore in the world, they are also explored manganese, copper, nickel, gold, bauxite and cassiterite.

The Project is settled on Parauapebas, which holds the ownership concession of the mining rights.

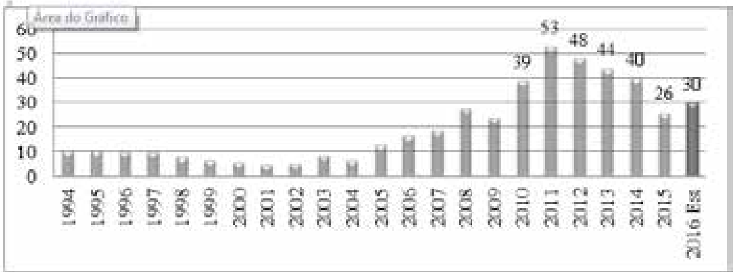
## SOCIO-ECONOMIC ANALYSIS OF THE REGION

Large projects of economic development conducted by the Government and/or by the private sector, with their new geographical objects (Santos, 2014) – areas of exploration, *company town*, hydropower, harbors, construction sites, increased and still increase the migratory process in Amazon region (Becker, 1989). In the case of the southeast of Pará, the population growth follows the same dynamic and has a direct link with the mining exploration and the migratory pressure stimulated by the Carajás Railroad (Graphic 1).




Graphic 1- Population Growth of the municipalities (Source: IBGE, 2015)

It is possible to observe at the Graphic above that the population growth occurs more forcefully in Marabá, Parauapebas and São Felix do Xingu. It is worth to mention the ascending curve of Parauapebas since from 2000, which corresponds with CVRD privatization, in 1997, and with the market *boom* of mining in Brazil, boosted by the demand of emergent countries, such as China (Graphic 2).



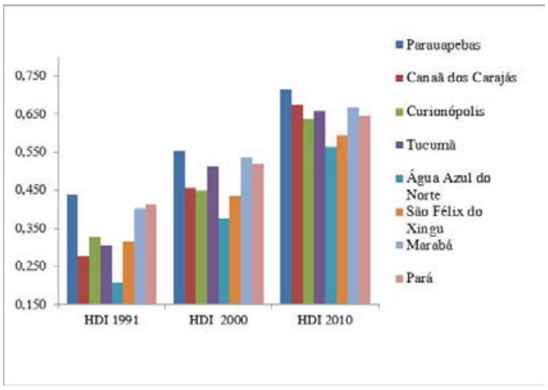

Graphic 2 – Evolution of Brazilian Mineral Production in USD billion (Source: IBRAM)

Parauapebas territorial space has being, at the same time, city-headquarters of VALE Company and the premise of several settlements of land reform government programs. The population flow relates largely with migrants from neighboring states, especially Maranhão, with low educational level, heading into the city with the expectation of obtaining employment and better quality of life (Enríquez, 2008).

Curionópolis, however, is the only municipality that has depletion in the total population, a fact that can be explained by the end of Serra Pelada artisanal mining and the subsequent granting of mining rights transferred to CVRD, which became the holder of the mining rights at the Serra Pelada region up to 2002.

Since the pre-exploration phase until the mine closure, the mining activity generates externalities, both positive and negative. On one hand, representing new opportunities for municipality where they are settled - economic growth and income internalization, that can be reversed in favor of the development of the local population – On other hand, demanding a previous planning set between the agents installed in the territory.

It is clear that the Carajás project influenced the socio-economic change in the region in question, from various perspectives. Based on the Human Development Index (HDI), it is possible to perceive an increase on it (Graphic 3).




Graphic 3– Evolution of HDI on the municipalities – Source: IBGE

When a city held a large mine, the economical dimension would be presumably highlighted. After all, it reflects directly in the dynamics of the local market, in the collection of taxes and compensations, on rents circulating in the economy, in the cost of living and in the economic well-being of the population. However, as said by Enríquez,

> If the economic dimension is a mining positive impact recognized by a significant part of society, it is also clear that the achievement of sustainability requires far more than the elevation of municipal GDP, since the negative economic impacts associated are also considerable, as the case of inflation, the rising prices of local goods and services and the cost of living in general (Enríquez et al., 2011, p. 9).

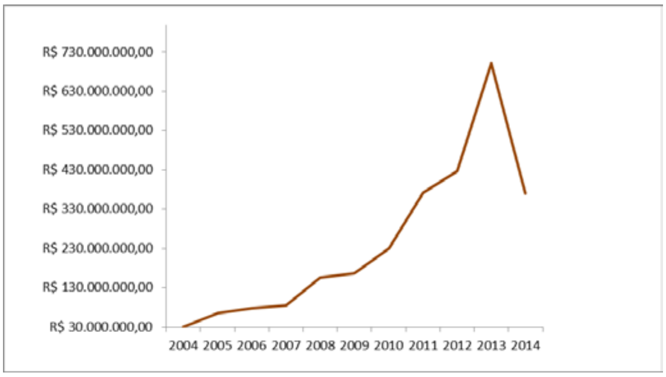
Specifically to Parauapebas this quote is in accordance with reality. Having the biggest HDI of the region, it also has the bigger GDP (Table 2).

Table 2- Evolution of the GDP in the municipalities – Source: IBGE

| **Municipality** | **GDP 2000 (Thousand R$)** | **GDP 2010 (Thousand R$)** |
|---|---|---|
| Parauapebas | 1.547.692 | 15.947.709 |
| Canaã dos Carajás | 27.757 | 1.563.173 |
| Curionópolis | 31.925 | 104.249 |
| Tucumã | 62.483 | 306.422 |
| Água Azul do Norte | 122.520 | 195.095 |
| São Félix do Xingu | 43.287 | 528.931 |
| Marabá | 572.172 | 3.562.534 |

But, under a regional approach, it is important consider that the GDP is value generating measure and not a value fixing one. In other words, the strong participation of the mining industry does not relate necessarily to the development of the territory. On the contrary, the economic segregation such as inflation and high cost of living, eventually forces those who are not absorbed into the mining industry to move to another city, which explains, in part, the worse economic and social indicators from the Parauapebas border cities. Besides, an increase on GDP does not mean, in most time, a better equity in income distribution, which can configured in a perverse growth for the city, with a high degree of income concentration, high GDP per capita and high poverty rate (Harvey, 2013).

It is important to mention the participation of the Compensation for Mineral Exploration (CFEM) in the total revenue of the municipality of Parauapebas (Graphic 4). CFEM is a royalty established by the Brazilian Constitution and it is due to the Union, States, the Federal District and the municipalities, as consideration for the economic use of mineral resources in their respective territories.




Graphic 4 – CFEM revenue tax in Parauapebas - Source: DNPM

The CFEM is an important source of revenue for the municipality of Parauapebas. It is worth to mention that the city also receives a diverse range of other revenues, directly and indirectly. In a linear analysis, considering only CFEM, the municipality had, in 2014, approximately R $ 2,000.00/inhabitant to be rolled back to the local community as infrastructure improvements, environmental quality, health and education. Therefore, it would be an inference that the municipality of Parauapebas, in terms of human development and quality of life, would possess high levels of these dimensions. However, using the environmental sanitation indicator as a reference, it is possible to perceive a disconnection between the revenue generated and the benefits collectivized by its collection (Table 3).

Table 3 – Served population with water supply and sewage in Parauapebas –Source: SNIS

| Year | Total Populaton (inhab.) | Total Pop. Served with Water Supply (inHab) | Percentage of Total Pop. Served with Water Supply (%) | Total Pop. Served with sewage (inhabitants) | Percentage of Total Pop. Served with sewage (%) | Volume of collected sewage ( 1.000 m³/year) | Volume of treated sewage (1.000 m³/year) | Percentage of treated sewage |
|---|---|---|---|---|---|---|---|---|
| 2006 | 88.519 | 63.905 | 72 | 16.440 | 19 | 188,52 | 188,52 | 100 |
| 2007 | 91.621 | 83.765 | 91 | 17.256 | 19 | 203,6 | 203,6 | 100 |
| 2008 | 95.225 | 111.645 | 117 | 16.830 | 18 | 646,3 | 646,3 | 100 |
| 2009 | 152.777 | 102.554 | 67 | 16.128 | 11 | 387 | 387 | 100 |
| 2010 | 153.908 | 102.525 | 67 | 16.128 | 10 | 1.209,11 | 1.209,11 | 100 |
| 2011 | 160.229 | 112.245 | 70 | 16.276 | 10 | 585,93 | 585,93 | 100 |
| 2012 | 166.342 | 132.901 | 80 | 17.380 | 10 | 625,15 | 598,65 | 95,8 |
| 2013 | 176.582 | 134.000 | 76 | 18.678 | 11 | 885,2 | 685,56 | 77,4 |

Of course, the analysis presented here has a simplistic view. After all, many other nuances are interrelated for the establishment of the current municipal conjuncture. However, due to the sizable and growing revenue flow, it is expected that certain structural problems, such as sanitation, health, education, for example, would be in a better situation.

In general, there is great ignorance about the principles and foundations on the use of CFEM by all those involved with the territory (private sector, public administration and civil society). There is a lack of transparency on the allocation of this instrument, a lack of commitment to its implementation and a narrow participation of society in the decision-making process related to the applicability of the resource.

In a regional perspective, it is worth to mention the possible pressure on public structures in the municipality of Parauapebas by the border towns. Health centers, hospitals, schools and local public infrastructure probably receives demands that goes far beyond their capacity, compromising the quality of such services.

## CONSIDERATIONS

In the case of large projects, the challenge of growing in a sustainable way is related to the fact that, often, the company is the main or only vector of development and source of income in areas that historically have urban infrastructure deficit, shortage of skilled labor, weakness in public management, complex logistics, low public service provision of education, health, sanitation, housing, safety etc. The region in question, composed of Parauapebas and its border towns, reflects this challenge.

As already mentioned, the analysis presented here does not have the necessary depth to understand all the particularities and issues, structuring or not, of the conjuncture. However, the inference lay on the basis of the technical studies made in the region (Enríquez, 2011, Trindade 2011, ICMM, 2012).

It is possible to identify impacts trends of large projects on the organization of these municipalities: i) rapidly changing population profile, from rural to urban, and specially due to the expansion of migratory flows; ii) speculation on the price of land; iii) pressure on public spending, with a view to the enhancement of the costs for the expansion of urban infrastructure to remote areas; and (iv) restrictions on the provision of public services (sanitation, education, health).

Add to this, the current mineral policy, which has been practically a continuation of the last twenty years. That is, focused on the generation of trade surpluses, instead of being drive to create development conditions to the mining industry in all their possibilities.

In Brazil, still exists a misunderstanding by all those involved. For one, companies that still operate much more on compensatory activities or motivated by the expectation of receiving some sort of incentive, than by an effective project of social empowerment, that in fact, can contribute to reducing disparities between large mine and local people. That is, from an understanding that does not absorb the social capital, social profit as an important asset (Enríquez et al., 2011). On the other, an unprepared and weak public administration still based on paternalism and clientelism and with little or no commitment to the collectivity. In addition, to a civil society voiceless and completely unaware of their rights.

The economic growth provided by mining can contribute effectively to the development of the regions in which they operate. But for this, it is necessary to introduce a new logic of coordination in order to face the challenges in the short, medium and long term. Therefore, it is necessary to strengthen the culture of collective construction between the three sectors - civil society, State, and companies.

There is an urgent need to overcome the fragmented and sectored logic of the traditional model of concentration for a new concept of local and endogenous development (Cabugueira, 2000) in order to overcome the needs of citizens, as explains Cabugueira,

> The new territorial development policy is intended to separate the imbalances by promoting the development of all territories with competitive development potential. Economic policy is based on a theory that proposes that the growth does not necessarily have to be polarized, but can be diffuse and proposes to develop a territory, using the existing potential in itself (Cabugueira, op. cit, p. 117).

That is, to address the existing deficits of urban inadequacy and to receive the migration flux due to the prospects generated is important to focus not only in the expansion of social infrastructure and urban infrastructure, but in a proper management of territorial development and in a changing of the organizational logic of the city/region.

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# MINING AS BASIS FOR THE 'ENERGIEWENDE' (ENERGY TRANSITION)

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## Mining as basis for the „Energiewende" (Energy transition)

24th World Mining Congress
MINING IN A WORLD OF INNOVATION
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# Mining as basis for the „Energiewende“ (Energy transition)


## Abstract

Mining is the fundament for the necessary turnaround of the energy supply all over the world. Mining is more than searching for and the production of coal, iron-ore or copper. Not just in the renewable power generation with wind and solar but particularly for smart grids and energy storage a lot of additional and sometimes rare metals are necessary. On the one hand there is classical mining with all its experiences and optimization potential. On the other hand there is more and more development in smart mining, recycling and urban mining. We are bound to follow up our social as well as our economic responsibility and more: The ethical quality of our systems and products. We must retain life quality, supply elementary requirements to the public and prevent damages to our environment in accordance in the sense of products and its contribution towards optimising life quality for all men: In environmental control, in retaining a high standard of economic activities, in contributing to the health of men and beast and in creating new jobs.


## Introduction

Since hundreds of years Germany has a strong mining industry. This has led to excellent and worldwide know how acknowledged by mine-operators, suppliers and mining-universities. Due to difficult geological situations, very high population density in the Ruhr area, the stringent environmental requirements and high economic pressure: innovation, reliability and safety shall be the key to success. So, many mining inventions from Germany have been accepted worldwide.

The mechanization, marked by the development of the coal plow (1937) and the drum shearer (1954) or the introduction of overhead monorail systems (1955) to the first 500-meter longwall face in 1990 German innovations were always at the forefront of development.

Although the focus on environmental protection became even stronger in recent years, work safety and social acceptance of mining, German mining equipment continues to be highly innovative. This goes especially for the digitalisation of mining processes with millions of databits sent per shift, recorded and used during every turn to optimize and automate the operations. The innovative power and joy of design is also true for mining-related areas such as urban mining and recycling, "heat mining" for the use of geothermal energy and for use in tunnel and infrastructure construction.

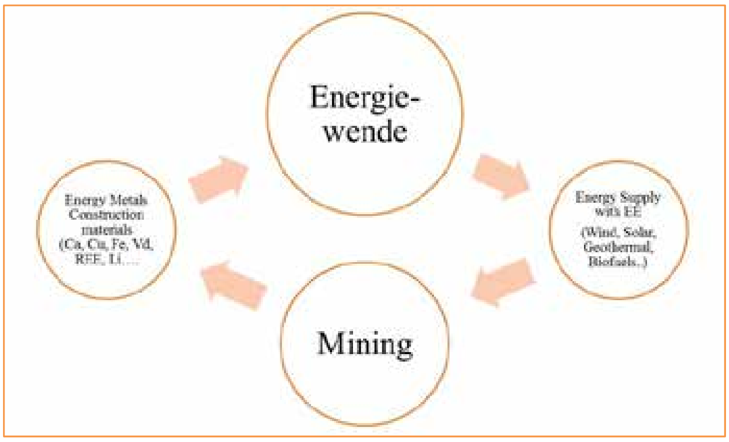


Fig.1: Energiewende – Mining –Cycle

## Energiewende (Energy Transition)

A new challenge for the German economy brings the political decision for the “Energiewende”, the phasing out of nuclear energy and in the long term from burning of coal as fuel. The implementation of the EEG (Renewable Energy Act, 1991) laid the foundation for the reconstruction of the coal-based power generation in Germany. Some might have thought that the end of the German mining industry is in sight. It is true that coal mining will phase out until 2018. But the lignite mines produce about 150 Mt/a and will be going on operating for the next decades in Germany. Whether next to the classical use of coal also coal liquidation is resumed, also depends on the developments in the world market. Germany is preparing itself to bring the coal away from being burnt and rather be used as a chemical feedstock.

But the end of the coal combustion is foreseen both in Germany and worldwide. The climate conference in Paris has paved the way in this direction. Whether this goal can be achieved in 10, 30 or 100 years, is not part of this article. Here it comes out the significance especially for the earlier strong coal embossed German mining. The active underground-coal mining in our deep pits ends in Germany by 2018. Although coal is important it is only one of many elements in the power generating and supply. The energy consumption will continue to grow worldwide. The expansion of renewable electricity generation represents an enormous challenge. By electromobility and "Power to heat" the importance of electricity will continue to increase. Many metals that were previously unavailable or only little used, will be irreplaceable. Already involved in the energy supply are more than 60 metals. This also places greater demands on the extractive industry - both in mining and in the recycling area.

Armin Reller /1/ from University of Augsburg (Germany) quotes, that “Securing future energy supply requires a critical awareness of the functionality, availability, substitutability and recyclability of the metallic resources. Uncontrolled ecological and adverse socio-economical impacts, as well as creeping dissipative losses, have to be minimized. Therefore it is necessary to help decision makers understand the nature of the valuable materials and metals extracted from the earth’s crust and what defines the continuation of sustainable supplies. Fortunately, metals can be both used and reused – they do not ‘die’.”

Following basic materials are always required for all types of renewable power generation:

• concrete for foundation work

• steel for the structure

• copper for electric coils and wires

Depending on the energy sector there are some mining products that are needed in the three key areas of the energy transition in a special manner. The resources for these metals are described below :

## Wind

The wind use generally requires the construction of steel towers on which the generators are fixed at the top. These convert the mechanical energy of the rotating blades into electricity. Here the rotor rotates by strong magnetic fields in the stator. These magnets are built either as a large copper coils or permanent magnets. These are rich in rare earth - especially neodymium, praseodymium and dysprosium. The majority of systems based on rare-earth are currently manufactured and installed in China. Rising and badly calculable prices due to the virtual monopoly China's rare earths are incentives for further development of generators with reduced material requirements. Two types of wind turbines for commercial power generation are in use: with gear or direct drive of the generators. Increasingly, wind turbines are built with direct drive. These are gearless systems that offer higher reliability and lower maintenance costs. Both aspects are important efficiency factors for wind turbines, especially in offshore applications. The gearless systems require larger permanent magnets and therefore a higher demand for rare earths.

## Solar

There are currently three technology approaches to use solar energy: photovoltaic (PV), solar thermal and solar thermal power plants (CSP).

- Photovoltaic cells convert solar energy directly into electricity. The two main types of buildings are one hand crystalline silicon cells, which make up about 90% of the world market, and for thin-film technology. Here a shortage could occur due to estimations by the German Wuppertal Institute /2/. Especially the demand for indium reaches a critical magnitude. If the market share of this technology remains like it is today from 26 up to 130 tons of indium is used for the production of solar modules by 2050. These are 0.2 to 1.2 percent of total global reserves. Add to that the competition of LCD manufacturers, which use indium as a transparent conductor in flat panel displays and touch screens. A third critical point is the dependence on China which is currently the only relevant supplier of indium. In addition to the possible scarcity of indium other ingredients of the PV thin-layer technology as gallium, arsenic, cadmium, tellurium, copper and selenium must be kept in mind with respect to their availability.
- Solar thermal is mainly used for water heating in domestic technology. For this purpose copper and zinc are mainly used.
- CSP systems concentrate the sun's energy, convert it into steam or store the generated heat in a tank. The steam is used either directly or by means of heat exchangers. The stored energy is converted into steam, which drives turbines and generators. The solar reflectors made of highly polished surfaces, which are typically coated with aluminum or silver. The supply of raw materials is not expected no have bottlenecks. Meanwhile plants in Spain with 200,000 parabolic mirrors reach a capacity of 50 MW.

## Network (Grid and Storage)

The majority of renewable electricity in Germany is produced by huge wind farms in the North and Baltic Seas. It has to be transported to the consumers in southern Germany and into the European. The high voltage transport lines and the distribution grid have to be expanded and partially re-be built. The demand for raw materials for the power poles requires large amounts of steel and aluminum. For the lines mainly copper is needed. The volatile electricity generation from wind and PV systems requires demanding switching and control systems and the development of energy storage systems. Besides physical pumped storage and compressed air systems, especially the chemical battery storage as vanadium redox or lithium-ion cells are relevant from the mining perspective. The raw material supply for the current standard redox flow batteries vanadium based is considered as critical /2/. In particular there is a great use of competition as vanadium is a critical alloying element e.g. for tool steels. In contrast, there are China, South Africa and Russia only three relevant producing countries. Until 2050, in Germany storage features will be installed with a total capacity of 52 gigawatt hours. Most of the storage will be done by lithium and redoxflow batteries. In this scenario, the expansion of lithium demand would amount to 3.12 to 6.24 kilotons, which would correlate from 0.024 to 0.48 percent of global lithium deposits. Thus the Wuppertal Institute does not expect raw material shortages.

The redox-flow technology could, however, come up against their limits as long as the rare vanadium is used as an electrolyte. Because then 81-162 kilotons of the rare transition metal would be needed to 2050. "This would correspond to 0.58 to 1.16 percent of vanadium reserves and is classified as critical," the study's authors warn /2/. There is also the strong competition for vanadium similar to indium needed for other industries. Thus, vanadium is not only an important alloying element for tool steels, but also a catalyst in the production of sulfuric acid. From the perspective of resource availability for short-term storage, the less critical lithium-ion batteries or physical storage (pumped storage power plants, compressed air storage) should be used. This is true until no redox flow batteries with vanadium-free or -reduced electrolyte for the same purpose are available. Appropriate alternatives are under development. But it cannot yet be estimated, if and when they will prevail on the market. For the researchers in particular the scalability to large loads and the storage capacity are as a priority.

A second field of investigation is the development of HVDC networks (high voltage direct current systems) with more than 1,000 kV. This technique previously used mainly on very long distances or for connecting offshore wind farms requires the use of tin, silver-plated copper and aluminum.

## Urban mining and recycling

The collection, sorting and recycling of manufactured products emerged in the late 20th century from an occupation on the edges of society to a fashionable profession. Yesterday's scrap men have become the environmentally sensitive recyclers of today and business is booming. Although every case must be examined on merits, especially energy balance, there may be compelling reasons to re-use refined materials in preference to extracting new ores and proceeding along the lengthy and often energy-demanding route of beneficiation, concentration, smelting and refining. The percentage of demand that can be met by recycling varies greatly from material to material and through time. Supply constraint has often increased efforts to recycle, as has been well demonstrated in times of war. Conversely part of the peace dividend at the end of the Cold War resulted in the dismantling of thousands of nuclear weapons and the recycling of sufficient uranium to supply about 13% of the nuclear power industry's needs between 2000 and 2012. As the cost of materials, especially the energy required to produce them, the cost of waste disposal, environmental awareness and associated legislation all increase, the future for recycling appears positive.

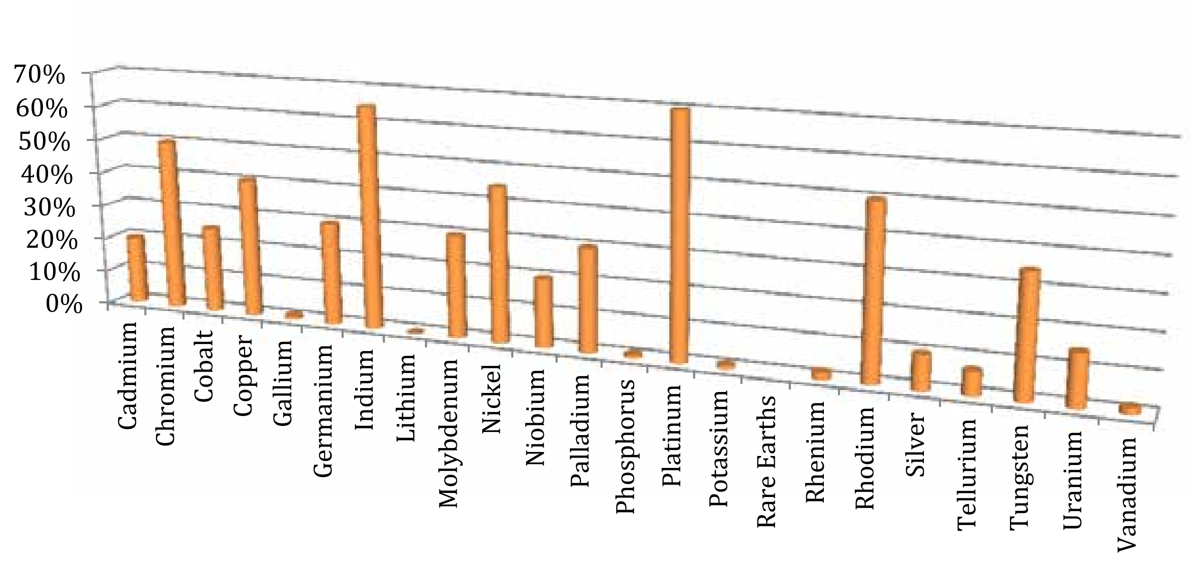


Fig. 3: Recycling Rates of some Energy Metals, /3/, /5/

As part of the energy transition other mining commodities gain in importance. In addition to sand and cement, these are mainly copper and rare earths. With sand and cement Germany is self-sustaining or concerning potash and sulphur even an exporter. For the wind power plants onshore and offshore and for the construction of electricity networks and energy storage copper is essential. Although there are no significant copper mines, Germany is the third largest copper producer in the world, due to a high recycling rate of almost 50% with 676 million t/a. Another important issue for the success of the mentioned German energy transition, in particular for storage technologies, electrical mobility and the supply with rare earths. There are approaches to realize commodity alliances or the development of partnerships in recycling activities to ensure an independent and reliable supply.

Currently, there is no optimized recycling process for the power electronics in electric mobility. Furthermore, the composition of the ingredients will change as the technology develops further. Therefore, flexible solutions are needed in the recycling process. Aside from a future use of gallium nitride, it is likely that power electronics will continue to contain precious metals like gold and silver as well as other technology metals like tantalum, indium or germanium.

For gallium and other technology metals, recycling processes currently only exist for production waste materials from the semiconductor and photovoltaic industry, where these materials exist in a concentrated and very pure form /4/. The EU Commission considers the supply situation of many of these economically significant raw materials to be critical.

## Example for Urban Mining at Rammelsberg/Goslar

The old mine Rammelsberg in Goslar meanwhile has been appointed world heritage. Since centuries metals, especially silver have been mined until 1988. Material from the rock treatment was discontinued in the so-called tailings ponds . Today the TU Clausthal tries to map the approximately 7 million tons of sedimentation sludge. The mining residues have been conducted earlier in the ponds. Low concentrations of metals and other valuable materials were included, which are increasingly important today. In addition there are estimated 180 tons of gallium, 1,000 tons of cobalt and other economical interesting metals. According to first analyzes the thick layers of sludge 100 tons of indium are expected, which are particularly interesting.

## Resumee

The mining suppliers in Germany have gone through difficult times. Firstly, due to the decline of the German coal production and because of low global commodity prices. But the strong medium-sized mining supplier are well positioned to compete globally due to their centuries of experience combined with innovation, creativity and customer focus. In order to bundle this know-how, the state government of Northrhine-Westphalia has launched the *network smart mining*. Actual and future technologies for mining suppliers are supported. One focus is in the field of recycling combined with sophisticated technical solutions for bound metals. A second field of activity is in the field of urban mining and the treatment of former mining sites with modern methods .

In addition to outstanding mining and materials handling technology both on the surface and underground, the more than 600 network members possess extensive expertise in the fields of industrial safety, environmental protection and post-mining. The task is to discuss all issues relating to sustainable and socially acceptable mining with the mining companies and contribute the experience from NRW. In the network competences are pooled, strength is concentrated to the advantage of customers throughout the world. The Network Mining represents a catalyzer for making contact between German companies on the one hand as well as functioning as an access point to customers all over the world.

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# MINING CONTRIBUTION FOR THE MUNICIPALITIES DEVELOPMENT

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# MINING CONTRIBUTION FOR THE MUNICIPALITIES DEVELOPMENT

## ABSTRACT

Mining activity in Brazil has significantly contributed to the country development. However, not always this contribution is fully noticed by society. This study aims to bring more evidence to this mining activity contribution, based on highly regarded development indicators, such as the Human Development Index (HDI), created for the United Nations Development Programme (UNDP). The HDI was traditionally designed as an instrument to evaluate the degree of countries development and was subsequently deployed to states and municipalities. Thus came the Municipal Human Development Index (IDHM) released by the UNDP and the FIRJAN Municipal Development Index (IFDM) released by the Federation of the Industries of the State of Rio de Janeiro. The statistical proofs show that the average of the municipalities where there are mining activities have superior development indices than the others, especially in the two major mining states: Minas Gerais and Pará.

## KEYWORDS

Mineral activity, human development, IDHM, IFDM

## INTRODUCTION

Brazil is the holder of one of the world's largest reserves of metallic and non-metallic minerals (Barreto, 2001). Brazil's largest mining companies are also among the world's largest mining companies, with the major part of their production destined for export. Mining industry has significantly contributed, directly and indirectly, to Brazil's economy. According to the Brazilian Mining Association (IBRAM), mining contributes "around 5% of the industrial GDP of the country. In Foreign Trade, mining industry contributed more than US$ 34 billion in mineral exports" and has also provided a "multiplier effect of up to 13 indirect or induced jobs; That is, almost 2.7 million workers involved in some way with the mining activity "(IBRAM, 2015).

This research aims to quantify the contribution of the mining activity in the development of the municipalities that have this type of activity in its territory, using the Human Development Index (HDI) as a measure. Created for the United Nations Development Programme (UNDP), the HDI was traditionally designed to evaluate the degree of countries development, consolidating since the 1990s as the best known indicator for such purposes (SAGAR et al., 1998; TORRES et al., 2003).

Subsequently, the HDI has been adapted to states and municipalities, giving rise to the Municipal Human Development Index (IDHM), published by the UNDP, and FIRJAN Municipal Development Index (IFDM), published by the Federation of the Industries of the State of Rio de Janeiro. The IDHM is calculated from data on income, longevity and education census conducted every ten years by the Brazilian Institute of Geography and Statistics (IPEA / IBGE / FJP / UNDP, 1998). On the other hand, IFDM is updated through government official employment, income, health and education data, which provides an annual disclosure of this indicator (FIRJAN, 2014). The two indices range from 0 to 1. The closer to 1, the higher human development.

The HDI metric indicates that Norway and Australia are two of the most developed countries of the world, both have a significant share of the mining activity in GDP. Thus, we use the IFDM and IDHM to verify through statistical evidence if the municipalities that have mining activity have a development index superior to the others. Here it is considered that the mining municipalities are those which have collected the Financial Compensation for Exploration of Mineral Resources (CFEM) in the last 6 years (2010-2015) (DNPM, 2016).

The paper is organized in two stages. The first used hypothesis test with a 95% significance level to verify if the municipalities that have mining activity (in this paper referred to as "mining cities") have development indices superior to other municipalities. In the second stage, it will be demonstrated through histograms, in which percentile are located the main mining cities of the two major Brazilian mining states, accounting for 80% of CFEM collected over the past 6 years (2010-2015), showing how the main mining municipalities are positioned in these two states.

## METHODS

This research aims to test whether there are significant differences in the IDHM and IFDM indicators means of mining cities, comparatively to non - mining districts of Brazil, with a 95% level of significance, that is, if the mining cities have better performance in these indicators in average when compared with other municipalities.

The material used in this research refers to the registration of IDHM (2010) and IFDM (2013) of municipalities with mineral activity versus municipalities that do not have mining activity. The importance of the participation of the mining activity in municipal revenues is an indicative of the mining participation degree in that municipality. The groups were divided into centiles (10th centile, 5th centile, 1st centile and all municipalities that have collected CFEM for the last six years) gathered by revenues of Financial Compensation on Mineral Resources (CFEM) in relation to the total revenue collected by the municipality, on average, in the period from 2010 to 2015. Thus the groups consider all mining municipalities, which have relevance above 1%, 5% and 10% of CFEM compared to the total revenue of these mining cities, as informed on the balance sheets disclosed in the National Treasury Secretariat website (STN).

In order to test whether the means of these indicators are the same or different, the T-test was developed for independent samples, which requires the normality of the data distribution and homogeneity of variances. Thus, data were submitted to normality test using Kolmogorov-Smirnov and Levene tests to assess whether the variances are homogeneous. In the case of evidence to reject the null hypothesis, then, it is concluded that the indicators fit the non-parametric Mann-Whitey statistic, which is used to test the equality of means when the assumptions of normality are violated.

## RESULTS

### Results of statistical tests

To test the hypothesis that municipalities with mineral activity have development indices superior to other municipalities, the averages of the two development indices covered in this research (IFDM and IDHM) were compared in four mining presence levels according to the collection of CFEM of last 6 years by revenue. In all comparisons, both IFDM as in IDHM, the mining cities averages were higher than non - mining, moreover, there was an increase in development rates in both indicators, as it increases the participation of CFEM in municipalities revenue as shown in table 1 and 2.

**Table 1 - Municipalities IDHM Average**

| Mining Municipalities Classification | Non-Mining | Mining |
|---|---|---|
| All | 0,6443 | 0,6772 |
| 1° centile | 0,6584 | 0,6803 |
| 5° centile | 0,6590 | 0,6824 |
| 10° centile | 0,6590 | 0,7156 |

**Table 2 - Municipalities IFDM Average**

| Mining Municipalities Classification | Non-Mining | Mining |
|---|---|---|
| All | 0,6319 | 0,6744 |
| 1° centile | 0,6502 | 0,6763 |
| 5° centile | 0,6508 | 0,6878 |
| 10° centile | 0,6508 | 0,7281 |

To confirm the statistical significance of the superiority of human development average of mining municipalities, the normality of the data were tested to see which statistical test is most appropriate for this data profile through its probability value (P-value). Tables 3 and 4 confirm the data are not normal, and table 5 and 6 that the averages are not homogeneous.

Table 3 - Kolmogorov-Smirnov Test (P-value) applied to IDHM

| Mining Municipalities Classification | Non-Mining | Mining |
|---|---|---|
| All | 0,0000 | 0,0000 |
| 1° centile | 0,0000 | 0,0180 |
| 5° centile | 0,0000 | 0,1660 |
| 10° centile | 0,0000 | 0,2000 |

Table 4 - Kolmogorov-Smirnov Test (P-value) applied to IFDM

| Mining Municipalities Classification | Non-Mining | Mining |
|---|---|---|
| All | 0,0000 | 0,0000 |
| 1° centile | 0,0000 | 0,0130 |
| 5° centile | 0,0000 | 0,0300 |
| 10° centile | 0,0000 | 0,0690 |

Table 5 -Variance Test (P-value) applied to IDHM

| Mining Municipalities Classification | Brazilian Municipalities |
|---|---|
| All | 0,0000 |
| 1° centile | 0,0000 |
| 5° centile | 0,0810 |
| 10° centile | 0,0010 |

Table 6 - Variance Test (P-value) applied to IFDM

| Mining Municipalities Classification | Brazilian Municipalities |
|---|---|
| All | 0,2300 |
| 1° centile | 0,0000 |
| 5° centile | 0,5370 |
| 10° centile | 0,1650 |

As the normality of the data was not confirmed, the nonparametric Mann-Whitey was used, which confirmed that indeed the mining cities have higher development indices, measured by IDHM and IFDM at a 95% significance level, in the four levels of mining influence, as shown in table 7 through the probability value (P-value).

Table 7 - Mann-Whitey Test (P-value)

| Mining Municipalities Classification | Municipalities |
|---|---|
| All | 0,0000 |
| 1° centile | 0,0000 |
| 5° centile | 0,0270 |
| 10° centile | 0,0000 |

**Positioning of the main mining cities in Minas Gerais and Pará**

Both states of Minas Gerais and Pará account together for 80% of the Brazilian CFEM collection in the past 6 years (2010-2015). It can be seem that the miners municipalities occupy a prominent position in these states. The most important mining municipalities (91% of revenues) in Minas Gerais are positioned in the percentile 91 in IDHM and also 91 in IFDM distribution of mining municipalities. In Pará the most important mining cities (90% of revenues) are positioned in the percentiles 93% in IDHM and 94% in IFDM distribution of Pará municipalities. These results are shown in the histograms of Figures 1 to 4.

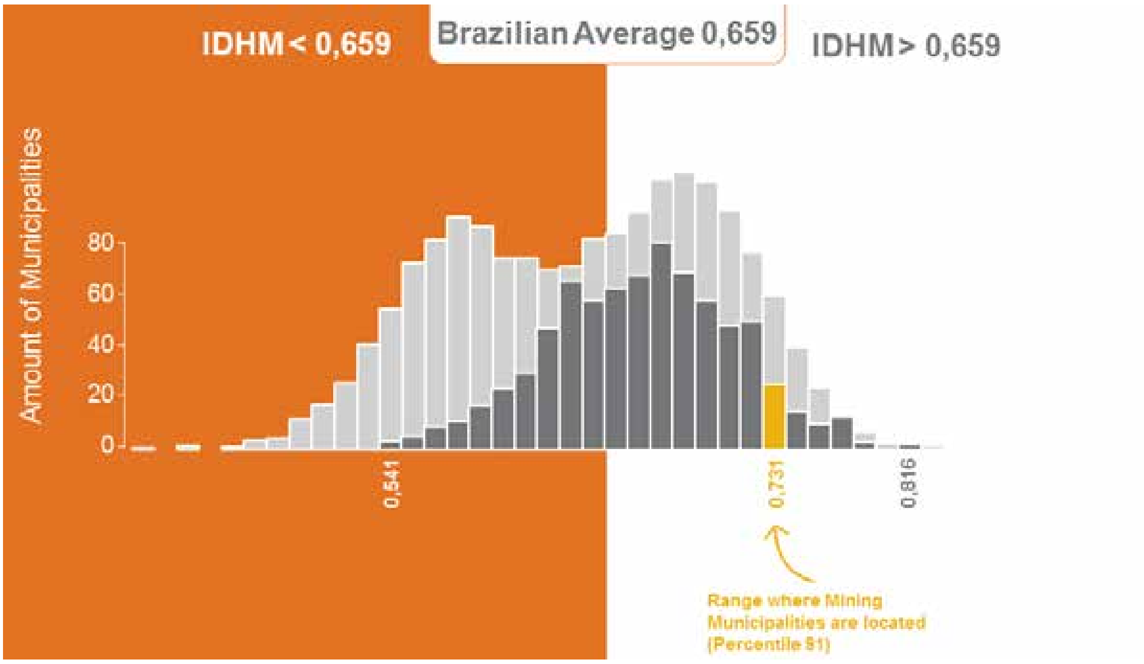


Figure 1 - Distribution of Minas Gerais municipalities by IDHM

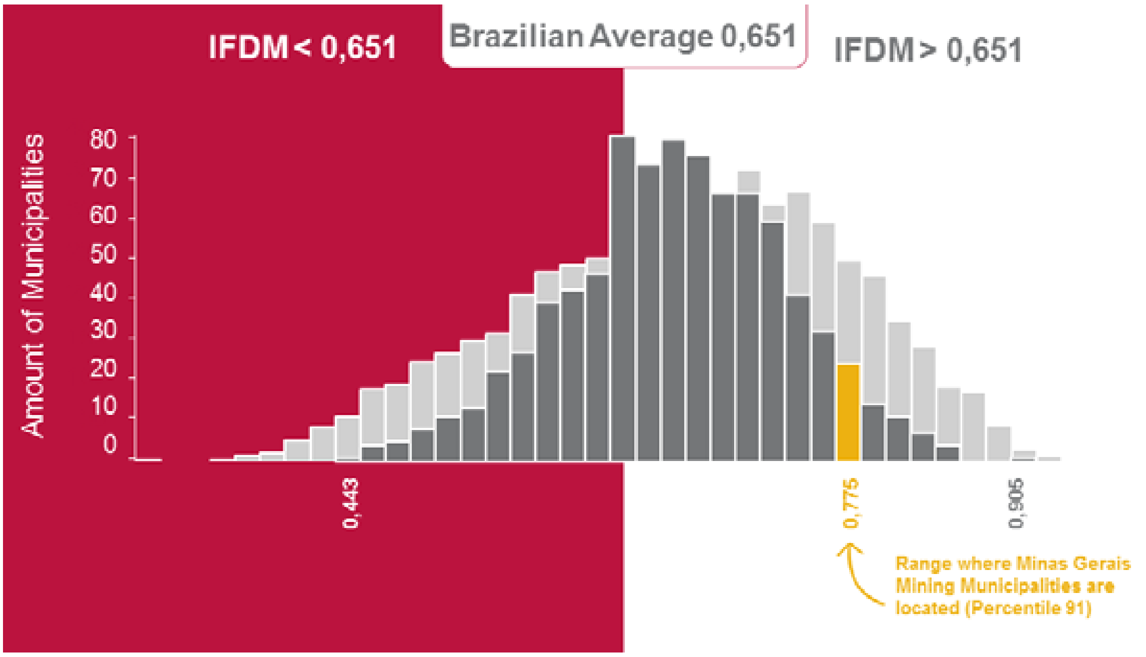


Figure 2 - Distribution of Minas Gerais municipalities by IFDM

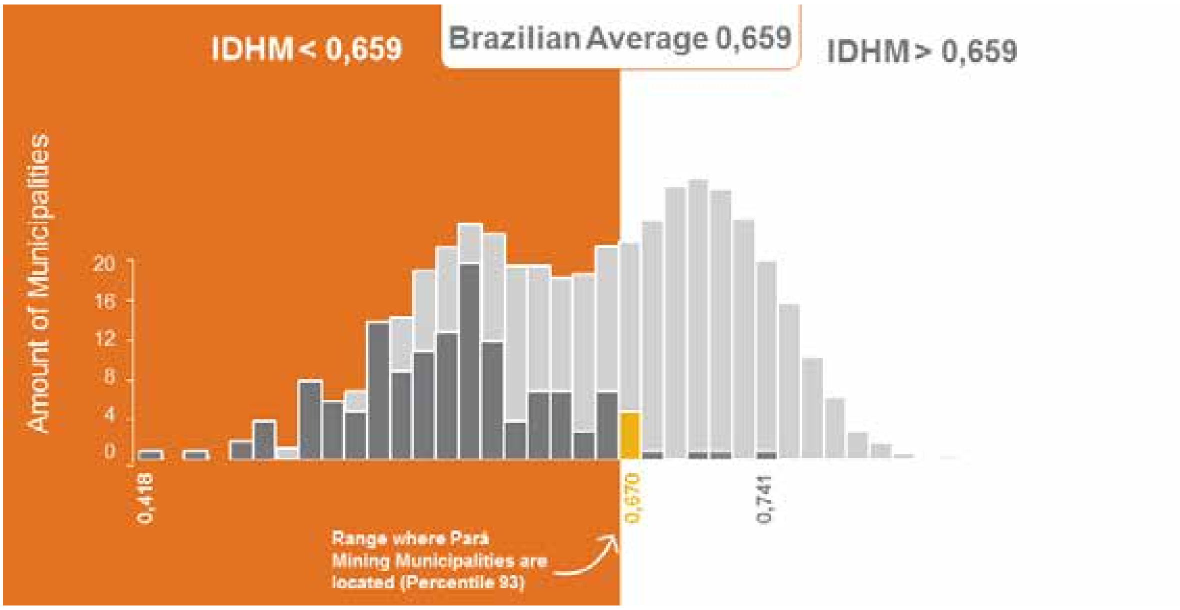


Figure 3 - Distribution of Pará municipalities by IDHM

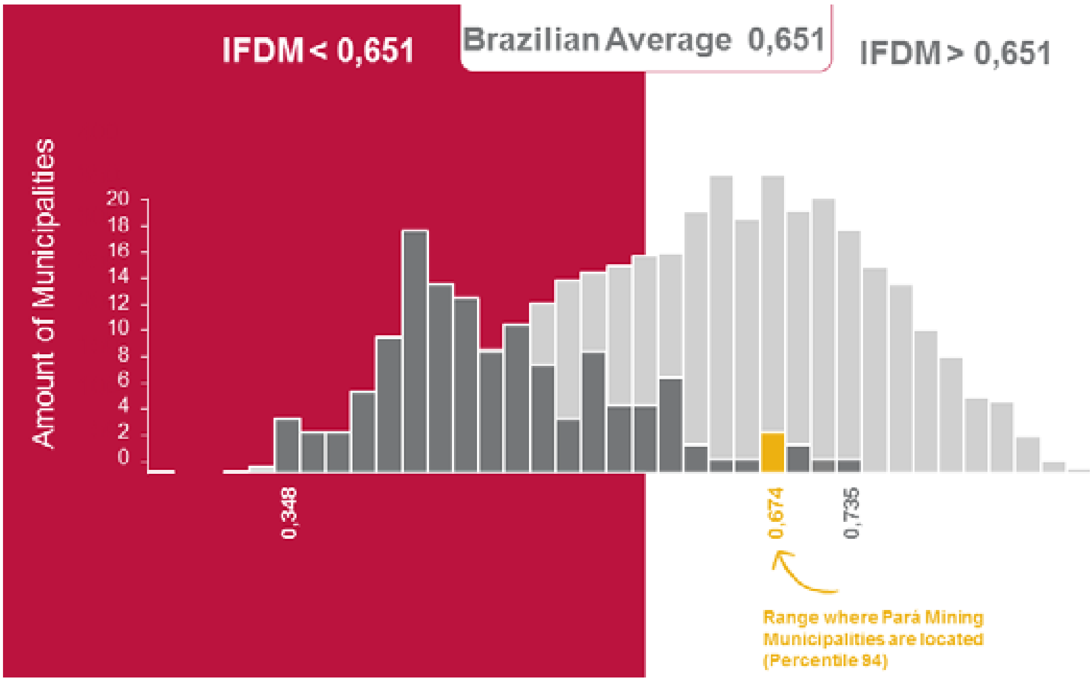


Figure 4 - Distribution of Pará municipalities by IFDM

**CONCLUSIONS**

This study analyzed the contribution of mining activities for the development of the places where it is present, especially of Brazilian municipalities. For this analysis, 2010 IDHM and 2013 IFDM development indicators were used, applied in municipalities where there are mining activity and identified through the collection of CFEM published by DNPM.

The hypothesis that mining municipalities have higher rates of development than other municipalities was tested in four levels of mining influence, according to CFEM representation in relation to their total revenue. The result of the research was that the mining cities are more developed than non - miners in all four levels of influence, in IDHM as well as in IFDM to a statistical level of significance of 95%. It was also found that the average on both indicators increase as you increase the level of mining influence.

The human development superiority of mining cities is more evident in the states of Minas Gerais and Pará, responsible for 80% of Brazilian CFEM collection over the last 6 years (2010-2015), where in both states the main mining cities of each one (responsible for 90% of the collection over the last 6 years) are located above the 90th percentile of the distribution of the cities from these states.

It is noteworthy that the factors analyzed in this study only explain the part related to the influence of mining activity. There are other variables, such as public administration, culture, history of the city, among other factors, which also influence to a higher or lower human development index.

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# MINING OF CRITICAL AND STRATEGIC METALS IN SOCIALLY AND ENVIRONMENTALLY SENSITIVE AREAS IN NAMIBIA

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# MINING OF CRITICAL AND STRATEGIC METALS IN SOCIALLY AND ENVIRONMENTALLY SENSITIVE AREAS IN NAMIBIA


## ABSTRACT

Namibia has a rapidly growing minerals industry and is a primary source for numerous valuable commodities, among which are many strategic metals; rare earth elements, tantalum and niobium. The insatiable global demand for such critical and strategic elements can therefore give Namibia an opportunity to become a major player in the market. The country has adopted a mining friendly policy that can attract investments and encourage the development of mining projects. Alongside this, some areas in Namibia are sensitive in terms of cultural heritage both socially and environmentally, whilst tourism grows as part of the competitive industry sectors. Thus, the potential exploitation of rare earths and respective metals may raise issues due to the presence of radioactivity, the use of hazardous chemical compounds and the treatment of their tailings. Under such controversial circumstances, future mining plans require thorough assessments and closer considerations with respect to the special boundary conditions that govern this specific sector of the mining industry. This paper investigates the mineability of three different deposits that are located in respective sensitive areas in Namibia with the use of evaluation indicators. Furthermore, suggestions are made in order to ensure the sustainability of the mining projects while fully satisfying the competing industries and preserving the environmental and cultural balance.



## KEYWORDS

Rare earth elements, niobium, strategic metals, environmental sustainability, mining in Namibia.


## INTRODUCTION

The Namibian economy relies heavily on its mining industry. In recent years this industry sector has been growing constantly, based primarily on diamonds and uranium production. Nevertheless, numerous exploration projects have revealed significant resources of other valuable commodities as well, which attract economic interest and have the potential to be exploited. Among these commodities are many strategic metals; rare earth elements, tantalum and niobium. Thus, an opportunity arises for the country to become a major player in the market of precious raw materials and strategic metals.

On the other hand, Namibia is a land with diverse characteristics; rich cultural heritage, stunning landscapes, its wildlife and large areas of unspoiled wilderness. There are currently 20 state-run protected areas comprising almost 17% of the country's total land area (Ministry of Environment and Tourism of Namibia, 2010). These protected areas are a centrepiece of Namibia's tourism industry, which in turn sustainably supports the country's economic development. According to the World Travel & Tourism Council (2015), the total contribution of tourism to GDP was 14.8% in 2014 and is expected to grow by 7.2% per annum by 2025. Tourism is a long-term activity with environmental impacts that are more easily controlled. Farming is the second most important industry and many Namibians work in this sector. Some have jobs on ranches where cattle and sheep are raised. Fishing is also a key sector, contributing approximately about 5% to GDP (Namibian Statistics Agency, 2016).

Nevertheless, the fundamental difference between mining and other industrial activities is that mining plants cannot choose where they will be located; they must be established at the site where the orebody containing the mineral is. This introduces a tension between mining and sensitive areas: if an economically attractive mineral deposit occurs in or near a sensitive area, should it be exploited? Such projects provide employment and business opportunities to local communities and may provide the option to remediate legacy sites. However, improperly managed activities can adversely impact the environment and the people living in that community. The mining industry is widely seen as dirty, polluting and unsafe. This image is always engraved in both developed and marginal communities and always puts the industry at a disadvantage compared to other industries which are seen as more glamorous. The major challenge is how the minerals industry can improve its economic capital without decreasing the environmental capital.

Such a discussion has been ongoing on the occasion of uranium mining and processing in Namibia. This discussion will be expanded in the potential exploitation of other valuable commodities as well; tantalum, niobium and rare earth elements (REE). Social concern is evident when it comes to rare earths and the environmental problems in China due to their extraction (Barakos & Mischo, 2015). Arguments are growing even bigger when potential mining of REE deposits is planned to take place in socially and/or environmentally sensitive areas. This paper introduces three case studies of economically interesting deposits in respective sensitive areas in Namibia, where the above mentioned strategic metals are being explored. The mineability of the deposits is investigated and suggestions are made in order to preserve the biodiversity and maintain the cultural balance of these areas.

## OVERVIEW OF MINING IN NAMIBIA

The mining industry brings in half of Namibia's foreign earnings, thus being the biggest contributing sector to the economy in terms of annuity, having generated revenue of NAD21.61 billion in 2014 (≈ US$1.37 billion). Mining accounted for approximately 11,6% of the GDP in 2014 (Chamber of Mines, 2016). Almost half of revenue is being generated from the diamond mining subsector, while uranium mining holds a significant percentage as well. For the past 2 years, the Fraser Institute has ranked Namibia as the second best country as an investment friendly destination in Africa. In 2015 Namibia toppled Botswana in rankings and is now seen as the best investment friendly destination in Africa.

Namibia supplies nearly a third of the world's output of diamonds. Namdeb is the largest diamond producer in the country. The majority of production is done with marine mining, along the coast and a few km west into the sea. Diamonds are also found in the deposits of old river beds. The main diamond region today is in the south around Oranjemund, where the authorities established the *Sperrgebiet* (Prohibited Area), limiting entry to the entire region to licenced miners, prospectors and their labourers.

Simultaneously, Namibia is the world's fifth-largest producer of uranium, holding 5.8% of global production (World Nuclear Association, 2015). There are two significant uranium mines capable of providing 10% of world mining output (Langer Heinrich; Rossing), while a larger mine (Husab) is set to start production in the near future. All uranium mines are located in national parks in the Erongo region.

Other than diamonds and uranium, Namibia produces other commodities as well. Special high-grade (SHG) zinc production is taking place in the Skorpion Zinc Mine near the southern town of Rosh Pinah. Regarding gold production, the Navachab mine, owned by QKR Corporation Ltd. and located near the town of Karibib, was the only industrial gold operation in Namibia until recent years. In other developments, the Canadian domiciled B2Gold Corporation started mining activities at the Otjikoto mine by the end of 2014. Moreover, dimensional stones, blister copper and lead concentrate production are other important mining activities in Namibia according to the Chamber of Mines.

There is strong government support for expanding uranium mining and some interest in using nuclear power. The Namibian Uranium Association (NUA) was established with the aim of enabling senior executives in Namibia's uranium industry to shape the context in which their industry operates. The NUA is acting to ensure that all parties directly involved in uranium mining and processing – including operators, contractors, and regulators – strive to achieve the highest levels of excellence in these fields of management. The Namibian Uranium Institute (NUI) supports the NUA's commitment to sustain a strong safety culture, based on a commitment to a framework of common, internationally shared sustainable development principles, The NUI is a member of the World Nuclear Association and is financially supported by the Namibian Uranium Association (NUA).

The Namibian mining-friendly policy has resulted in the initiation of numerous exploration projects along the country. Exploration is not only focused on uranium and diamond resources, but on other significant minerals and metals as well. Rare earth elements, niobium and tantalum are among the commodities that have been found in Namibia and exploration has revealed some remarkable resources. Among the exploration sites that have attracted interest are the three case studies that are investigated in this paper and that are discussed below. Two of the case studies deal with rare earth element deposits (Lofdal, Dicker Willem) and the third projects regards to a tantalum-niobium deposit (Epembe). All three projects have been granted with Exclusive Prospecting Licences (EPLs) with exclusive rights to the respective lands. The exclusive rights are granted only for the minerals specified in the licences.

## SENSITIVE AREAS IN NAMIBIA

There is no established definition of what constitutes a sensitive area. Different words and phrases are used, almost interchangeably at times that imply sensitivity, but may not mean it in the strict ecological sense. An area can be susceptible in terms of cultural heritage preservation as well. Environmental sensitivity means that one or many components of the area in question are vulnerable to change, pollution or interference of any kind. The uniqueness of an area may as well be attributed to the presence of other -competitive to mining- sectors of the economy; tourism, agriculture, livestock farming and fishing.

Namibia's Policy for prospecting and mining in protected Areas and national monuments aims to promote sustainable development in Namibia by allowing mining activities in protected areas, i.e. National Parks (LAC, 2009). The policy stipulates that any mining development in a National Park must be balanced against the risk that it could jeopardize the potential for long-term sustainable development.

### Protected Areas Network

Worldwide, the mining industry has always posed a great threat to protected areas. While the environmental consequences may be the most obvious, the indirect social effects may also impact on protected area values (Phillips, 2001). Due to the continuing demand for minerals, the depletion of resources in readily accessible areas and changing technologies and economics in the mining sector, mining is increasingly being proposed in remote and biodiversity-rich ecosystems that were not previously explored (GTI, 2009). This trend in opening up new prospective areas for mineral resources development provides an opportunity for the mining industry to demonstrate that practices have improved since the minerals industry has always had a bad image with respect to harming the environment.

Namibia is one of the driest countries in sub-Saharan Africa and thus is extremely vulnerable to climate changes. The authorities are precautious when it comes to environmental protection to such a degree that it is enshrined in the Namibian constitution. The Ministry of Environment and Tourism has established a Protected Areas Network (Figure 1). This network consists of 20 national parks displaying amazing geological marvels and diverse ecosystems, in many cases found nowhere else on earth (Ministry of Environment and Tourism of Namibia, 2010). Namibia's network of National Parks and other protected areas such as reserves, national monuments, and conservancies house a wide variety of threatened endemic species, unique landscapes and geologic formations that draw increasingly large numbers of tourists.

Apart from landscapes, flora and fauna, conservationists have begun to recognise that the human and social dimensions of the management of sensitive areas require more attention. People, small societies and tribes still have strong cultural links to the land they or their forefathers once lived on. Hence, relocating them could prove injurious for the integrity of their culture, history and ultimately even for their survival. Namibia has an estimated population of 2.3 million people, comprising 13 ethnic groups. For the sake of brevity, only the tribes of the Herero, Himba and Damara are mentioned in the case studies description below since they are located in the sensitive areas of mining interest.

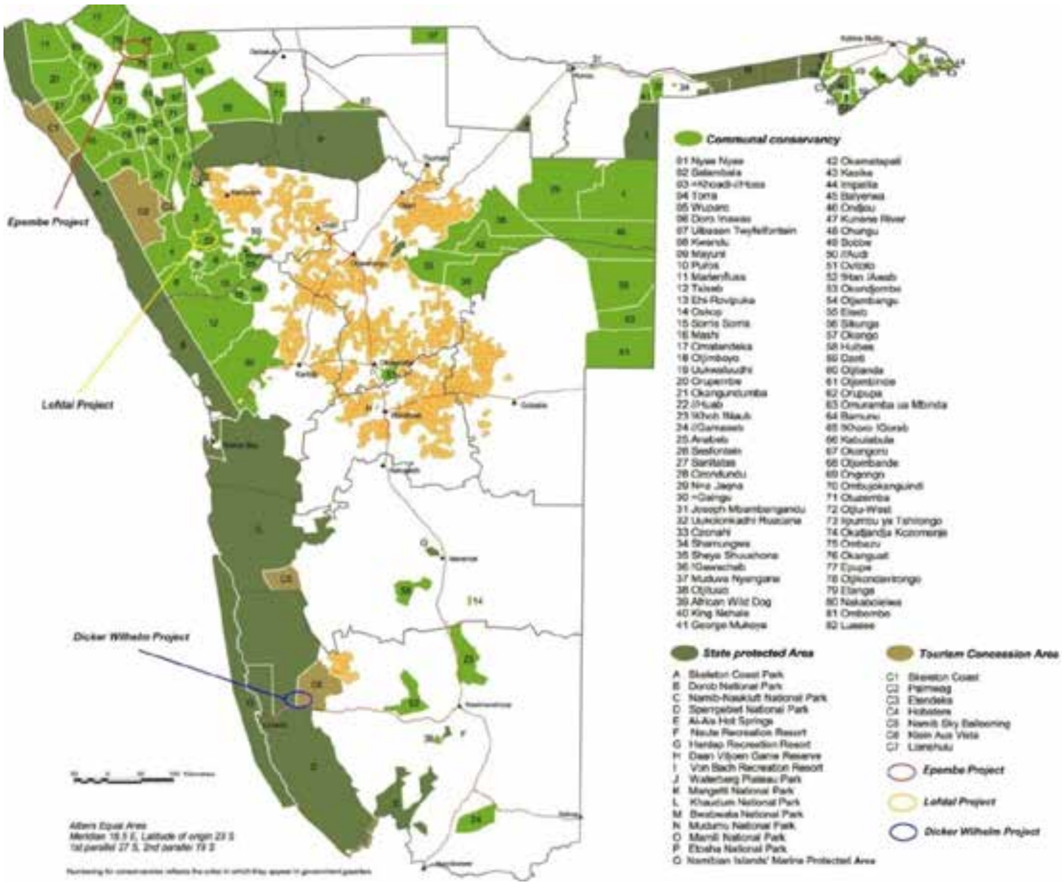


Figure 1 – Conservation and Protected Areas Network of Namibia (http://www.nacso.org.na)

**Environmental Policies and Regulations in Namibia**

Namibia is one of the few countries that incorporated environmental sustainability in her constitution. Article 95 emphasizes the importance of environmental protection by stating that Namibia shall actively promote and maintain the welfare of the people by adopting policies aimed at the maintenance of ecosystems, essential ecological processes and biological diversity of Namibia and utilization of living natural resources on a sustainable basis for the benefits of all Namibians. The Namibian Government has enacted a number of laws and policies intended to protect fragile ecosystems and manage mining operations so that people, wildlife and the environment are preserved during development of new projects. Namibia's Policy for Prospecting and Mining in Protected Areas and National Monuments aims to promote sustainable development in Namibia by allowing prospecting and mining in protected areas. The policy stipulates that any mining development in a National Park must be balanced against the risk that it could negatively interfere with the potential for long-term sustainable development. The policy states that a full Environmental Assessment (EA) is required for any mining in a Protected Area and/or National Monument, as set out in the Environmental Management Act.

Ramachandra (2011) points out that it is imperative to maintain a balance between the capacity of the environment and the quantum of sustainable utilization. Sustainability issues have come to the forefront in mining over the past three decades. The image of the mineral industry was heavily tainted owing to the initial mining practices having not taken issues pertaining to the environment seriously. In 2011-2012 the Southern African Institute for Environmental Assessment was the lead organization for conducting a Strategic Environmental Assessment that was undertaken over the whole uranium province inland. This addressed the whole region and all the projects, and is to result in a Strategic Environmental Management Plan to be implemented by the government and individual project companies.

## CHALLENGES FACING THE MINING INDUSTRY

Our modern way of life has resulted in higher than ever demand for commonly mined commodities, as well as for rare earths and other critical and strategic elements. The importance of REE to some of the world's fastest growing markets has been extensively reported in literature and ranks them among the most critical and strategic metals. The global demand is constantly growing, while the fluctuant situation that governs the REE market has initiated a global exploration boom in recent years. Respective prospecting in Namibia resulted in the discovery of significant rare earth sources. According to Dr. Gabi Schneider, former Director of Namibia's Geological Survey, whilst the presence of rare earths in Namibia has been known for many years, the interest in them has only now increased due to their use for new technologies (Weidlich, 2010).

Nonetheless, the exploitation of some reserves has come into conflict with other human needs in terms of land resources and environmental consequences. Adverse environmental mining impacts range from permanent landscape alternation to soil contamination and erosion, water contamination or elimination, the loss of critical habitats for plants and animal species and finally the threatening of the cultural heritage integrity of an area. Therefore, the mining industry should be enforced to meet the triple bottom line of sustainability; being economically viable, environmentally sensitive and socially responsible. But even so, environmental degradation during mining and post-closure is inescapable, regardless if the foot print is minor or significant. In many cases, the worst conflicts occur when mining impacts on protected areas in terms of cultural heritage or landscapes with sensitive ecosystems. This challenge grows up even bigger when it comes to mining and processing of REE and other metals where special boundary conditions exist.

### Environmental Protection and Biodiversity Conservation

The main threats from mining activities are habitat loss and destruction. This is of particular concern to biodiversity in several protected areas in Namibia as many endemic species are known to have very limited distribution ranges and are thus vulnerable to extinction through habitat destruction. Namibia's abundant wildlife is one of its greatest tourist assets. Among the protected areas, Etosha National Park itself is home to more than 100 mammal species. Inefficient environmental sustainability management can result in the degradation of biodiversity in sensitive landscapes. Thus, mining companies must operate with a view to environmental awareness and protection.

### Social Licence and Stakeholder Engagement

Given the multi-disciplinary nature of environmental issues, the mining industry needs to work in synergy with all the stakeholders. The presence of several tribes in scattered places of Namibia suggests the existence of cultural heritage that must be preserved. Showing an element of respect towards their customs and involving the inhabitants in the exploration and mining projects will contribute to the obtainment of a social licence. Furthermore, the mining companies should inform and familiarise the local societies and the general public with the mining and processing operations and with their potential risks. Due to erroneous practices of the past, rare earth elements are given a bad name and there is a misconception that their extraction is a "dirty business". The REE mining industry can and must change this belief through the proper design, operation and management of a mine and its associated pollution control systems.

### Mining and Processing Techniques and Treatment of Tailings

The incorporation of cleaner production techniques in mining and processing has some key benefits; better environmental management, social and governmental support, improved quality control and reduced operational costs. Choosing environmentally friendly mining processes is significant with regards to operating in sensitive areas and especially when it comes to rare earth elements. Open-pit mining is cheaper and easier to implement, yet it is one of the most environmentally taxing. About 73% of extracted rock goes to waste. Meanwhile, underground mining generates only 7% of waste rock but is by far more expensive (Hartmann & Mutmansky, 2002). In-situ leach mining is widely applied in uranium mining and thus could be a cheaper and more environmentally friendly method for the REE mining industry as well. Nonetheless, it can be also very harmful if the solution leaks into the water supply.

Moreover, the processing of rare earth elements is a rather sophisticated process that includes the use of chemical compounds which can be hazardous for the sensitive ecosystems in Namibia. The presence of radioactive materials in REE and other metal bearing deposits is another issue to deal with and thus, particular health and safety measures need to be implemented (Barakos, Mischo & Gutzmer, 2015). Namibia has a long history of uranium mining/processing/transport; therefore radioactivity can be managed easily. Radioactive residuals can also be present in tailings as well as chemical components from processing. Hence, the treatment and disposal of tailing requires special attention and careful evaluation.

**Unsustainable Water Uses**

Water is a scarce and precious resource and Namibia's unique biodiversity has adapted itself over centuries to this constraining factor. The only perennial rivers of the country flow along its northern and southern borders. These are transboundary resources and are typically home to high levels of biodiversity. The effects of large-scale water abstraction from these rivers could have serious impacts on the environment. The mining and processing operations for REE and other metals require significant amounts of water while contamination of water with high-surface-area particles and process chemicals can also be a major concern. Consequently, these areas are considered sensitive and water consumption must be done in a frugal manner while any mining activities in or around these areas should be carefully evaluated in terms of wastewater minimisation, treatment and reuse.

**Rehabilitation**

In Namibia many old mines were abandoned without suitable decommissioning processes and procedures being followed. On the Geological Survey database, 257 abandoned mine sites have been identified and most of them have been put through a risk assessment procedure to check if they present a significant risk to human and/or the landscape. Given the environmental pollution legacy in and around the REE mining areas in China, social concern is growing, especially with regards to the protected areas where the ecosystems are more fragile. Thus, a mining licence is not to be granted unless an environmental impact assessment and rehabilitation plan are included, giving assurance for environmental sustainability.

**Legislation**

Strong legislative frameworks assist in ensuring that ecological integrity is maintained where a mining activity is in conflict with the need for environmental protection, irrespective of whether an area is sensitive or not. The Namibian government is working in this direction through the enactment of effective laws. Strong and sophisticated regulations however, must be combined with comprehensive monitoring programme as well. The establishment of NUA and NUI and the key role of the Chamber of Mines implies that these challenges are being addressed effectively. When it comes to REE special boundary conditions impose particular regulations. Water usage, waste disposal and radiation are some of the aforementioned challenging factors that govern the rare earth industry and demand stringent regulatory frameworks. Nevertheless, Namibia can adapt legislative instruments regarding REE that are being applied elsewhere (Barakos, Mischo & Gutzmer, 2016). The knowledge and experience obtained from the management of the uranium industry can also guarantee the proper management of the REE mining industry.

## CASE STUDIES

Having noted down the challenges, three exploration case studies are examined. Starting from the north to the south, a big niobium-tantalum deposit is investigated at Epembe. Furthersouth, a significant REE source is being explored at Lofdal and finally another interesting REE geological formation has been found on the Dicker Wilhelm Mountain in the southern part of Namibia (Figure 1).

## The Epembe Project

The study area is located at the north-western border of Namibia, close to the large town of Opuwo in the Kunene region. Geologically the area is dominated by a relatively simple, steeply dipping carbonatite-syenite intrusion. Ta-pyrochlore is the only ore mineral, hosting tantalum, niobium and uranium (Bull, 2013). The Epembe dyke is Namibia's largest carbonatite dyke; 10 km long and up to 400m wide. The African Mining Capital Pty Ltd holds the prospecting license EPL 3299.

### Challenges

There is very good infrastructure surrounding the area. The Ruacana power station and the Kunene River are located nearby and can thus guarantee power and water supply, while other basic needs and services are available in Opuwo (Figure 2). The deposit is in a sparsely vegetated and arid communal area with no farm-owners, yet with strong community support. The Herero and the Himba are the local native people who have been living in the region for centuries. The latter are the official guardians and land owners within the region and are heavily involved with the project. The mining development of Epembe will affect neither the environment nor the inhabitants. On the contrary, many of the Himba people will benefit as they will work for the company that will operate the mine.

The high uranium content of the pyrochlore may on the one hand warrant evaluation of the deposit as a uranium source as well as a tantalum source, while on the other hand lead to specific measures in order to restrict radiation. In regard to processing, the separation of the metallic elements can be done with well-known techniques (floatation) that will have no environmental impact.

### Mineability

Notwithstanding its low grade, the deposit is big and has the potential to be amongst the largest tantalum deposits globally. Its small depth and low stripping ratio indicate the implementation of a surface mining operation. The inclusion of the native inhabitants in the project validates the social licence needed. Consequently, the project is in conflict free jurisdiction with no barriers to development.

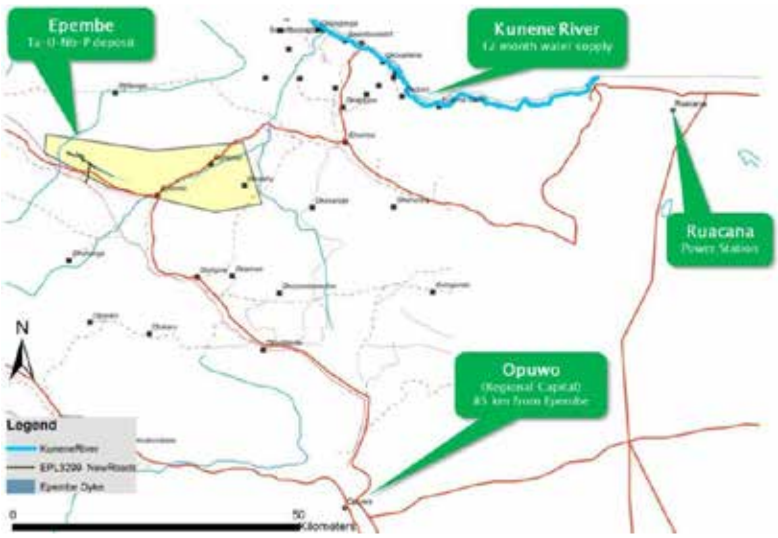


Figure 2 –Map of the Kunene area indicating the location of Epembe (modified after Bull, 2013)

## The Lofdal Project

Lofdal is located in Damaraland, 35km west of Khorixas and 450 kilometers northwest of Windhoek. The district scale project (EPL 3400) is 100% owned by Namibia Rare Earths (Pty) Ltd and deals with the exploration of a heavy rare earth element (HREE) resource. Within a vast area of a 200 km$^2$ carbonatite complex, there are multiple high quality rare earth targets. Currently, interest is focused on Area 4 (Figure 3) where exceptionally high HREE ratios are found in xenotime dykes (Wall, Niku-Paavola, Storey, Mueller & Jeffries, 2008).

Challenges

The Lofdal project is situated in a remote area with limited to no infrastructure. Water supply is restricted and there is not a high voltage powerline nearby. There are only gravel roads and no substantial lodging facilities. The small town of Khorixas is the closest settlement with finite supply or service capabilities. The area is underpopulated, arid. Land cultivation is scarce and the inhabitants, named Damara, deal mostly with livestock breeding. There is no reported social argument with the local society regarding the exploration activities or the potential development of a mining plant.

The Petrified Forest is a National Monument, established in 1950, situated on a small sandstone plateau close to the exploration area (Figure 3). It is a deposit of large tree trunks that have "turned to stone" through a process of diagenesis about 200,000 years ago. The presence of both sights implies the conduction of a detailed environmental impact assessment that will certify the integrity of the landscape. Thorium and uranium have been detected during exploration (Wall et al, 2008). Hence, a Management Plan and a Radiation Monitoring Plan will be required.

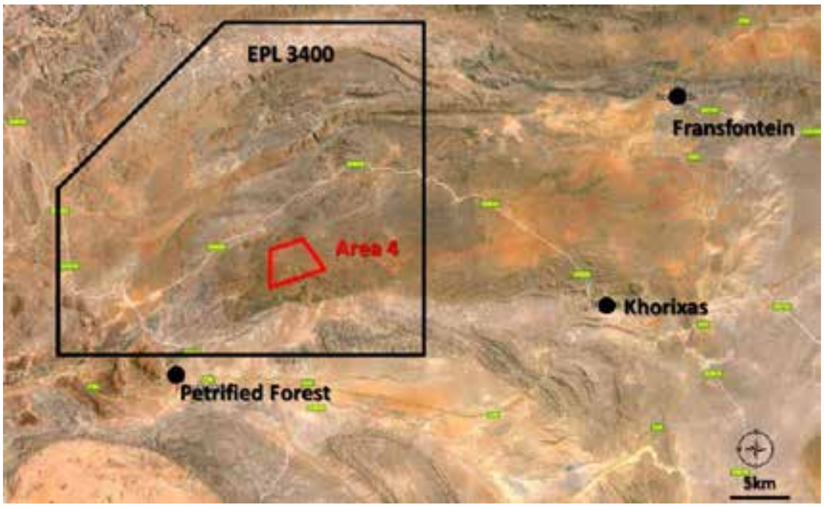


Figure 3 –Location of the Area 4 of the Lofdal REE project

Mineability

The examined area has unusually high concentrations on HREE. Thus, the project attracts global interest and despite the remoteness and the poor infrastructure, the Lofdal project has great potentials and will most probably launch mining operations in the future. The longitudinal shape of the dykes could result in evaluating the perspective of a swallow underground mining development, which would also leave a smaller foot print on the landscape. Yet, the probable solution seems to be an open-pit mining operation. The establishment of a processing plant close to the mine site appears to be profitless and the optimal solution would be to transfer the excavated ore to the nearest harbor along the coastline in the west.

**The Dicker Wilhelm Project**

Dicker Wilhelm, also known as Garub-Berg, is a mountain located in the Karas region in southwest Namibia, between Aus and Luderitz. The geology of the area had been studied long before (Cooper & Reid, 1998; Woolley, 2001). An EPL was granted to Shali Mining (Pty) Ltd to explore for REE potential in the area. Initial sampling indicated an interesting rare earth mineralisation bound to a circular carbonatite complex. Within a short distance, there is another outcrop of carbonatite dykes (Keishohe), enriched in a similar REE mineralization, proximal to Dicker Wilhelm (Woolley, 2001).

Challenges

The mountain is part of the Namib-Naukluft National Park and is also adjacent to the Sperrgebiet National Park (Figure 1). Its surroundings are home to the desert wild horses of Garub. The horses have adapted to the very harsh desert environment and are unique to this part of the world (Figure 4). There are no people living in this greenfield area and no farming activities take place. Nevertheless, Dicker Wilhelm is included within the boundaries of a protected national park and thus all possible disruptions and environmental consequences due to mining must be thoroughly assessed.

There are occurences of both light and heavy REE in the carbonatites. Furthermore, occurences of thorium (mostly) and uranium prove the presence of radioactivity. Although the initial indications are relatively low, assessment of health and safety measures can be required if mining development proceeds.

On the other hand, the infrastructure surrounding the area is ideal. Luderitz is a town and industrial harbor located 60 km away. In the opposite direction, Aus is just 20 km away and has excellent train lodging facilities. A railway to Luderitz harbor passes the exploration site in a distance of just a few km. There is a tar road from Aus to Luderitz directly adjacent to the exploration site. Hence, the supply of fuel, water, consumables, and all services are available in Luderitz, while a major powerline to Luderitz crosses nearby. Finally, it is possible to establish a processing plant in the harbour area at Luderitz.

Figure 4 – Desert wild horses of Garub and the Dicker Wilhelm in the background (Peters, 2008)

Mineability

The evaluation of the mineability of the Dicker Wilhelm REE source is still at an early stage. Currently, expenditures are minimal and all exploration activities have stopped. Nonetheless, it must be mentioned that any future mining operations should leave a minimum foot print on the mountain and the surrounding protected area in order for the biodiversity of the land to remain as intact as possible. Under these circumstances, if exploration reveals an economically attractive rare earth deposit, a mining licence could be granted. However, a surface mining operation on Dicker Wilhelm will have irreversible effects on the landscape. Hence, an underground mining development solution should be adapted and all extracted ore should be transferred to processing facilities located in the Luderitz industrial area.

## CONCLUSIONS

The need for specific commodities, including REE and tantalum is growing bigger all the time. The resource findings in Namibia combined with the adapted mining-friendly policy can turn the country into a major global player of the respective mining sectors. Modern society has a need for these metals, but this must be balanced by the need to maintain a sustainable environment with a high degree of biodiversity. Mining and the environment are uneasy bedfellows, especially in protected areas, where prospecting and mining is permitted. A balance is being sought to ensure that, in keeping with the Namibian Constitution, the resources can be used for the benefit of all with minimum impact on the ecosystem. Namibia has established a Network for Protected Areas rich in biodiversity and for the conservation of significant natural resources such as water. Mining operations in these areas should only be permitted after careful assessments demonstrating the commitment to protect the landscapes and rehabilitate the mining sites. Strong legislative and regulatory frameworks assist in ensuring that ecological integrity and sustainable management of the environment are maintained.

Simultaneously, the number of tourists to Namibia is constantly growing. To ensure the tourism economy develops in the right way, there is need for a delicate balance between the conservation of uncommon species of flora and fauna, and mining related development in order to maintain the current prominence of tourism in Namibia. In every case there should be a weighing of the benefits of using the land for either mining or tourism depending on the amount of ore, location and tourism value of the area. Besides, there are always opportunities for both competing industries to optimally co-exist since they are both critical to the development of Namibia. This can only be possible if the policies and regulations which have to be adhered to for the mutual gain for all competing industries are understood and enforced.

The exploration projects being evaluated in this paper are representative examples of potential mining in sensitive areas of Namibia. Each case study deals with different challenges that may indicate which mining method should be implemented or what kind of other assessments are to be made. The concluding remark for all three projects is that under certain circumstances, mining licences can be granted.

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# MINING PLANNING OF GYPSUM EXPLOITATION WITH TERRACE MINING APPROACH

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# MINING PLANNING OF GYPSUM EXPLOITATION WITH TERRACE MINING APPROACH


## ABSTRACT

This paper proposes a mining scheduling methodology for the mine gypsum Ponta da Serra of the group's concession Royal Gipso, which operates with the mining method *Terrace Mining*, and is located in the region of Araripe, Pernambuco, Brazil. One of the main aims of production scheduling is maximize the net present value, combined with a development sequence of the mining that seeks operational flexibility improvement of the mine and at the same time guarantee the goals of production and quality of the ore. The proposed methodology allows a sustainable approach for scheduling mine so that the panels (terraces) of the mine already exploited will serve for disposition of overburden, which reduces the degraded area to be rehabilitated in the mine, with significant benefits associated with a reduced environmental impacts without compromising productivity goals and economic competitiveness. The results achieved will confirm the expected upgrading with the application of this methodology and will serve for a proposal mining project template for gypsum mines.



## KEYWORDS

Gypsum; mining scheduling; Terrace Mining; Sustainability


## INTRODUCTION

A global challenge in the coming years will be environmentally friendly and financially attractive exploitation of non-renewable resources to meet the growing demand of increasingly consumerist society. Currently, open-pit mining contributes significantly in the production of mineral goods (Shishvan & Sattarvand, 2015).

The open pit mining can be defined as a surface excavation for the removal of minerals of economic interest. It can be used for the exploitation of metal and nonmetallic mineral deposits near the surface, usually with depths less than 150 m. The volume of the deposits may vary from a few tons to million tons (Souza, 2001).

Mining in multiple benches or Open Pit Mining is a mineral exploitation method through which the deposit is accessed by means of digging of a large opening on the surface, called pit, to expose the ore. The operation of this mining method starts with a small pit and develops to a higher one. This proceeds until the final configuration of the mine called final pit, be achieved. These sequences of pits are known as "pushbacks" (Shishvan; Sattarvand, 2015).

A variation of the Open-Pit mining method is the Terrace Mining, which is applied to mineral deposits which have thicker overburdens or when the footwall of the ore has a steeply dip. In this method, the waste material can be transported into the pit areas where the ore has already been exploited. The Terrace Mining works with multiple benches for both the ore and to the sterile material. The whole mine moves through the deposit, but not necessarily in a single stage, it is not a single stage operation. The number of benches is a function of the excavation depth (height of the benches 10 to 15 meters and from 1 to 32 benches in the form of a terrace). The waste material is deposited at 180° from the front work (taken back) in places where the ore has already been exploited (Bullivant, 1987).

The open-pit mining method of simple benches is traditionally used by the mining industry in the Gypsum Pole of Araripe, located in the State of Pernambuco, Brazil (Filho, Alfonso, & Souza, 2012). Successive cuts of benches needed to deepen the mine requires the movement of large volumes of earth and sterile from the overburden for the deployment and operation of the mine, besides of generating large piles with sterile material removed from the mine. The mining by Terrace Mining allows the deposition of overburden removed from the upper layers of the deposit within the formed cuts in previous stages of mine development, which makes the method more attractive environmentally and economically.

The sequencing of production, *scheduling*, is a making decision process carried out regularly which plays an essential role in industry. A scheduling effective of production has become a necessity in today's competitive environment, being of great importance to achieve goals and efficient use of resources (Andrade, 2014).

The scheduling in open-pit mines is an important stage of mine planning, since it determines the raw materials to be produced annually over the life of the mine, evaluates the operation value of the enterprise, and contributes to the sustainable use of mineral resources. Find an optimal scheduling is a complex task that involves large data sets and multiple restrictions (Lamghari, Dimitrakopoulos, & Ferland, 2015).

However, besides of technical and economic criteria, a demand that has been increasingly required in the scheduling mining is meeting the environmental constraints of the mine. From the seventies, environmental protection came to have greater importance in making decisions on the scheduling, which caused serious changes in the mineral industry. This development has generated a change of view on the role of mining in society: the mining activity came to be understood as a form of temporary soil use, not end use as it was in the past, and companies in the sector began to think in the environment at all stages of mining, with the implementation of activities directed to revegetation, landscaping, soil improvement and regional socio-economic development (Carvalho, 2009).

However, in the last decade, there was a significant increase in global demand for mineral commodities. This fact initiated many efforts to increase the productive capacity of the mining sector, both in terms of production infrastructure, and the research of new mineral resources. In this context, there is a needed to expand production of operating mines, as well as opening of new projects.

Every new mining project or expansion of an existing one requires the acceptance of environmental agencies. Thus, every new project or change in sterile disposal projects also depends on environmental licensing. This situation introduces additional uncertainty on the scheduling, since the disposal of sterile by expanding current deposits or through the creation of new projects will depend upon the approval of the entire legal procedure implementation of licensing in a timely manner to meet the mine plan requirements.

This way, the main objective of this work is to show a mine scheduling methodology for gypsum mines to serve as a model for other orebodies, based on the gypsum deposits of the Araripe region, Brazil, through the mining method Terrace Mining, which allows to take into account a sustainable environmental approach in order to anticipate the exhaustion of the pit aiming the disposal of sterile within the pit respecting technical, economic and environmental parameters.

## MINING METHODS IN PLASTERER POLE OF ARARIPE

The fundamental difference between the methods currently in use in mining gypsum, Open Pit Mining and Terrace Mining concerns especially on the form of overburden disposal from casting, since the gypsum’s mining procedure is identical.

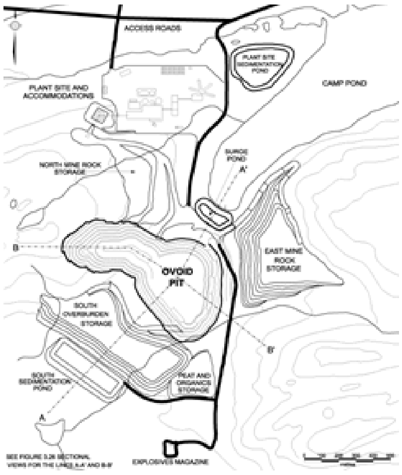


Figure 1 - Typical layout of an Open Pit Mining

Also are found differences regarding geometry of the pit and, sterile and ore haul roads, which in Terrace Mining are separated, whereas in Open Pit Mining the same approach is used in both transport (sterile and ore).

In terms of mining scheduling, the fundamental difference is that in Terrace Mining, the cuts are made perpendicularly to the approaches and parallel to the provided area for deposition of sterile through backfilling method.

They are needed independent access for movement of ore and waste, disposed at the pit limit, connecting the casting front with landfill sterile, which is made in a previously mined area, and the gypsum front of work to the external environment, as described in the figure below.

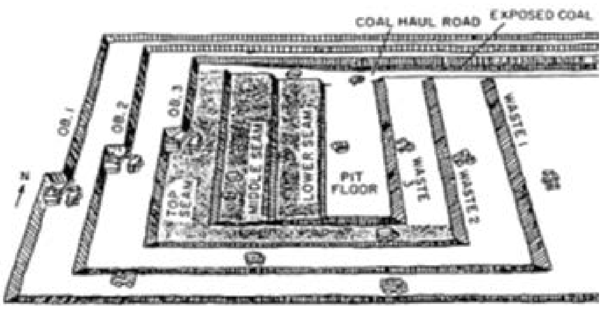


Figure 2 - Typical layout of Terrace Mining Method

The overburden excavation operation (casting) is greatly simplified by the absence of the need for construction and operation of a sterile pile for disposal of overburden, reducing traffic in external approaches, the sterile transport distances and favoring the environmental recovery process of the mined area. They are also found economic benefits due to less need for trucks to transport of waste and reduction of distances.

## UNIT OPERATIONS IN GYPSUM MINING WITH TERRACE MINING

The gypsum mining in the mining method of Terraces is composed of several unit operations, which will be described below.

Firstly need to be built all mine infrastructure works, for the exploitation, specifically, the access roads to the mine and sites of this infrastructure (offices, storages spaces etc.).

Then the vegetation removal of the surface must be performed, so that you can reach the capping of the deposit. This operation is usually performed with bulldozers, with the help of chains, if necessary, wheel loaders for loading material into trucks, also used in this operation.

Once released the surface of the overburden, it can be performed the casting operation, which consists in excavating the overburden material that cover the ore, for the release of this one. This operation can be performed with: bulldozers, hydraulic excavators, trucks, draglines and wheel loaders. At the same time which is carried out the casting operation, are constructed accesses to the ore. Only the first cut excavated on this operation is deposited in the form of sterile pile, since the ore does not present any free face yet. The remaining cut to be executed, in this method, is deposited in the mined out area of the pit.

The mining of ore is usually done with the unit operations of drilling, blasting, loading and transportation of ore. For this, are used drills rigs, wheel loaders, hydraulic excavators and trucks.

In the mining of gypsum and, in the mining method Terrace Mining, environmental rehabilitation occurs concurrent with the mining, this means that the sterile material from overburden stripping operation is deposited in the pit as the ore mining occurs.

## SCHEDULING MINING

### Dimensioning of the overburden excavation equipment

The mining scheduling in the Terrace Mining starts by extending the side access for transport of sterile from the overburden, generally carried out through two benches of about 8-15 m of high, connecting the overburden excavation levels with the respective deposition levels within the mining, in areas already exhausted by gypsum mining.

The advance in gypsum mining fronts is performed in parallel, in a perpendicular direction to the cuts, both to that are being developed as well as to that are being filled with sterile. Figure 3 show this procedure.

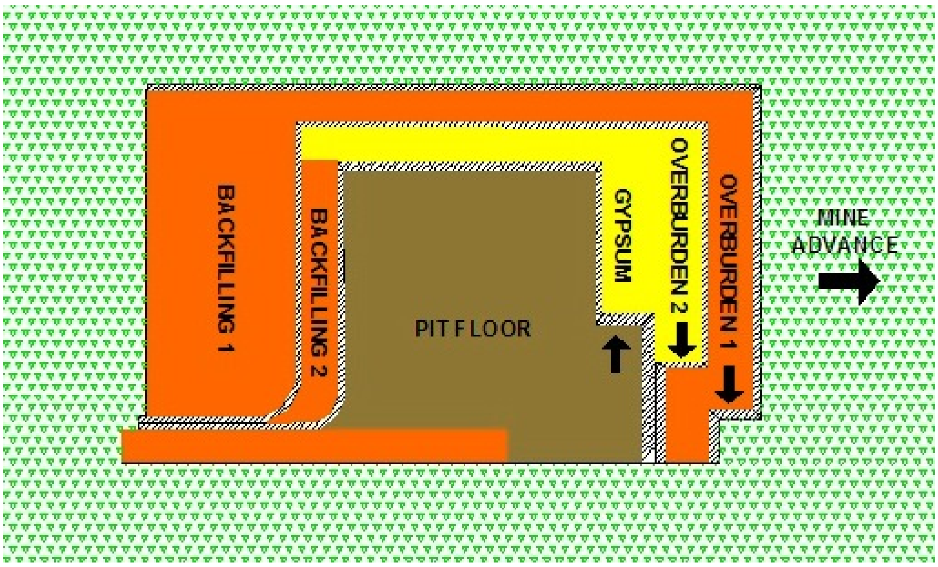


Figure 3 - Advance scheme in Terrace Mining

The width of the cuts at the overburden benches must be set according to the size of excavation equipment (hydraulic excavator), compatible with the type of transport truck and scaled depending on the local sterile-ore ratio and producing desired ore.

Assuming a production of 25.000 tons/month of gypsum and based on the data of the Figure 4, can be obtained the amount of gypsum produced monthly, considering a density of 2,3m$^3$/ton.

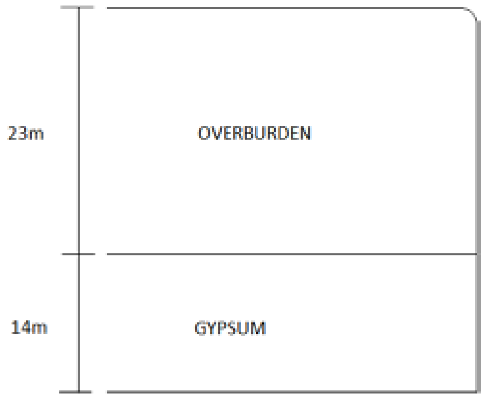


Figure 4 - Gypsum and overburden

$$\text{Vol of Gypsum} = 25.000\text{ton} / 2{,}3\ \text{ton.m}^{-3} = 10.000\text{m}^3 \quad (1)$$

Thus, the required area of gypsum to be worked each month is:

$$\text{Area of gypsum/month} = 10.000\text{m}^3 / 14\text{m} = 715\text{m}^2\text{/month} \quad (2)$$

The width of the cuts in the stripping of overburden operation will be equal a one dual haul road. Considering a dump truck of 16m$^3$, the vehicle width is 2,50m, and then the cut will have a width of 10 m approximately, as shown in the scheme below.

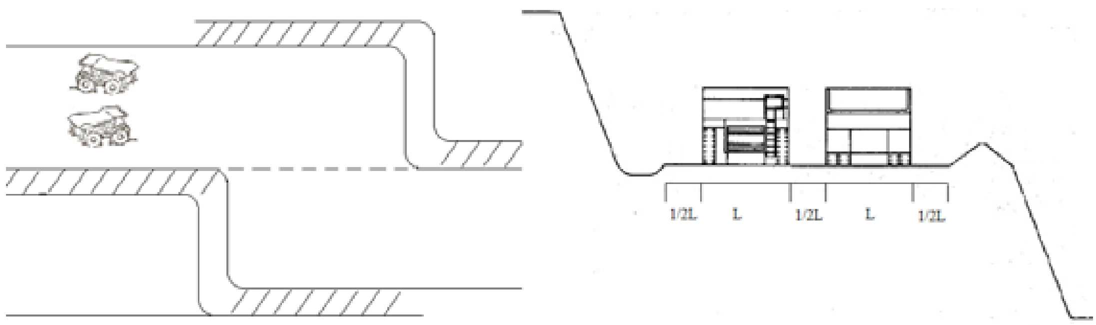


Figure 5 - Width of the cuts

$$\text{Cutting width} = 3{,}5 \times 2{,}5 = 8{,}75\ \text{m (it was considered 10 m)} \quad (3)$$

For a cutting width, there is the need of the following month advance:

$$\text{Monthly advance (gypsum and overburden)} = 715\text{m}^2 / 10\text{m} = 71{,}5\text{m/month} \quad (4)$$

Assuming an average width for the gypsum ore of 150 meters approximately, each cut to be executed will have a lifetime around 2 months.

$$\text{Lifetime of the cut} = 150 / 71{,}5 = 2\ \text{months} \quad (5)$$

In stripping of overburden operation, aiming to meet the ore exposure needs and considering a sterile-ore ratio average of (23m$^3$/14m$^3$) 1.64:1m$^3$/ m$^3$, and cutting width of 10m with an average height of 10m for each bench (Figure 6), the excavation equipment required for the operation can be dimensioned, based on the daily productivity calculated as shown.

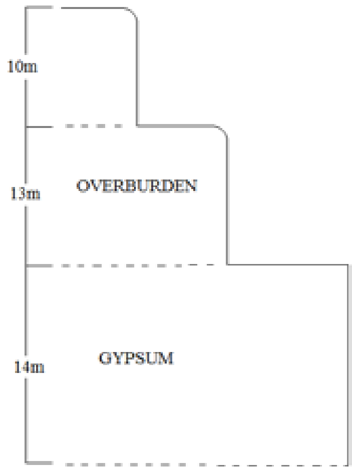


Figure 6 - Dimensions of the benches

Volume to be dismounted by excavator monthly.

$$1° \text{ bench} = 715m^2 \times 10m = 7.150m^3 \quad (6)$$
$$2° \text{ bench} = 715m^2 \times 13m = 9.295m^3 \quad (7)$$

Totalizing 16.445m$^3$/month.

Assuming an average swelling of 60%, has a volume of sterile blistered to be excavated and transported:

$$V_e = 16.445 \times 1{,}6 = 26.312m^3/\text{month} \quad (8)$$

The excavator working regime is summarized in the table below:

Table 1: Excavator working regime

| | |
|---|---|
| Hours/day | 8h/day |
| Bucket factor - $C_e$ | 0,65 |
| Turning coefficient - $C_g$ | 1,1 |
| Efficiency - $E_f$ | 0,75 |
| Cycle time | 40 s |

The equation for determining the hourly productivity of excavation equipment, which allows the determination of the minimum size of the bucket is:

$$P_l = (60 \times 60 \times C_e \times E_f \times V_c) / (t_c \times C_g) \quad (9)$$

Considering an average time of 40 seconds for cycle of the excavator, it is possible to estimate the minimum size of the bucket, as follows:

$$\text{Hourly productivity} = (26.312m^3/\text{month}) / (8h/\text{day} \times 22\text{day/month}) = 149{,}5m^3/h \quad (10)$$

Then,

$$V_c = (P_h \times t_c \times C_g) / (60 \times 60 \times C_e \times E_f) \quad (11)$$

$$V_c = (149{,}5 \times 40 \times 1{,}1) / (60 \times 60 \times 0{,}65 \times 0{,}75) = 3{,}7\ m^3/\text{cycle} \quad (11.1)$$

Systematically can work with 2 hydraulic excavators on the overburden, one on the top bench ($h_b$ = 10m) and the other on the lower bench ($h_b$ = 13m). Using the same scaling formulation, it's desired the following minimum buckets, using the monthly productivity of each excavator to:

For the superior bench:

$$P_{h\ Sup} = (11.440m^3/month) / (8h/day \times 22day/month) = 65m^3/h \quad (9.1)$$

$$V_c = (65 \times 40 \times 1{,}1) / (60 \times 60 \times 0{,}65 \times 0{,}75) = 1{,}63m^3/cycle \quad (11.2)$$

For the inferior bench

$$P_{h\ Inf} = (14.872m^3/month) / (8h/day \times 22days/month) = 84{,}5m^3/h \quad (9.2)$$

$$V_c = (84{,}5 \times 40 \times 1{,}1) / (60 \times 60 \times 0{,}65 \times 0{,}75) = 2{,}11m^3/cycle \quad (11.3)$$

The volume of sterile produced for each section will be:

$$V_{b1} = 715m^2 \times 10m \times 1{,}6 = 14.440m^3/month \quad (12)$$

$$V_{b2} = 715m^2 \times 13m \times 1{,}6 = 14.872\ m^3/month \quad (13)$$

Totalizing 26.312m$^3$/month, as already shown.

**Dimensioning of transport equipment**

According to the layout intended for operation, it has an average transport distance in the overburden bench:

| | |
|---|---|
| Top bench : | 145 m. |
| Lower bench : | 125 m. |

Considering the transport distances above and the average speed of 20km/h, one can determine the total cycle time for transportation.

Table 2: Maneuver times and route

| | |
|---|---|
| Load / maneuver | 1 min |
| Going route | 145/125m |
| Discharge / maneuver | 1 min |
| Back route | 145/125m |

The charging time, considering the hydraulic excavator of 1,75m$^3$ on the top bench 1 and 2,23m$^3$ at the lower bench 2, and a cycle time of 40 seconds, and trucks of 16m$^3$, it has:

$$\text{Superior 1: } t_{cycle} = 16/1{,}75 \times 40'' = 365{,}7 \Rightarrow 6 \text{ minutes} \quad (14)$$

$$\text{Superior 2: } t_{cycle} = 16/2{,}25 \times 40'' = 284{,}4 \Rightarrow 5 \text{ minutes} \quad (14.1)$$

And the trucks cycle time, regardless of the maneuvers:

$$T_{sup1} = 145m / (333m/min) = 0{,}4354 \text{ seconds} \Rightarrow 0{,}5 \text{ minute} \quad (15)$$

$$T_{inf2} = 125m / (333m/min) = 0{,}3753 \text{ seconds} \Rightarrow 0{,}5 \text{ minute} \quad (15.1)$$

The table below shows the total cycle time of the overburden stripping operation of the excavator-truck set:

Table 3: Total cycle time of the overburden stripping operation

| | Load / maneuver | Going route | Discharge / maneuver | Back route | Total |
|---|---|---|---|---|---|
| Bench 1 | 7 | 0,5 | 1 | 0,5 | 9 |
| Bench 2 | 6 | 0,5 | 1 | 0,5 | 8 |

The number of trucks needed to carry out the dismantling provided in the mine can be calculated from the productions required for casting operation, which are respectively 11.440m$^3$ to the top bench 1 and 14.872 to the bottom bench 2, as already showed.

The average productivity of the truck, considering the calculated cycle times can be obtained from the following equation, as described in the dimensioning of the excavator:

$$P_l = (60 \text{ x } C_e \text{ x } C_f \text{ x } V_c) / t_{route} \quad (9)$$

Therefore, for the top bench 1, it has a productivity of:

$$P_{sup1} = (60 \text{ x } 0{,}75 \text{ x } 0{,}85 \text{ x } 16) / 9 = 68m^3/h \quad (9.3)$$

And to the lower bench 2, the following truck productivity:

$$P_{inf2} = (60 \text{ x } 0{,}75 \text{ x } 0{,}85 \text{ x } 16) / 8 = 76{,}5m^3/h \quad (9.4)$$

Taking into account the compatibility between the load times and travel time it has need for trucks to the casting operation, as described down:

$$N°_{sup1} = (9 / 7) \text{ x } (0{,}85 / 0{,}75) = 1{,}457 \Rightarrow 2 \text{ trucks} \quad (16)$$
$$N°_{inf2} = (8 / 7) \text{ x } (0{,}85 / 0{,}75) = 1{,}295 \Rightarrow 2 \text{ trucks} \quad (16.1)$$

## CONCLUSIONS

Both mining methodology, *Open Pit Mining* and the *Terrace Mining*, allow a good operating performance of gypsum mining. The first method is applied in the region by local custom or tradition, whereas the companies in the region are generally small, and do not invest, or have done little, in technical studies, in order to find more profitable alternatives for the extraction of this mineral good.

The gypsum of Araripe region lying under a layer of clay, and therefore, for access to the ore the clay need to be excavated. The difference between these two mining methods is on the casting operation, i.e., the excavation of the clay layer. The adoption of *Terrace Mining* provides the reduction of transport costs in the casting operation, since the sterile material is now deposited directly into the pit while the mining of gypsum occurs. In addition, there is the elimination of maintenance costs of waste piles, needed in *Open Pit* mining, and costs with the acquisition of new areas for construction of these piles.

The purpose of mine planning in this transition between the two mining methods, from *Open Pit* to *Terrace Mining*, is to select and dimension the equipment of casting operation, define the geometry of the benches in sterile, design backfills inside the mined pit and the access roads, in order to achieve the desired production by the company.

Thus, the planning of gypsum mining with *Terrace Mining* is an important stage of gypsum mining, since it determines all the above mentioned parameters, providing:

- Reduction of costs in the casting operation, due to less need for trucks and smaller distances at the operational methodology of *Terrace Mining*;
- Environmental rehabilitation of the mined area, with backfill being done inside the pit, avoiding the need for landfills for disposal of sterile outside the mined area;
- Reforestation of the grounded area enabling, thus a future use of the mined area;
- Implementation a more competitive and environmentally friendly mining for the region.

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# MINING TOURISM AND GEOTOURISM: ALTERNATIVES SOLUTIONS TO MINE CLOSURE AND COMPLETION

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# MINING TOURISM AND GEOTOURISM: ALTERNATIVES SOLUTIONS TO MINE CLOSURE AND COMPLETION


## ABSTRACT

The mine closure integrates the costly phase of the environmental recovery to a mining achievement, often, this stage, is required and imposed by regulators, becomes this way an implication to mining companies that will give the social and environmental support for enjoyed space. Many of the developed solutions for the area environmental reclamation don't satisfying social needs of ambient that mineral activity had involved before closure and, generally, produce deficits in job creation, at any rate direct or indirect, combined with the low capital and products moving at the local level. Perceiving the experienced realities in mine closure, this paper craves to show the geotourism and the mining tourism as solution to environmental issues founded in closure of mining operations, seeing their efficient employment in mining elements of landscape, ambient and history, and besides that, with your positive applicability to return of economic well-being to population involved with mining. The article cares yet in to detail corresponding alternatives and to compare your advantages for use with others alternatives already implemented, through an exposition of cases and your respective results previously registered in bibliographies.



## KEYWORDS

Mining tourism, mine closure, geotourism, environmental reclamation.


## INTRODUCTION

Mining has something else in its essence than just an economic activity, mining integrates and modifies social and environmental sectors in which is related, being responsible for transformation of landscape segments, changing society, environment and natural resources. Following deeper into environmental changes brought about by mining activity, sees the necessity to manage in a proportion precatory to suggested changes, all phases constitute activity since its inception, full operation until its closure.

Many authors divide mining in moments shape a particular purpose to follow up on economic activities of a venture, such as mineral research, know ore bodies and his features to assign profitability and mining, explore and process ore to use for effective and efficient ways. Hartman & Mutmansky (2002), for example, summarize life stages in: prospecting, methods and technologies; exploration and delineation of the ore body to feasibility study; development of prospectus or openness and accessibility for production; explotation and large ore production; at last, environmental reclamation post-mine phase.

Can attribute, from definition phase, in particular environmental impacts for each stage. Although there always coexist social environmental threats associated with mining industry concern with sustainable development arises recently, in the last twenty years, either through conventions, regulations or certifications all mining phases are progressing in order not to harm the parties involved of the mineral extraction process, that is focused on a cleaner and sustainable production. Among the stages of life cycle of a mine environmental rehabilitation period is one of most delicate and problematic when it comes to rearranging all modified landscape, and for this reason requires integrated strategic planning to the mine operation.

About environmental reclamation or mine closure, it is known that are processes lawfully initiated to the startup of mining operations, following them until completion of their functionality with progressive rehabilitation and monitoring, laying sketched practices in planning for closure by decommissioning of unit operations aimed at maintaining a social-environmental quality of the territory. Sánchez et al. (2013) describe term decommissioning in line arguing deactivation begins just before to ends of mineral production, might be uninstalling individual structures with mine still in operation, and closes with removal of all unnecessary installations and implementation of measures to ensure safety and social-environmental stability of area, in order to meet mine closure objectives such as reinforce Luz & Sampaio (2015).

Certainly, what Fellows Filho (2000) placed regarding mine deactivation concepts or mine closure definitions, or, even, mine decommissioning, are not yet well defined and each author in this thematic have resorted to a denomination more particularized, very probably is due, nearest interaction between steps for mine closure definitions. However, what is evident from the case in your configuration are your goals and their problems. These are peculiar to each mining venture and shape according to the needs to reduce their future environmental and social liabilities, considering what elucidates Sánchez (2015) about social impacts caused by the mine closure, with illustration of municipalities have grown in mining dependencies and meaning of closure process when it occurs, is observed, so, mine closure as a synonym for unemployment and damage to social actors when handled incorrectly and without appropriate management tools.

Seen in these terms, there is need to engraft in plans for completion of mine both socioeconomic actions and environmental compliance how to the evaluative criteria objectives for closing, in order to include the general aspects, such as, Heikkinen et al. (2008) list to targets and best practices in: physical stability (physically stable structures from erosion and functioning as were designed); chemical stability (chemical quality of soil, surface and groundwater), biological stability (natural environment with typical balanced ecosystem and rehabilitation of local biological diversity), geographical and climatic influences (proper closure into the local climatic demand, topography and adequate proximity of human habitations), quality of natural resources, land use and visual aesthetics (optimized restoration for land use and production opportunities for sustainable development) and socio-economic issues (minimizing negative socioeconomic impacts and inclusion of local communities in implementing appropriate action).

Release of an area for other activities are totally dependent on the primary goal of mine closure, completion. When mine was completed is able to transfer his custody to another owner or investor, therefore, to a mining company is incumbent, in many cases, decide the allocation area together with stakeholders and local community. In view of numerous problems for company's performance in local reclamation, more precisely with significant costs. Opportunities arise, favorable trends and factors suggest rehabilitation of site with minimum cost and maximum adaptation without geological heritage, mining, environmental, cultural and historical be lost entirely. These are challenging situations for companies which tourism appears as solution to area use and environment constituent of mining landscape. Based on this proposition, the text, based on theoretical discussion made possible by bibliographical research and interpretive study for application, delineates in the next topics geotourism and mining tourism, new modalities of tourism industry, as opportunities to mining activities and mine closure phase; as well as aims to report new trends through display cases, exposing social and environmental advantages in use of these tourist activities, and seek to understand them into mineral industry context.

## DISCUSSIONS

### Assimilation of Mining and Tourist Industries

With globalization process, dynamics of society are being adapted to evolution social, economic and global political standards. Performance of this process in a large proportion of scales made tourism industry further increased your market segmentation range, since the tourist destinations have been adapted directed to new global dynamics, each seeking to have their differential and get featured from the trends (Beni, 2003). The same author also emphasizes globalization has caused greater availability and ease of access of products, of installations and tourist services at global level, not to mention information mirroring, in this way opening up the range for many different categories of tourism by decentralizing them and increasing availability of destinations through need for the experimentation tourists.

Commonly, tourist market segmentations are divided as suggested in Lage (1992): geographic (natural or artificial attractions of a region), demographic (groups visiting a region), psychographic or psychological (volition or psychological motivation for choosing a destination), economic (financial constraints) and social (social classes and associated destinations). Various tourism targets are established to understand your industry behavior and frequently is adopted geographical or psychological segmentation for division of tourism categories. Nature tourism or rural tourism, urban and coastal tourism are classic examples of division by geographical limitations, while adventure tourism, religious, professional and sustainable are statements of reasons and objectives for which tourism is done.

Among geographical tourism segmentations, which deserves mention is a gamut of attractive and objectives for achievement of something or some action that a geographic location can provide, causing motivations for tourists feel attracted to visit, play, work, relax, to exercise profession, know and develop its purpose in this particular place. Knowing this, relates to the existence of types of tourism to a geographical environment, such as rural tourism, which can only be practiced where, obviously, their nature and absence of urbanization; ecotourism, for example, is a type of tourism part of field of tourism niche or nature, but it needs environment preserved by law to be pragmatically practiced.

Following more profound on those concepts, a definition of geotourism can be found a recent kind of tourism was, firstly, defined by Hose (1995) as a supplier of interpretive structures to landscape composed of geological and geomorphological elements beyond level of mere aesthetic appreciation, in this regard Larwood & Prosser (1998), McKirdy et al. (2001) and McKeever & Gallagher (2001) suggest geotourism is associated with ecotourism in attracting tourists to natural geographic environments. For his part, Gray (2004) made tourism types separation, saying attractive of geotourism by abiotic factors while ecotourism in biotic terms, he also comments about as geodiversity values are not yet understood how biodiversity. Indeed, geotourism can be classified as an integral part of nature tourism, with a section dedicated to aspects in greater proportions for knowledge of geological heritage and geodiversity of a geosite, not excluded biodiversity can aggregate geosite.

When geodiversity (mineral resources) is explored through technological methods occurs what is known by mining. Understanding this process as a user of the natural geological heritage of an area can be seen that the environment where mining is developed has geological features (on mineralogy, petrography, stratigraphy, pedology, structural and geomechanical), geomorphological and specific physiographic in conjunction form local geodiversity, essential for the geotouristic practice. Geotourism in mines has acquired greater proportions in recent years, scientific productions known as (Conesa et al., 2008; Matos et al., 2010; Bezerra et al., 2014; Fernandez et al., 2015) cite geotourism associated with mining, now named by mining tourism, a new subclassification of geotourism (Figure 1) associates geological heritage with industrial and history.


Figure 1 – Subdivision of geographic localities types of tourism

The history of global environment explains progress and development of industry diverse branches, technological advancement of industrial systems over the past centuries made the possible origin of the historical, social and cultural heritage said "industrial". The heritage tourism described in Edwards & Coit (1996) as tourism in places with history as the main theme of attraction, since industrial heritage tourism is concerned with the development of landscapes originated with industrial processes of various periods, both terms focused on the subject of practicing tourism. Mining is an industry, likewise, owns the industrial heritage, in the specific case, called historical mining heritage or, simply, mining heritage, which in turn is also the landscapes maker, consequently, in tourist attractions, constituting mining tourism. Lamb (2010) puts mining heritage associated with geological heritage to include material and immaterial traces related to mining activity, as well as geological aspects (geodiversity) promote exploration.

Because of easy accessibility to information, caused by globalization process, mining tourism seems to gain front space to the magnitude of other tourist activities already in existence. (landscape is biotic factors - related local ecological systems, and landscape related to abiotic factors - conditions and substantial physical resources to the existence of an ecosystem, including soils, rocks, minerals, relief and physiographic standards) to technological heritage (mining technology, operation, processing and also historical heritage connected to miners), as previously mentioned.

**Geotourism, Mining Tourism and implementations of your activities**

Lately, for attract a portion of public that is interested in curious, unusual and inedited, the geotourism has been a highlight. Applying nature of what would be geotourism to mine closure situations, study focus of this work, the mining tourism, that is possible to obtain since, as already explained, mining tourism would add the sum of geological heritage (work object from geotourism) and industrial heritage (industrial tourism work object). Therefore, the public that targets geotourism can also be motivated by mining tourism attractiveness.

Mowen & Minor (2003) understand motivation refers to a state leads to behavior aimed at a goal. Based on the premise, what are motivational incentives mining tourism and geotourism can produce a mine environment? The motivation of tourist is completely connected to the environment offered for the practice of tourism, if a mine in full operation or an exclusive mine for tourism practices can produce risks to tourist safety, then, follows that a safe environment, even though to practice risky adventures, is a motivating environment. First, the adaptation of a mine for tourism after its closure, or in productive activity becomes a key element for a motivational process of tourist.

Creation of theme parks, geo-mining parks, geoparks, cultural and recreation while preserving the geological and historical identity of a place, still promote appreciation of these along with local culture. The procedure for opening geo-mining park in accordance with one adaptation project described in Orche (2003), in the author park opening project, must be justified by public interest (possibilities the mine offers according to their tourism potential), should also contain social demand of installations (leisure and cultural installations - museums, exhibitions, memorials, typical restaurants, hotels, and many others, is worth mentioning the important practice of museology, description of mine feature and facilities to recover (geological, technological, historical and environmental aspects, current status and their relations with surrounding region), proposed activities (tourist area layout - delimitation of park, mining property, if a mine will continue to produce, inventory of buildings and facilities for adaptation - are open pit or underground), security plan for park, put informative, programming and publicity, offering local recreational and cultural services and feasibility study.

Without adaptations to security and activities to be implemented is quite impossible for installation of geo-mining parks, the Figure 2 illustrates how a process of adaptation promotes changes in the landscape itself, leaving area accessible.


Figure 2 – Mining tourism adaptation and development in mine closure

In the second instance, sees to tourist motivation of tourist associated with the availability of activities mining tourism with geotourism can offer on site. Activities related to tourist segments are broad. These enable countless bias motivation, which may vary in galleries of visitation, mine tours, observatory viewing, historical and cultural exhibitions in region, adventure tourism practices (such as climbing, abseiling, canoeing, diving and among other adventure sports), sustainable tourism (in environmental reserves for reforestation), geological tourism itself (geological elements only as of appreciation objects) and mineral tourism (sale and exposure of minerals and gemstones), professional tourism, pedagogical and knowledge (focused to direct knowledge for professionals or students in these areas of geosciences) and other practices related to intention of visitation and mining tourism proposal of tourist development. Figure 3 depicts activities subject to realization in geo-mining parks.

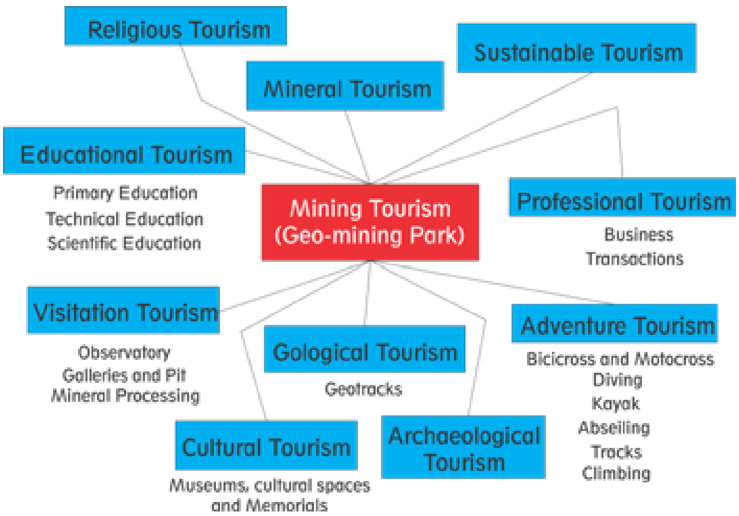


Figure 3 – Mining heritage and touristic motivations to practice of activities in mining tourism

Geotourism and mining tourism in Brazil

Many countries worldwide have already been used the mining tourism principles apply to mining heritage as a tourism object. The trend in Brazil, shown no different in many cases of mines (Figure 4), both open pit and underground, using geotouristic and historical potential as attractiveness factor. The main examples of Brazilian geo-mining parks are the "Parque Temático Mina Brejuí" (Currais Novos, Rio Grande do Norte) (Figure 4a), "Minas do Camaquã" (Caçapava do Sul, Rio Grande do Sul) (Figure 4b) and "Mina da Passagem" (Mariana, Minas Gerais) (Figure 4c).


Figure 4 – Main cases of geo-mining parks in Brazil [Figure components: a) Brejuí mine and entrance for a touristic gallery; b) Minas Outdoor Sports – practice of adventure tourism in “Minas do Camaquã” (Minas Outdoor Sports, n.d.); c) Trolley to access the underground galleries of “Mina da Passagem” (Ruchkys, 2007)]

The Brejuí mine has your historical heritage associated with World War II, with the production of concentrate scheelite mine and having largest mine title of South America was internationally noted till have their paralyzed production activities in 1996, but returned in 2005. Touristic activities open to the general public were initiated from 2000, before, has already received technical and university schools for technical visits. Since then, the theme park was expanded, cataloging more than 26,000 tourists who can enjoy the cultural and historical riches by visiting tunnels, residues dunes, mineral museum, chapels and other attractions (Nascimento et al., 2008).

In the Rio Grande do Sul State, the case of the "Minas do Camaquã" known as the first mining of copper in Brazil. The history testifies to the Brazilian industrial expansion and openness to foreign capital, at the end of the nineteenth century were explored gold, copper and other ores by Belgian and British companies, already in twentieth century national companies (the current owner “Companhia Brasileira de Cobre”, CBC, Brazilian Company of Copper) exploited the gold, copper and ore deposits at the site until its closure in 1996, when after more than a century of exploration claims exhaustion. Since 2007, the community surrounding search alternatives in tourism to revitalization of industrial area, have already been implemented on the initiative and commitment of the company (CBC), the event said "Minas Fest", the “Gaúcho” Traditions Center and "Cine Rodeio", the Outdoor Mining sports (adventure sports company created operates in the "Minas do Camaquã") and various tracks in adapted galleries and vision for the artificial lake of the pit (Cunha & Bazotti, 2015).

The Passagem mine, first mechanized gold mine in Brazil, located in Mariana/MG, is one of the largest gold mines in the world open to visitors. Currently, a good example of using old mines to the practice of geotourism. As the way of access to underground galleries, visitors use a trolley with banks. During visitation, receive information about the history of the mine and old gold exploration methods. A few years ago, the mine also began to be used to swim in the flooded galleries and tunnels for water the water table. On site, there is supporting infrastructure with restaurant and bathroom, plus a craft shop and a museum with pieces from the time of the gold cycle (Ruchkys, 2007).

## CONCLUSIONS

With recent advances on the sustainable development and cleaner production applied to mineral industry solutions meet environmental needs of the social and environmental degradation caused by mining are of paramount importance, considering mining corporations have legal duties and his image in the market is linked directly with their backup to society after use of mineral resources in an area. In view of what was presented in this article, geotourism and mining tourism are presented as a recovery tool, and environmental conservation in degraded environments by mining, the mine closure process. Knowing properties of both visitor activities include for adaptation and installation in a closed mine, sees itself multiplicity in use, contrary to what would be in other forms of post-rehabilitation use, such as creating environmental reserve with reforestation area, agricultural activities and internal use of a company, which would be one-dimensional in acting, as many of socio-economic factors like employment and area utilization, also social and environmental, as conservation of geo-mining and social identity heritage with the place, would be with gaps not fulfilled. That's why mine closure planning is indispensable to ensure an efficient choice of use.

For practiced tourism quality of mines is the employment of qualified staff is required to monitor and inform tourists about specifics of geological environments, mining, historical and cultural, as well as in making, divulgation of geo-mining park material content so that scientific knowledge is disseminated in order to protect heritage established locally. Many social, economic and environmental benefits occur when mining tourism is applied through the implementation of geo-mining parks in the mines on the closure process (Table 1), although having many obstacles to implement them, such as legislation of country, mining company policy, geodiversity barring and explored mineral resource, environmental and safety conditions.

Table 1 – Advantages obtained through use of mining tourism in the mine closure

| ADVANTAGE | SHORT-TERM | MEDIUM TERM | LONG-TERM |
|---|---|---|---|
| **SOCIAL** | *- Generation of direct jobs in tourism;<br>- Leisure and entertainment options;<br>- Scientific and historical knowledge;<br>- Mining-society or government-society interaction.* | *- Rescue of historical and cultural heritage of a locality;<br>- Cultural identity formation.* | *- Generation of indirect jobs on a large scale;<br>- Contingent increase in services (restaurants and hotels);<br>- Investment in education and professionalization of workers in most diverse branches.* |
| **ENVIRONMENTAL** | *- Mitigation of visual impacts and residues left by mining;<br>- Territorial occupation and defining spatial dimensions;<br>- Management of hydric resources and environmental factors, so as to reduce liabilities.* | *- Conservation of geological and mining heritage (geodiversity);<br>- Population environmental awareness.* | *- Conservation of local fauna and flora (biodiversity).* |
| **ECONOMIC** | | *- Alternative economic activity (end of dependence on the monopoly of mining activity).* | *- Reduction of economic effects suffered by mining activity output;<br>- Increased per capita income of town.* |

Reuse of mining areas enclosed by touristic activities of geotourism and mining tourism become materialized in mining parks construction, geoparks, geo-mining parks or theme parks. This integration of mining and tourism is possible when the tourist interest initiatives seek to integrate planning allocation of future mined area use. Practical use of these tools is also possible during the production phase of a mining activity, integrating both activities and benefit not only companies but as government and population involved. Geotourism and mining tourism arise, therefore, as alternatives in the area use, above all, in an attempt to rescue historical heritage, social, environmental, mining and geological of a given territory.

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# MODEL EXPERIMENT FOR CO-AXIAL UNDERGROUND COAL GASIFICATION SYSTEM DEVELOPMENT

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# MODEL EXPERIMENT FOR CO-AXIAL UNDERGROUND COAL GASIFICATION SYSTEM DEVELOPMENT


## ABSTRACT

Underground coal gasification (UCG), a technique used to recover coal energy by the *in-situ* conversion of coal into gaseous products, enables recovery of coal energy from unused coal resources abandoned under the ground for either technical or economic reasons.

The technique of a conventional UCG system is to gasify the coal in a gasification channel made by a well linking injection and production wells. A conventional UCG system can be adopted efficiently for thin, flat, and deep coal seams. Considering these limitations, it might be difficult to adopt conventional UCG systems in Japan because of geological conditions that are complicated by the existence of faults and folds. Therefore, a co-axial UCG system that is compact, safe, and highly efficient is suggested as an alternative UCG system. The co-axial UCG system is flexible for adoption under complicated geological conditions because this system uses only well drilling with a double pipe: oxidants are injected from an inner pipe. Gaseous products generated in the coal seam are collected from an outer pipe.

For this study, UCG model experiments were conducted for two UCG systems using coal blocks of 0.55 × 0.60 × 2.74 m: a co-axial method and a linking method of a conventional UCG system. Model experiments of three types were conducted: test 1 (co-axial method), test 2 (co-axial method), and test 3 (linking method). In tests 1 and 2, the gasification agents were supplied respectively for 23 hr and 51 hr. The average calorific values of produced gas were, respectively, 4.68 MJ/Nm$^3$ and 4.75 MJ/Nm$^3$. In test 3, the gasification agents were supplied for 111 hr. The average calorific value of the produced gas was 7.78 MJ/Nm$^3$. These results demonstrate that the gasification efficiency in the co-axial UCG system should be improved. We are developing an efficient UCG system.



## KEYWORDS

Underground coal gasification, Gasification efficiency, Unused coal, Co-axial system


## INTRODUCTION

Coal is a fossil fuel used all over the world as a primary energy resource with several advantages compared with other fossil fuels: it has huge reserves, wide distribution throughout various parts of the world, and low price. However, environmental issues such as air pollution and global warming are suspected to be attributable to carbon dioxide ($CO_2$) generated when the coal is burned. Consequently, the development and diffusion of clean coal technologies (CCT) are promoted to mitigate $CO_2$ emissions from the use of coal: technical development of improving use efficiency and carbon capture storage (CCS).

Japan uses 170 million tons of coal annually. Annual domestic coal production amounts to only 1.3 million tons. Therefore, almost all coal is imported from other countries. Most coal mining in Japan was closed by 2001 because of complicated geological conditions for mining development and high prices of domestic coal. However, abundant unused coal resources remain underground, but they are not recoverable because of technical and economic reasons. Such coal resources are estimated to be 30 billion tons in Japan, with 15 billion tons of coal present in Hokkaido. For that reason, technology of Underground Coal Gasification (UCG) has great potential to recover vast amounts of energy from these coal resources.

Many benefits are anticipated from this technology: using unused coal, lower capital/operating costs, no surface disposal ash, and the possibility of combination of CCS. Developments of UCG have been studied in all the countries of the world such as Australia, China, India, South Africa, New Zealand, Canada, and the USA (Klimenko, 2009). UCG systems studied in these countries, however, are usually large-scale developments, and are not suited to Japan where residents live near the development area and where geological conditions are complicated. Therefore, a small-scale UCG system that is compact, safe, and highly efficient, should be developed for using heretofore unused coal resources. Our institute is developing a compact UCG system, a "Co-axial UCG system", as a local energy resource.

## UNDERGROUND COAL GASIFICATION

Underground coal gasification (UCG) is a technique to extract energy from coal without mining. Actually, UCG operations mainly consist of three steps. In the first step, an injection and a production well are drilled to the coal seam. Then a well link is established between the wells as the gasification channel. The second step is to ignite the coal seam *in-situ* and inject gasification agents such as air, oxygen, and steam to recover a synthesis gas from the production well. The final step is to return the environment back to its original state (Kačur et al., 2014).

For UCG processes, carbon monoxide (CO), hydrogen ($H_2$), and methane ($CH_4$) are recoverable as the main combustible gases. These gases are formed by chemical reactions in the underground gasifier under high temperatures. A gasification channel is divisible roughly into three zones: an oxidization zone, a reduction zone, and a drying and pyrolysis zone. Figure 1 portrays the division of the gasification channel into three channels. The role of the oxidization zone is to heat and increase the temperature of the coal seam to enhance chemical reactions in the following zones. In the reduction zone, $CO_2$ and $H_2O$ are reduced to CO and $H_2$ as main chemical reactions. $CH_4$ is formed under the catalytic effect of coal powders or metallic oxides. In the drying and pyrolysis zone, gases of various kinds are formed such as $CH_4$, $H_2O$, CO, $CO_2$, $H_2$, and $C_2H_6$ because of the pyrolysis occurring in the coal seam.

The calorific value of the synthesis gas recovered by UCG is usually low (3–4 MJ/Nm$^3$) when air is injected as a gasification agent, meaning that the usage of the gas is limited because of its low calorific value. For this reason, technologies of separation and recovery or improvement techniques of product gas quality should be discussed in terms of the efficient utilization of the gas recovered by UCG.

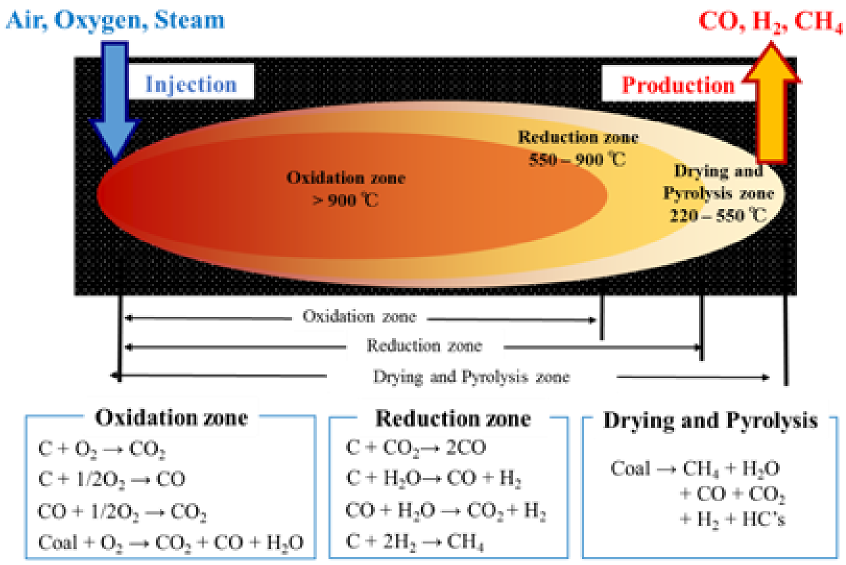
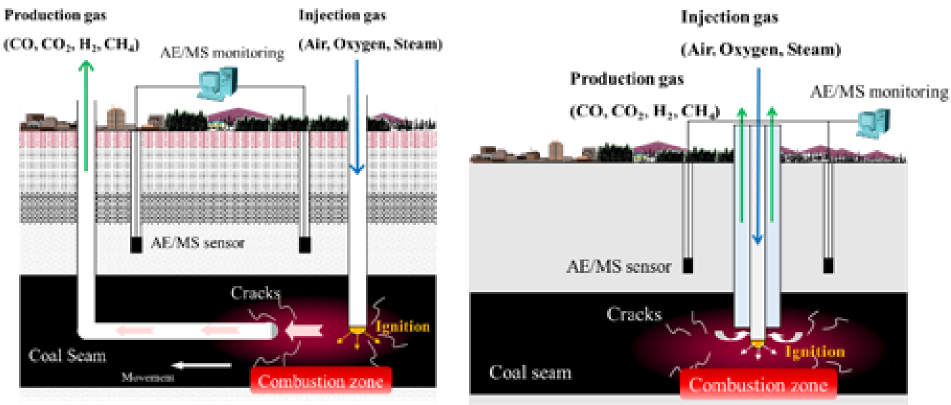



Figure 1 – Division of the gasification channel into three channels (Kačur et al., 2014).

### UCG System

An old technique of UCG systems is gasification of the coal in a gasification channel made by a well linking the injection and production wells. Figure 2(a) presents the concept of a conventional UCG system (forward combustion). Generally, forward and reverse combustion approaches are used in UCG processes. In the former, the coal seam is ignited in an injection borehole. The combustion zone moves to a production borehole. By contrast, in the latter, the coal seam is ignited in a production hole and the combustion zone moves to an injection borehole. The controlled retractable injection point (CRIP) method, which uses reverse combustion, is a commonly used UCG system in recent years. This method improves the overall efficiency of the UCG process because this method produces higher quality gas as a result of its lower heat loss (Bhutto et al., 1988).

The conventional UCG system is suitable for thin, flat, and deep coal seams. An alternative UCG system must therefore be developed in Japan because geological conditions are complicated, with the existence of faults and inclined coal seams. Additionally, effects on the surrounding environment must be adequately considered because local communities exist near the developing site. Given this background, we are developing a co-axial UCG system that is compact, safe, and highly efficient. Figure 2(b) presents the concept of a co-axial UCG system. This system uses only well drilling and a double pipe. Gasification agents are injected from the inner pipe to expand the combustion zone. The production gas is recovered from the outer pipe. A co-axial UCG system is applicable for coal seams having complicated geological conditions. Furthermore, this system only slightly impacts the surrounding environment. Moreover, the combustion zone in a co-axial system is smaller than that of a conventional UCG system because it is limited to the area around a well.




(a) Conventional UCG system (b) Co-axial UCG system

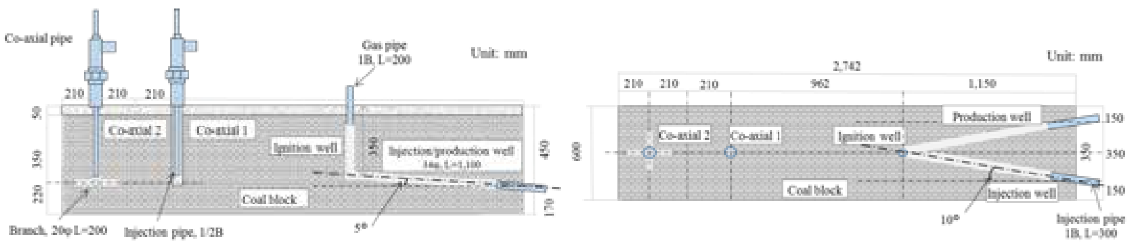
Figure 2 – Concept of UCG system.

## UCG MODEL EXPERIMENT

Ex-situ UCG model experiments were conducted using coal blocks from 4–11 and 17–24 August 2015 to collect various data for commercial viability and pilot-scale testing of UCG. Model experiments of three types were conducted: test 1 (co-axial method), test 2 (co-axial method), and test 3 (linking method).

### Experimental Set up and Process

A diagram of UCG model experiments conducted using coal blocks is shown in Figure 3. Coal samples were supplied by the Sanbi Mining Co. Ltd. Some coal blocks of more than 0.5 m diameter were used to construct a simulated coal seam. A mixture of cement and fine coal was filled into the gap separating coal blocks to establish continuous conditions. The simulated coal seam size was 0.55 × 0.60 × 2.74 m. External walls of the simulated coal seam were covered with refractory cement to prevent heat release and gas leakage. Typical proximate and ultimate analyses of the coal are shown in Table 1.



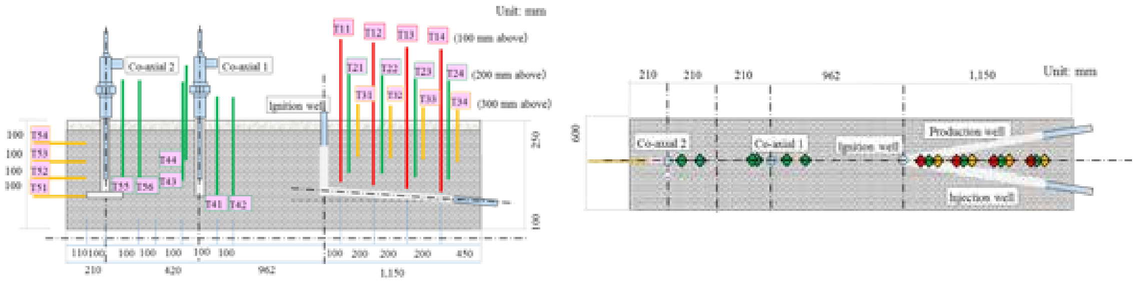

(a) Side view (b) Top view

Figure 3 – Diagram of UCG model experiments.

Table 1 – Proximate and ultimate analyses of the coal

| Calorific value (MJ/kg) | Proximate analysis (wt%) | | | | Ultimate analysis (wt%) | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Moisture | Ash | Volatiles | Fixed carbon | C | H | N | S | O |
| 32.1 | 2.1 | 4.3 | 43.1 | 50.5 | 78.4 | 5.74 | 1.44 | 0.07 | 9.94 |

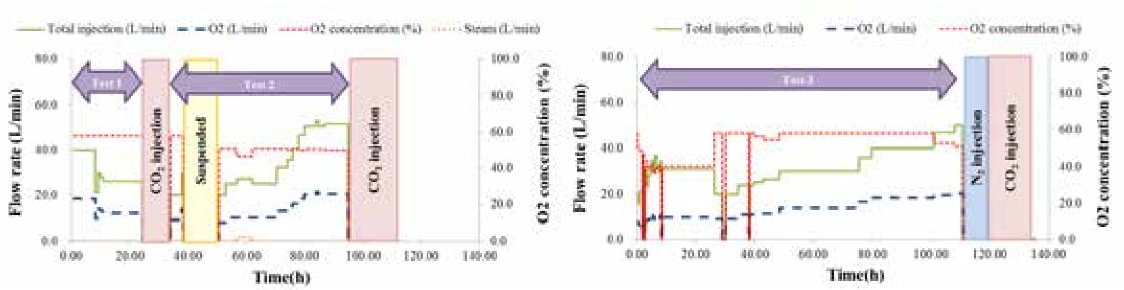
The UCG model experiments were conducted by division into two sections: a co-axial section and a linking section. Two types of a co-axial well were prepared in the former section. A 35-mm-diameter vertical well was drilled in both wells. The floor in one of them was made of 20-mm-diameter branch wells of 100 mm length for expanding the combustion zone. In the linking section, two horizontal wells of 35-mm-diameter were drilled and intersected with one another as an injection and a production well. Additionally, an ignition well was drilled from the surface of a simulated coal seam to the joint of two wells to simulate reverse combustion. Thermocouples were installed to monitor the inner part of the coal seam, as shown in Figure 4.




(a) Side view (b) Top view

Figure 4 – Scheme of thermocouples.

Ignition was conducted with heated charcoal and oxygen until the combustible gas was generated. Heated charcoal was supplied to the bottom of the co-axial wells and an ignition well. In test 2, the experiment was suspended for 5 hr after the ignition because of melting of a co-axial pipe, but the test was continued after installation of a new pipe. Figure 5 portrays the injection conditions used for each experiment. During the experiment, a mixture of air and oxygen was used as a gasification agent. Steam was also injected. Additionally, the total injection flow was increased gradually in tests 2 and 3 with a decrease of combustible components of the product gas. The flow rate of the product gas was measured using an ultrasonic flowmeter. The compositions of synthesis gas ($O_2$, $N_2$, $CO_2$, $H_2$, CO, $CH_4$, $C_2H_4$, $C_2H_6$, $C_3H_6$, and $C_3H_8$) were monitored every hour using a gas chromatograph (Micro GC 3000A; Inficon Co. Ltd.). The total times to inject gasification agents in respective experiments were 23 hr, 51 hr, and 111 hr. At the end of these experiments, $CO_2$ or $N_2$ gas was injected to extinguish the fire. After the process, a mixture of white cement and gypsum was filled into the post-gasification cavity to investigate a cross-section study of the combustion zone. Figure 6 presents the overall scheme of UCG model experiments.




(a) Tests 1 and 2 (b) Test 3

Figure 5 – Gasification agents during experiments.

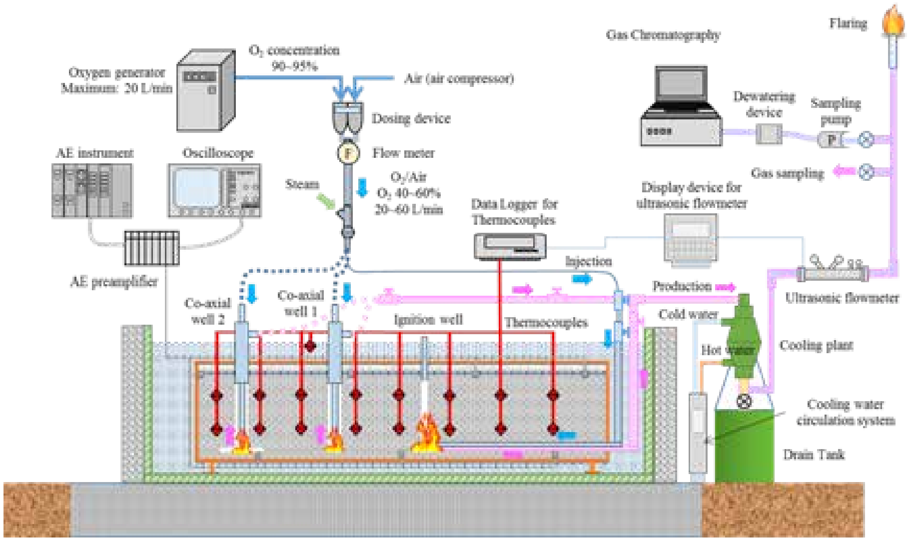



Figure 6 – Overall scheme of UCG model experiments.

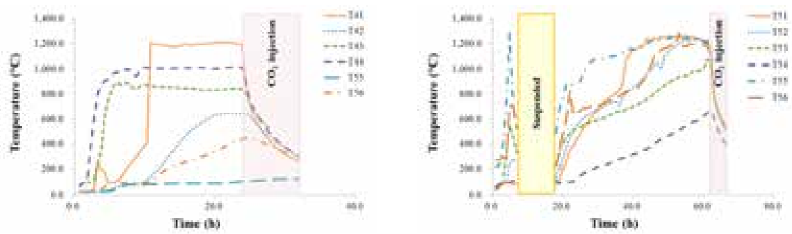
## RESULTS AND DISCUSSION

### Temperature and Cross-Section Study

Figures 7 and 8 present results of temperature profiles for each test. In test 1, the temperature in T44 located in the upper part of a co-axial well increased, reaching over 1,000 °C in the initial stage of the experiment. Subsequently the temperatures increased in T43, T42, and T41. These results indicate that the combustion zone moved in a downward direction along a co-axial well.

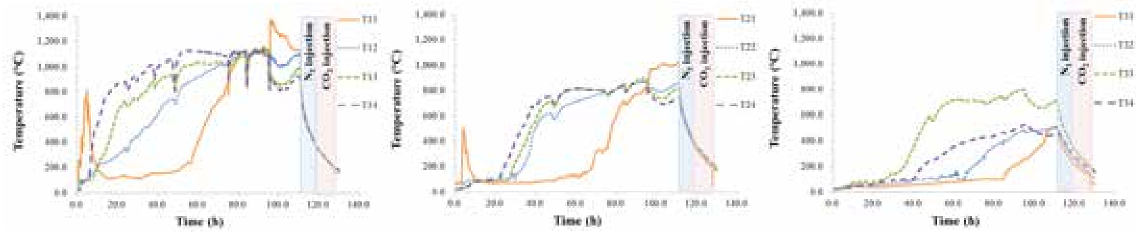
In test 2, the temperatures around the base of co-axial well, T51, T52, T55, and T56, are mainly increased. They reached over 1,200 degrees by the end of the experiment. This fact means that the combustion zone was expanded from the bottom of a co-axial well in an upward direction. The reason for the difference of the expanding direction in tests 1 and 2 remains unclear. However it is expected to be affected by the concentrations of oxygen or the branch wells prepared in the bottom of a co-axial well.

In test 3, the temperatures increased in T11 and T21 near the ignition area. These temperatures, however, decrease rapidly after a few hours. Then T14 and T13 around the inlet of oxidant show a drastic increase of temperatures. This fact indicates that the combustion zone was expanded at the beginning, not from the ignition area but from the oxidant inlet. Moreover, test 3 simulated forward combustion because the temperature elevation occurred along an injection well toward the flow of oxidant. Yong et al. (2014) pointed out the difficulty of laboratory experiments on reverse combustion because of the coal characteristics and dimensions of the experiments. Test 3, therefore, switched from reverse to forward combustion because the gasification channel length was insufficient for the velocity moving a fire. Finally, the combustion zone was expanded in a wide range because most of thermocouples show more around 900°C. Furthermore, the effect of fire extinction by an injection of $CO_2$ or $N_2$ gas was confirmed in all tests.



(a) Test 1 (b) Test 2

Figure 7 – Temperature profiles in co-axial tests.




(a) 0.1 m above the channel (b) 0.2 m above the channel (c) 0.3 m above the channel

Figure 8 – Temperature profiles in linking test.

Figure 9 presents an estimation of the post-gasification cavity based on a cross-section study, as shown in Figure 10. In test 1, the combustion zone is expanded around the upper part of a co-axial well, not the lower part. However, in test 2, the zone is expanded in both upper and lower parts. Test 3 shows the largest post-gasification cavity among the experiments. The combustion zone is expanded along an injection and a production well in an especially wide area. These results agree with those obtained from temperature profiles.

These results suggest that the gasification period and combustion zone can be improved in a co-axial UCG system by expansion of the reaction zone in the bottom of a well and the gradual increase of injection flow. The combustion zone, however, is limited to the area around a co-axial well. Moreover, the gasification period is shorter than that of the linking method, which is a conventional UCG system. Consequently, additional techniques to upgrade the co-axial UCG system must be discussed: expanding the combustion zone by crack development artificially and extension of co-axial wells through directional drilling.

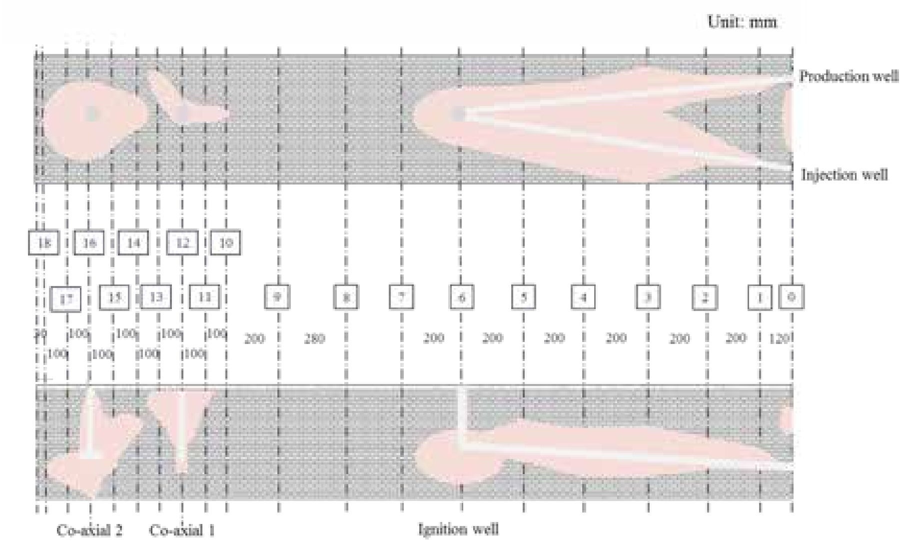



Figure 9 – Estimation of post-gasification cavity.

(a) Test 1 (b) Test 2

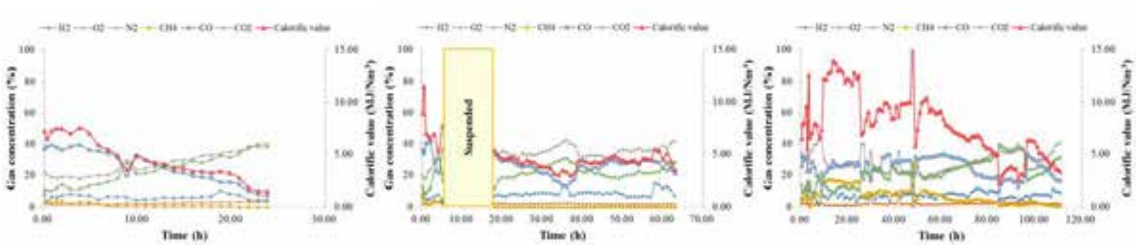
(c) Test 3

Figure 10 – Cross-section study.

**Compositions of product gas and calorific value**

Monitoring results of the main compositions and the calorific value of a product gas are presented in Figures 11(a)–11(c). The gas concentrations of tests 1 and 2 show a similar tendency. The CO contents and the calorific value increased, respectively, immediately after ignition in tests 1 and 2. Then, the $CO_2$ contents increased, whereas those of CO and the calorific value decreased gradually. In fact, $H_2$ maintains a stable concentration during each experiment. Also, $CH_4$ is little detected constantly. At the end of test 1, the CO contents and the calorific value were decreased to 10% and 1.5 MJ/Nm$^3$. The $CO_2$ contents were 40%. Nevertheless, a stable value was maintained in test 2 because of its gradually increased injection flow: the CO contents were 25–30%, the calorific value was 4.5MJ/Nm$^3$, and the $CO_2$ contents were 20%. Steam injection usually enhances $H_2$ production (Yang et al., 2008). The effect of steam injection to the product gas, however, was not clear in test 2. For that reason, the effect of steam injection was too small to enhance the chemical reaction.

The monitoring results obtained for test 3 exhibit differences from those of tests 1 and 2. The CO contents remain at about 30% until 70 hr elapsed from the beginning of test 3. The calorific value and $CH_4$ show a similar tendency: they showed a higher value during 10–24 hr, and decreased gradually after 60 hr had elapsed. Actually, $H_2$ maintained a stable concentration during the experiment. Additionally, the combustible contents and the calorific value increased after 95 hr because the inlet of oxidants was changed from an injection to an ignition well to promote the gasification reaction on the production well side. According to product gas results in each experiment given in Table 2, the average calorific values in co-axial UCG system are similar: 4.68 MJ/Nm$^3$ in test 1 and 4.75 MJ/Nm$^3$ in test 2. In contrast, the average calorific value in test 3 is 7.78 MJ/Nm$^3$, which is much higher than that of a co-axial UCG system.



(a) Test 1 (b) Test 2 (c) Test 3

Figure 11 – Main compositions and the calorific value of a product gas.

Table 2 – Average calorific value and compositions of product gas

| | Calorific value (MJ/Nm$^3$) | $H_2$ (%) | CO (%) | $CH_4$ (%) | $CO_2$ (%) | $C_2H_4$ (%) | $C_2H_6$ (%) | $C_3H_6$ (%) | $C_3H_8$ (%) |
|---|---|---|---|---|---|---|---|---|---|
| Test 1 | 4.68 | 6.17 | 26.09 | 1.19 | 22.59 | 0.17 | 0.01 | 0.01 | 0.00 |
| Test 2 | 4.75 | 8.09 | 26.38 | 0.61 | 21.05 | 0.18 | 0.02 | 0.02 | 0.00 |
| Test 3 | 7.78 | 7.24 | 24.89 | 6.94 | 21.93 | 0.61 | 0.46 | 0.15 | 0.11 |

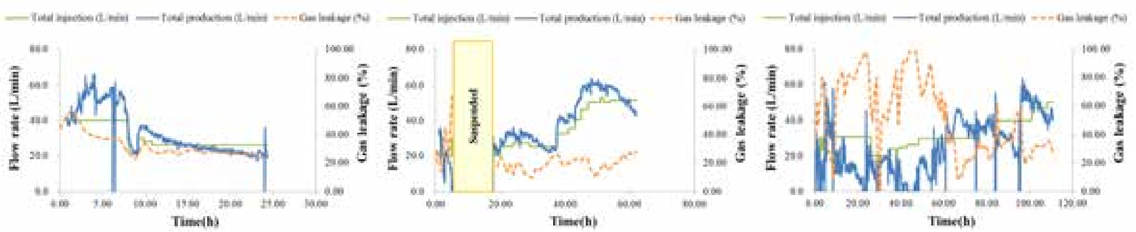
**Assessment of Energy Recovery**

The total energy generated from coal is calculable by the calorific value and the product gas flow rate. The effect of gas leakage, however, must be regarded as predicting the energy generation as gaseous products because a great amount of gas leakage occurred during each experiment. The gas leakage can be assumed by the amount of nitrogen, which is an inert content not related to chemical reactions in the UCG process. Figures 12(a)–12(c) present results of an assumption of gas leakage based on the amount of nitrogen included in injection and product gases. According to these results, the energy generation, listed in Table 3, is calculated based on an assumption that the gas compositions are the same as those of the gas leakage and product gas as shown below.

$$E_{\mathrm{T}} = \sum \frac{H_{\mathrm{V}} \times V_{\mathrm{P}}}{R_l} \times 100 \quad (1)$$

$$E_{\mathrm{A}} = E_{\mathrm{T}} / t_g \quad (2)$$

In those equations, $E_{\mathrm{T}}$ stands for the total energy (MJ), $H_{\mathrm{V}}$ signifies the calorific value of product gas (MJ/Nm$^3$), $V_{\mathrm{P}}$ denotes the measurement flow rate of product gas (Nm$^3$/h), $R_{\mathrm{l}}$ represents the gas leakage (%), $E_{\mathrm{A}}$ is the average energy (MJ/h), and $t_{\mathrm{g}}$ represents the total gasification period (h).




(a) Test 1 (b) Test 2 (c) Test 3

Figure 12 – Flow rate of inject and product gases, and the assumption of gas leakage.

Table 3 Total and average energy recovery

| | Test 1 | Test 2 | Test 3 |
|---|---|---|---|
| Total energy (MJ) | 383.2 | 673.4 | 2804.8 |
| Average energy (MJ/h) | 16.0 | 13.2 | 25.3 |

Slight differences exist between the average energy generation in tests 1 and 2, which simulated a co-axial UCG system, but the total energy in test 2 shows a higher value attributable to the longer gasification period. Nevertheless, both energy values in test 3 of the linking method are much higher than that of co-axial method. This finding engenders the conclusion that an expansion of the combustion zone has the effects not only of extending the gasification period but of promoting the gasification reactions.

Balance computation is a useful method to discuss the amount of coal reacted in the UCG process (Wiatowski, 2015). The amount of gasified coal is calculable by the balance of C element, as shown in Table 4. The amount of carbon content in a tar is not included in the balance sheet. The amounts of C element in tests 1, 2, and 3 are, respectively, 20.3 kg, 38.1 kg, and 108.4 kg, meaning that 25.9 kg, 48.5 kg, and 138.3 kg of coal are expected to have been gasified. Considering that the coal calorific value is 32.1 MJ/kg, the gasification efficiency, the energy recovery rate from coal, is calculable using equation (3).

$$R_g = \frac{E_T / W_g}{Q_c} \times 100 \quad (3)$$

where $R_g$ is the gasification efficiency (%), $W_g$ represents the gasified coal (kg), and $Q_c$ stands for the coal calorific value (MJ/kg).

Table 4 Calculation of C balance

| Component | Test 1 | | | Test 2 | | | Test 3 | | |
|---|---|---|---|---|---|---|---|---|---|
| | Total amount of product gas | Balance of C element | | Total amount of product gas | Balance of C element | | Total amount of product gas | Balance of C element | |
| | mol | mol | kg | mol | mol | kg | mol | mol | kg |
| $CH_4$ | 47.2 | 47.2 | 0.6 | 20.0 | 20.0 | 0.2 | 1124.4 | 1124.4 | 13.5 |
| CO | 958.6 | 958.6 | 11.5 | 1726.1 | 1726.1 | 20.7 | 3999.4 | 3999.4 | 48.0 |
| $CO_2$ | 673.1 | 673.1 | 8.1 | 1410.8 | 1410.8 | 16.9 | 3442.6 | 3442.6 | 41.3 |
| $C_2H_4$ | 6.2 | 12.4 | 0.1 | 5.7 | 11.5 | 0.1 | 98.7 | 197.4 | 2.4 |
| $C_2H_6$ | 0.4 | 0.7 | 0.0 | 0.8 | 1.6 | 0.0 | 72.8 | 145.6 | 1.7 |
| $C_3H_6$ | 0.3 | 0.8 | 0.0 | 0.5 | 1.4 | 0.0 | 24.8 | 74.3 | 0.9 |
| $C_3H_8$ | 0.0 | 0.0 | 0.0 | 0.1 | 0.2 | 0.0 | 16.9 | 50.8 | 0.6 |
| Total | 1685.7 | 1692.8 | 20.3 | 3163.9 | 3171.5 | 38.1 | 8779.6 | 9034.5 | 108.4 |

Table 5 Calculation results of gasification efficiency

| | Amount C element (kg) | Gasified coal (kg) | Gasification efficiency (%) |
|---|---|---|---|
| Test 1 | 20.3 | 25.9 | 45.9 |
| Test 2 | 38.1 | 48.5 | 43.2 |
| Test 3 | 108.4 | 138.3 | 63.2 |

Table 5 presents the calculation results for gasification efficiency. The values of gasification efficiency in tests 1 and 2, which simulate a co-axial UCG system, were 45.9% and 43.2%. By contrast, that in test 3 of linking method was 63.2%. Comparison of the results shows that a co-axial UCG system has lower efficiency for energy recovery from coal than that of a conventional UCG system because of the low quality of product gas. The product gas quality depends on reduction during the UCG process, meaning that temperature field is strongly affected. Therefore, it might be possible to estimate the gasification efficiency by creating a proper numerical model. Additionally, improvement of the product gas quality, such as the effects of injection conditions and steam injection, must be discussed to improve the gasification efficiency in a co-axial UCG system.

## CONCLUSIONS

The co-axial UCG system is a compact, safe, and highly efficient system which can be adopted even under geological conditions that are complicated by the existence of faults and folds. Results show that the gasification period and zone can be improved by an expansion of the reaction zone in the bottom of a well and a gradual increase of injection flow in a co-axial system. However, the system demands more consideration to improve the combustion zone and gasification efficiency. To develop a more efficient UCG system, the improvement of injection conditions, the effects of steam injection, and expansion of the combustion zone by artificial crack development will be investigated examined as future challenges.

## ACKNOWLEDGMENTS

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# MODELING OF GEOMECHANICAL PROCESSES IN ROCK MASSIF AT MINING OF SOLID MINERALS DEPOSITS

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# MODELING OF GEOMECHANICAL PROCESSES IN ROCK MASSIF AT MINING OF SOLID MINERALS DEPOSITS


## ABSTRACT

This article has described approaches to modeling state and behavior of the components in the system of mining a bedded deposit (coal seam), which are of the highest concern from the standpoint of mining safety. In this case, the roof subsidence of the coal seam and the phenomenon of "sudden spalling" of edge coal. Roof subsidence is a function of many parameters that are often difficult to assess in a mine. The model of “sudden spalling" of edge coal has been founded on the common physical notions and laws of deformation and motion, and excludes any empirical relations typical of the considered modeling domain. At the same time, the model has succeeded, though not in full measure, to yield the results observable in actual coal mining. This is the formation of an extended zone of sheared coal-spalling zone-reaching 10–15 m and more in size under coal and gas outbursts. and this is the actually known fact that maximum abutment pressure is shifted under sudden gas-dynamic event. The two examples of the geomechanical studies into the state and behavior of coal seam mining elements illustrate the general provisions of rock mass deformation modeling given in the beginning of the article.



## KEYWORDS

Mathematical modeling, coal seam, roof subsidence, destruction, sudden spalling,


## INTRODUCTION

Safe and efficient mining is only possible with the comprehensive preliminary analysis of geomechanical scenarios induced by accessing, preparation and mining of a mineral. The geomechanical analysis is to identify most rational parameters of mining systems, detect probable critical states due to disastrous phenomena in rocks and to formulate appropriate predictive criteria. Eventually these objectives are unachievable within the phenomenological approach. It is a common practice to perform such analysis using geodynamic models showing the structure of rock mass and indicating technological aspects of a mining system to be used. Appropriateness of a chosen geomechanical model is defined by the contiguity between the model data obtained for a specific problem and the actual measurements taken in rock mass (Zakharov, 2011). The geomechanical analysis increasingly uses methods of 3D mathematical modeling to describe the state and behavior of rock mass and mineral deposit, both in mine planning and actual mining. 3D mathematical modeling of stress state at the stage of mine planning allows spotting adverse induced geomechanical processes that initiate disastrous geodynamic events, and determining the safest mining flowcharts that to a maximum degree account for geology, geotechnology and mining equipment employed.

The process of mathematical modeling—analysis of an object using a mathematical model—can conventionally be divided into four interrelated stages: formulation of laws describing behavior of an object in mathematical terms; solution of a direct problem, i.e. the model-based analysis of values of wanted parameters for the comparison with the data of field evidence on the modeling object; adjustment of the model in conformity with the field observation data and solution of inverse problems, i.e. adjustment of the key model parameters accepted originally within allowable ranges; analysis and updating of the model as new information on the object under study is obtained, gradual transition to a new improved model.

Majority of effective stresses (gravitational and modern tectonic) exhibit nonprobabilistic distribution, and the field of such stresses has a certain level within a rock mass and is uniform, or slightly alters along principal axes. Stresses associated with random unordered discontinuities in rock mass structure represent local perturbations of the main field of modern stresses and show themselves as local rock failures under mining-induced deformation. For this reason, all modern local stresses along with structural discontinuities should be reckoned among characteristics of strength and deformation of rock mass and its components. An exception is the pronounced local discontinuities comparatively large in size, which should be considered at certain stages of investigation of strata pressure or rock mass movement as separate structural elements with intrinsic strength and deformation characteristics.

Initially, when studying state and behavior of rock masses, it is always advisable to use simplified, idealized models of deformable media, simulating excavations by cuts conforming with mined-out voids. Such models with the well-developed dedicated mathematical apparatus to solve problems of rock mechanics enable most efficient exploration of mechanisms of large-scale redistribution of stresses and movements in rock mass, or formation of stress concentration and relaxation zones. Furthermore, it is always possible to sophisticate the models or to add them with other models, for instance, models of long fractures, in order to reveal their influence on the adjacent rock mass rock behavior. As a rule, many concerns connected with the presentation of the reality within elasticity models get withdrawn as a result.

The review of numerous experimental data on deformation of overlying rocks above an excavation shows that rock mass strains, either linear or angular, are very small, especially for deep-level excavations. This offers ground to describing overlying rock mass behavior using methods of continuum mechanics, in particular, linear elasticity. With the computer technologies, this problem is solvable with any boundary conditions preset: displacements, loose arching or abutment. Rock mass is assumed linearly elastic in this case, with Young's modulus $E$, Poisson's ratio $\nu$ and average relative density $\gamma$. Computer technologies involved in geomechanical analysis are based on advanced numerical methods to calculate stress state using software packages. The algorithm–backbone of computational tool of many program products is the finite element method.

## BEDDED DEPOSIT

The primary problems to be solved in geomechanical modeling of mining of bedded deposits are estimation of state and behavior of pillars, mined-out void roof and coal seam edges. Each of the listed structures is of specific nature and features distinctive mechanisms of deformation and failure; nonetheless, all these problems are possible to solve within a single geomechanical model embracing all these structures in the volume of rock mass. This approach is expedient when different structures and zones mutually influence each other. On the other hand, it is required to have much more computational resources for the finite element modeling in order to present details of the structures and zones under analysis. A rational geomechanical approach in the framework of a unified geomechanical model requires simplification of the general problem when possible, by generating detail finite element mesh only for the rock mass area under study. In this fashion, a unified geomechanical model can yield a series of finite element models to analyze various events due to rock pressure.

From the standpoint of mine safety and operational integrity, the most hazardous situation is the unexpected roof subsidence, which happens cyclically, with face advance.

## CONCEPTUAL MODEL OF ROOF SUBSIDENCE

Although rock mass is a block-structure medium (Sadovsky, Bolkhovitinov & Pisarenko, 1982), mining generates extended unsupported roof spans subsiding under rock weight, that actually are plates with the clamped edges and are well described using a plate theory.

Sagging of roofs composed of incompetent sandstone layers is conditioned by delamination. Delamination takes place along planes with low mechanical strength, composed of coaly, marly or mica interbeds, and along probable slip bands. Finer layers of rocks composing immediate roof and false roof fall in a mined-out cavity as extraction is advanced. Main roof, keeping integrity, bridges the mined-out cavity partly filled with caved rocks of immediate roof, deforms and gradually subsides in the course of mining. Some time main roof may come into contact with caved rocks. In this case, the plate (main roof) acquires additional support from the caved rocks, which reduces the main roof deflection and, accordingly, lowers horizontal stresses that induce transverse fractures. When the main roof sagging is sufficiently large but the main roof is yet not supported by the caved rock, or it compresses then insufficiently, the main roof fails. There are two types of the main roof collapse—primary and secondary subsidence at certain frequency, a quantitative index of which is the roof caving increment (Borisov, 1980). Under roof collapse, loads applied on support pillars, floor and roof change instantaneously, shock loading and stress relaxation take place in different areas in rock mass. Forecasting of the primary and secondary roof subsidence is the essential component in planning methods and means to ensure coal mine safety.

## NUMERICAL MODEL OF ROOF SUBSIDENCE

When solving problems on roof collapse in excavations without support pillars in a bedded deposit, it is assumed that the problem is symmetrical relative to the planes $x = 0, y = 0, z = 0$, which reduces the problem to an eighth of the rock mass, including the mined-out void (Figure 1). Production coal seam 1 occurs at a depth $H$=500 m. It is also assumed that the roadway roof does not contact caved rocks. Partial and, moreover, total subsidence of roof considerably changes deformation process and is withdrawn from the present study as a subject for separate research.

The problem is solved in terms of complementary stresses, i.e. stresses in rock mass with exposures are given by:

$$\sigma_x = \sigma_x^0 + X_x,\quad \sigma_y = \sigma_y^0 + Y_y,\quad \sigma_z = \sigma_z^0 + Z_z, \tag{1}$$

where $X_x, Y_y, Z_z$ are the complementary stresses due to drivage, $\sigma_x^0, \sigma_y^0, \sigma_z^0$ are the original stresses.

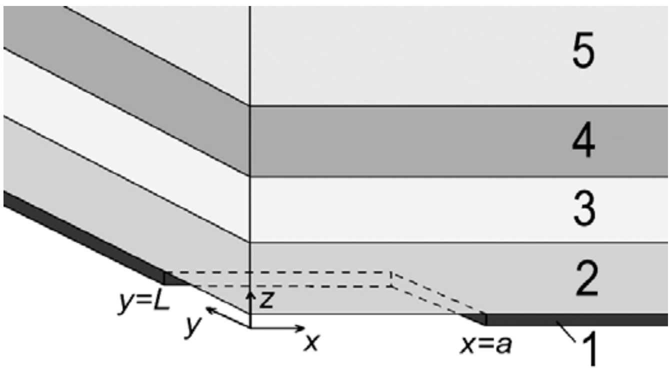



Figure 1. Schematic plot of the problem on roof deformation in bedded deposit.

This approach assumes that the computational domain undergoes loading by stresses that act over new exposures but are taken with the opposite sign. In particular, on a rectangular exposure of a roadway roof, i.e. when $0 < x < a$, $0 < y < L$ and $z = h$, it is set that $\sigma_n = -\sigma_z^0$, $h$—thickness of coal seam. Considering smallness of $h$ as against $H$, it is acceptable that $z = 0$ and, finally:

$$\sigma_n = 500\gamma, \tag{2}$$

$\gamma$ is the average density in depth.

On side exposures in a roadway, again due to smallness of $h$:

$\sigma_n = 500\gamma$ at $x = a$, $0 < y < L$, $0 < z < h$,

$\sigma_n = 500\gamma$ at $y = L$, $0 < x < a$, $0 < z < h$.

Solution of the problem with such boundary conditions for a preset domain will make it possible to find the addition stresses $X_x, Y_y, Z_z$, and, with provision for (1), the total stresses in rock mass with openings. Some difficulties arise due to gaping fractures. Initially, location and geometry of gaping fractures are unknown as distinct from the data on excavations. Nonetheless, in accordance with the general approach, the surfaces of such fractures are free surfaces, too, and it is required to preset normal stresses at such free surfaces as on exposures in excavations. The calculations involved finite element package ANSYS with automatic variation of contact conditions at the preset surfaces (Trofimov & Filippov, 2015). The surfaces should be preset beforehand.

As to uncertainty of a fracture length, it is worth making allowance for the following features of ANSYS. The computational domain is composed of a number of contacting bodies with probably different deformation characteristics. In the case discussed, these bodies are five layers representing the roof and coal seam (Figure 1). Actually, each contact of the layers is two surfaces belonging to the contacting layers. The boundary conditions can be set at each of the surfaces. ANSYS automatically places required finite elements between these surfaces to implement the preset boundary conditions at them when the computational domain is subjected to deformation. Such boundary conditions may include total adhesion of the surfaces, sliding with and without friction, non-widening of a gap between the surfaces, etc. In the case under analysis, at the both surfaces along the contact, normal stresses should be set so that to fit the original stresses at the same points of the contact but with the opposite sign, as it has been done for the excavation. Under rock mass deformation, in places where the gap between the surfaces widens, the necessary boundary conditions in terms of stresses will be set automatically. In places where no widening of the gap takes place, the efficient loads mutually compensate as the surfaces cannon penetrate one the other. As the result, the condition of the rock mass continuum is materialized. This approach may include an iterative procedure of the problem solving.

Extraction of coal violates equilibrium in rock mass, and deformation processes are initiated. All strains are localized above the mined-out void and are spatially bounded within an ellipsoid-like body with half-axes *a, L* in the horizontal section. Vertical extent of the noticeable displacements depends on the minor value, *a* or *L*, and is equal to it approximately. This is the zone of vertical tensile stresses (Kuznetsov & Trofimov, 2000; Kuznetsov & Trofimov, 2012). Given the tensile strength of the contacts is low and some areas of the contacts fall in the vertical tension zone, gaping fractures initiate in these areas and are filled with methane desorbed from coal. Growth of such fractures induces the risk of methane inflow in underground excavations, which creates danger of high gas content of mine air and air-and-methane mix explosions. Figure 2 illustrates the calculated configuration of gaping fractures and distribution of vertical displacements above the mined-out cavity. The vertical scale is changed for the sake of demonstrativeness. Delamination greatly increases the roof sagging. Fracturing results in elimination of interaction between the roof layers. In this way, subsidence of main roof in a long roadway is almost in full equivalent to sagging of thick heavy plate with different conditions of clamping along the plate perimeter. Currently, there are many available methods to estimate mined-out void roof subsidence mainly based on the theory of plate with a plastic hinge.

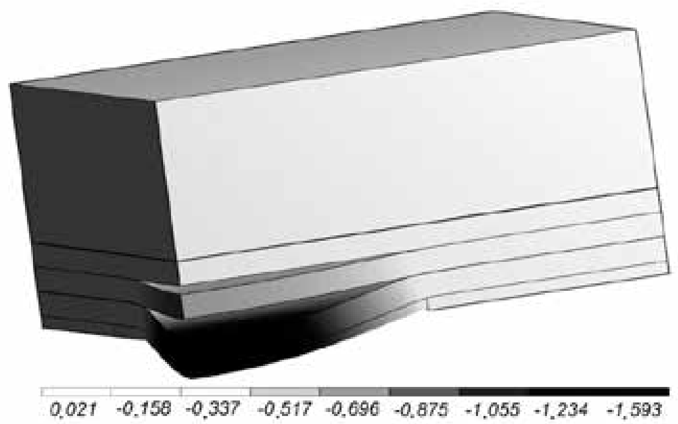



Figure 2. Vertical displacements in roadway roof rocks.

At a certain advance of production face under particular conditions, transverse fractures may initiate and intersect the main roof along the normal. The most probable orientation of such fractures is along straight lines through the center of mined-out void in parallel to the face and along the face advance. These are the lines of the major horizontal tensile stresses at the lower surface of the roof. When these stresses exceed uniaxial compression strength of the roof rocks, gaping fractures emerge in the roof. It is noteworthy that initiation and widening of gaping fractures in many ways depends on the condition of the roof above the seam edges. i.e. on all the four sides of mined-out cavity. At the upper surface of the roof, normal horizontal tensile stresses may also appear and initiate gaping transverse fractures that partly embrace the perimeter of the mined-out cavity. Such fractures are initiated under face advance, at the center of each side of a rectangle, and grow over larger part of its perimeter. This process is illustrated in Figure 3, in plan view: 1—coal seam; 2—face and direction of the face advance; 3—fracture above the boundary of mined-out cavity; 4—fractures at the lower surface of the main roof; 5—mined-out cavity.

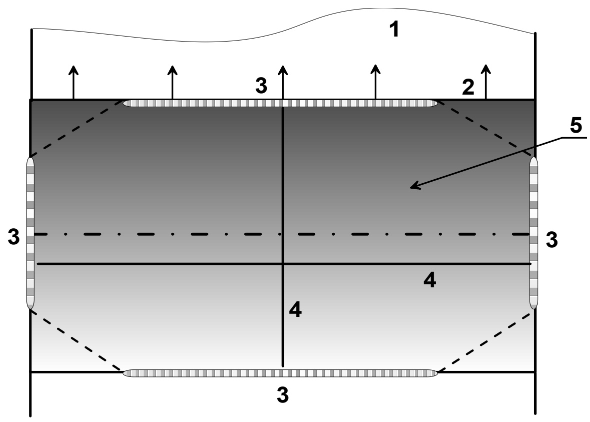



Figure 3. Schematic drawing of mined-out cavity roof.

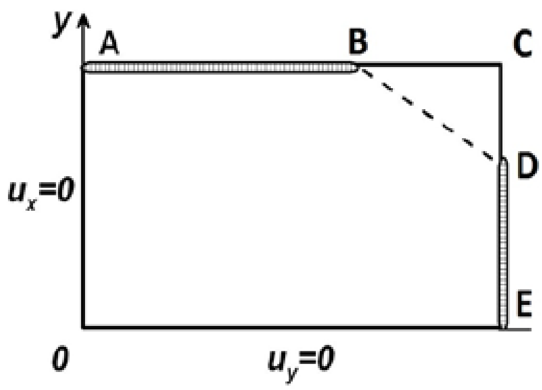
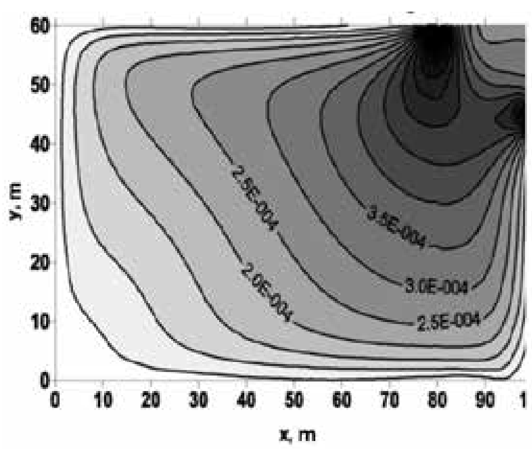


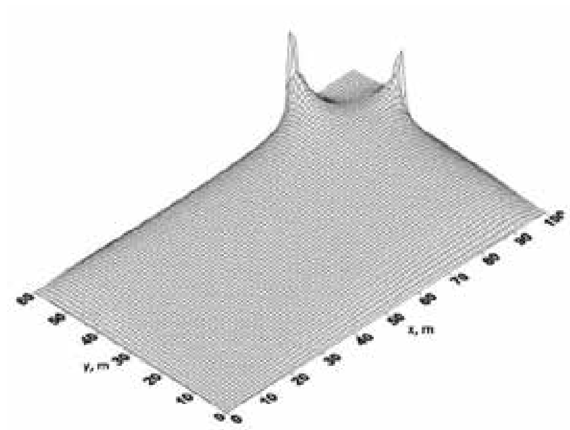

Figure 4. Analytical model of mined-out cavity roof.

Actually, formation of fractures is a more complicated process though readily modeled. As a matter of fact, fracturing along the center lines does not mean total failure of the roof. As the face is continuously advanced, a fracture induced in the middle of the mined-out void grows, from the one hand, though the roof remains stable, and, on the other hand, prevents a new crack initiation. In such a manner, asymmetry of roof deformation, well known in practice, is formed. In case of symmetrical propagation of failure, it is sufficient to analyze a forth of the plate due to the problem symmetry (see Figure 4). It is assumed also that for the generated rectangular parallelepiped, at the ribs $x$ = 0 m and $y$ = 0 m when z = 15 m (spacing of the roadway roof and the main roof), displacements along the normal, i.e. $u_x$ and $u_y$, respectively, equal zero. The faces of the parallelepiped are stress-free when a fracture initiates, and can displace in accordance with the plate equilibrium conditions. In the sections AB and DE, where the gaping fractures have formed, it should be set that there are no constrains for any degree of freedom, both at the ribs and at the faces. In the sections BC and CD, full restraint is set along all coordinates and for all displacements. The plate as if hangs in this part of the boundary. Loading is only due to proper weight of the plate.

Figure 5 shows isolines of principal strain distribution over the top surface of the plate (roof) and spatial distribution of strains for the sake of visualization. Expectedly, strains feature unlimited values at the points B and C. Put it otherwise, failure can initiate at these points of the plate. In the section BC dotted in Figure 4, strains are comparatively high, too, which implies that failure of the plate may propagate along this line or close to it. In this manner, the oval-like perimeter of the roof failure is formed.




(a) isolines of major principal strains




(b) spatial distributions of major principal strains

Figure 5. Major principal strains in the model.

## CONCEPTUAL MODEL OF DEFORMATION IN COAL SEAM EDGE

Coal mining with longwalling usually causes spalling; coal gradually disintegrates and softens in spalling zones. Width of such zones is variable depending on the specific ground conditions of coal occurrence and is mainly 2–4 m, though this value may differ greatly sometimes. As cutter-loader moves forward, the spalling zone is shifted depthward the seam by value of the cut width on average (Borisov, 1980; Mining Encyclopedia. Moscow, Sovetskaya Entsiklopedia, 1989). The key determinant for the extent of the spalling zone is variability of strength characteristics of coal and rock interfaces in the roof and floor. After possible alternatives of strength distributions per interfaces have been analyzed, conditions for stable advance of spalling zone in coal seam at successive cuts are defined. It is possible that propagation of spalling zone becomes unstable when the face is advanced in the region, where coal and rock interfaces exhibit high shear strength, and approaches a weakening area. A so-called sudden spalling may occur in the edge of the seam, which enlarges the spalling zone up to 10–15 m and above for a small time period of the order of 0.1 s (Kuznetsov & Trofimov, 2010; Trofimov, 2014).

Such problems are as a rule solved with the sufficiently accurately known data (thickness of coal seam, mining depth, length of longwall and mined-out void, elastic and deformation characteristics of coal and sidewall rocks, i.e. their ranges and average values). Usually, initial stresses in rocks are known incredibly. Even higher uncertainty grasps strength characteristics of coal, sidewall rocks and their interfaces. It is possible to describe nonlinear deformation associated with coal failure in edges of coal seam within a plastic model but its parameters are highly uncertain, as well. In view of such a situation connected with source data required for problem solution, it may be concluded on impossibility to have any significant quantitative results to describe coal seam state and behavior. Nevertheless, actual coal mining has revealed many quantitative mechanisms of both dynamic and quasi-static events due to rock pressure. Using this as the basis, mathematical modeling aims to display rock mass behavior under varied combinations of the above listed characteristics and to show if there are combinations of real values of such characteristics when deformation changes from quasi-static to dynamic mode. It is of importance to identify the governing parameters. Unknown parameters may vary within sound ranges, and their critical values for dynamic events of rock pressure are found as a result. Thus, the goal of mathematical modeling in this case is not the prediction of place, time and intensity of an event but finding the general laws of development of such events. The discussion below proceeds from these general provisions.

The problem formulation is illustrated schematically in Figure 6. The problem is two-dimensional, and straight lines $x = 0$ and $z = 0$ are assumed the symmetry axes. The mining depth $H$ = 500 m, the seam thickness $2h$ = 2 m, the initial length of mined-out cavity $L$ = 80 m. The computational domain is 100×60 m. The areas with different particularization of finite elements are shown with tints of grey in the figure. The darker zones are finer elements 0.2 m in size. The key subject to be examined in more details is the coal seam and its vicinity, i.e. zones of small length and depth, where stresses change slightly. This allows supposing that both in these zones and in the entire computational domain, it is possible to set constant initial $\sigma_x^0$ and $\sigma_y^0$ equal to 12. 5 and 12.5 MPa, respectively, as is consistent with the depth $H$. Such assumptions considerably simplify problem solution with the essence of the studied processes kept untwisted. Delamination of the seam roof is neglected, which allows disregarding sheeting of the roof in the course of mining. All rock composing the roof are assumed elastic, with $E = 3 \cdot 10^{10}$ Pa and $\nu = 0.25$. the coal seam is elastic, too, with $E = 2 \cdot 10^9$ Pa, $\nu = 0.28$, and density $\rho = 1300$ kg/m$^3$. The problem solution involves complementary stresses, therefore, the only load applied to the boundaries of the computational domain is the normal stress $\sigma_x = -\sigma_x^0 = -12.5$ MPa at the face and the normal stress $\sigma_y = -\sigma_y^0 = -12.5$ MPa at the mined-out area roof. In this regard, displacements and velocities in rocks are calculated correctly. The total stress to be found needs adding the calculated complementary stresses with the respective initial stresses. Thus, the problem formulation encompasses all possible simplifications made to assess dynamics of elastic recovery of the seam when its cohesion with sidewall rocks is lost.

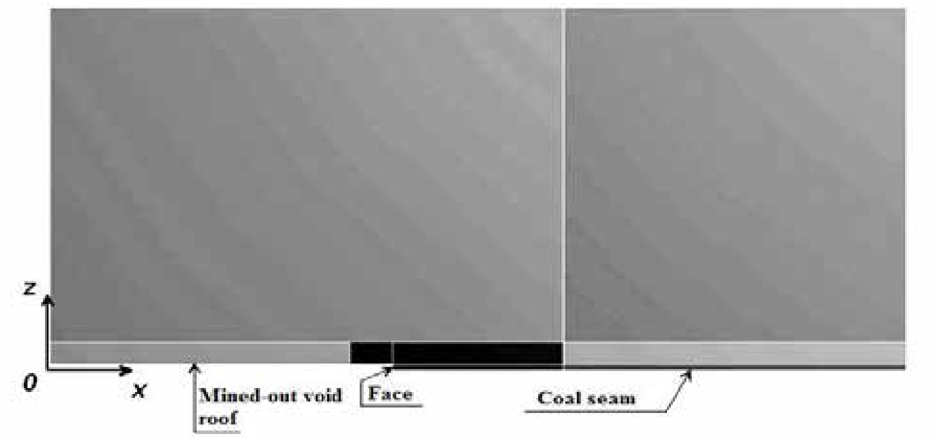
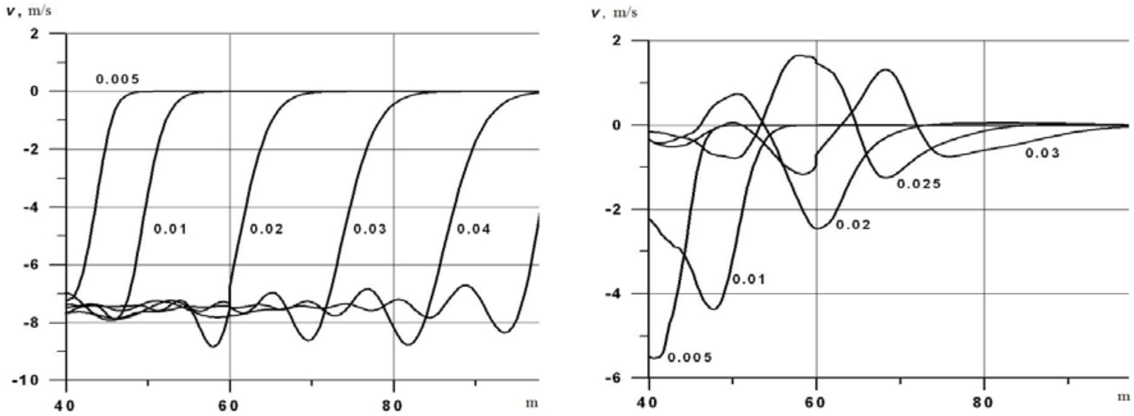



Figure 6. Computational domain.

## FEATURES OF DEFORMATION AND WAVE PROCESSES UNDER SUDDEN SPALLING IN COAL SEAM EDGE

The primary test calculation involves a condition of no interaction between the seam and sidewall rocks along the entire perimeter of the contact. This deformation mode can be implemented in the accepted model by setting relevant boundary conditions. One-dimensional deformation envelopes the seam only and can be described using the known analytical solution or by a finite-difference solution readily derived from the one-dimensional formulation (Kuznetsov & Trofimov, 2014). In this case, the velocity of the one-dimensional elastic wave, or relaxation wave, is estimated in accord with the relation $v = \sqrt{E/\rho}$ and equals ~ 1200 m/s for the values of the parameters accepted in the problem. The wave covers the distance of 60 m, i.e. spacing of the face and computational domain boundary, for ≈ 0.05 s. In the analytical model in use, the wave is reflected from the boundary and heads on the face. This does not happen in the reality, that is why the calculated data can only be considered at $t < 0.05$ s. Figure 7a shows velocity distributions of coal seam points at different times: 0.005, 0.01, 0.02, 0.03, 0.04 and 0.05 s. Hereinafter in the figures, the numbers specify the given curve time in seconds.

Later on, force interaction starts at the whole coal and sidewall rock interface. Friction is set at the seam roof section 40 m $<x<$60 m, and adhesion is assigned at the section 60 m $<x<$100 m, which means that closure at the interface is possible but absolute displacement is prohibited. This considerably complicates the wave pattern as sidewall rocks are involved in the motion, though the relaxation wave is still traceable, although on a smaller time interval (Figure 7b). "Smearing" intensifies at the wave front and maximum velocity of coal seam points drops. In other words, the disturbing wave gradually attenuates while propagating depth-wise the seam. Oscillations in the rare of the wave have higher amplitude than at the weave front. The velocity of relaxation wave grows. From Figure 7b, it is equal to ~ 2000 m/s (versus ~ 1200 m/s in Figure 7a). It can be supposed that in this case, it is valid that $v = \sqrt{E/\rho(1-2\nu)}$, which is applicable to an infinite medium and yields $v$ = 1900 m/s with the accepted values of the parameters. The wave velocity in sidewall rocks is ~ 4900 m/s.




(a) no seam and sidewall rock interaction

(b) friction coefficient 0.3 at seam and side wall interface

Figure 7. Velocities of coal seam points at different times.

Aside from the force interaction at the coal seam and sidewall rock interface, the description of failure in the spalling zone uses the model of plastic deformation of coal. The form of the law of plastic deformation is of no importance as there are no actual data on the parameters of coal seam deformation. Of importance is the fact that deformation parameters decrease in the zone of stress concentration, i.e. coal seam gets softer. Accordingly, coal seam is relaxed and stress concentrations reduce and are redistributed to other areas of the seam. This allows using the simplest bilinear plasticity model, and its parameters are selected so that to ensure real values of spalling, its rate, time, etc. Prior to sudden spalling, i.e. before a new exposure appears after a cut, the normal stresses at the face are conditioned by the elastic deformation of rocks. As a result of using the plastic model of coal seam deformation, the maximum abutment pressure is generated at a certain distance from the face. The position of the maximum abutment pressure zone is not fixed for the considered times (to 0.05 s), but at the maximum time, this zone is ≈ 12–13 m away from the face (Figure 8). In this zone, plastic deformation and failure of coal takes place.

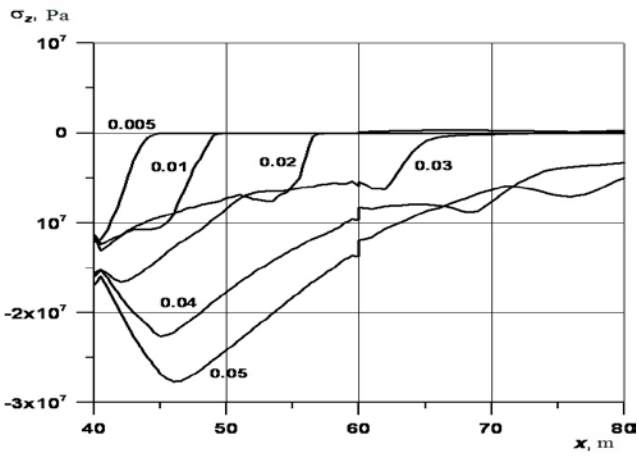



Figure 8. Normal compressive stresses at coal seam at different times.

**CONCLUSIONS**

This article has described approaches to modeling state and behavior of the components in the system of mining a bedded deposit (coal seam), which are of the highest concern from the standpoint of mining safety.

Roof subsidence is a function of many parameters that are often difficult to assess in a mine. These parameters are the structure of overlying rock mass, the presence of transverse fractures in the roof, the properties of interfaces of roof rock layers, the strength and deformation characteristics of rocks, etc. A variety of probable combinations of these parameters conditions the diversity of variants and scenarios of roof rock deformation, including dynamic events with disastrous aftereffects. As a matter of fact, it is highly important to reveal what actually does take place in the stratified roof of a coal seam and to identify key mechanism of events running there, i.e. to construct a relevant conceptual model. Failure criterion for the bedded roof rocks in mined-out voids is the key point of the roof rock stability description. This article considers stress–strain state of roof rocks with an account for possible delamination and transverse fracturing. When transverse fractures initiate in a large portion of the mined-out void perimeter, failure occurs. Dissecting fractures and sagging of the roof are not the cause for its caving but they increase vertical displacements that depend on characteristics of effective deformation of rocks and may reach high values, 1 m and more. Roof rock falls are conditioned by initiation and growth of vertical transverse fractures across rock layers in the roof, which, together with horizontal schistosity, generate an unstable fall-hazardous system. According to the theory of plates, the zones of relaxation and even tension (and, consequently, vertical transverse tensile cracks) should be expected in the middle of the sagging roof rocks and at the lining (above the face). Nonetheless, disintegration and failure of a roof layer can be avoided even with such fractures initiated if the fractures partly intersect this layer, and the layer preserves its load-carrying capacity, since the main roof blocks, bounded by jointing on all sides, can hold under the locking-in effect.

The nature of coal seam edge deformation often has the determining influence in underground coal mining. The present studies illustrate an attempt to modeling a very complex natural phenomenon associated with gas-dynamic events induced in the course of coal mining, namely, sudden spalling of edge coal. The model has been founded on the common physical notions and laws of deformation and motion, and excludes any empirical relations typical of the considered modeling domain. At the same time, the model has succeeded, though not in full measure, to yield the results observable in actual coal mining. First, this is the formation of an extended zone of sheared coal—spalling zone—reaching 10–15 m and more in size under coal and gas outbursts. Second, this is the actually known fact that maximum abutment pressure is shifted under sudden gas-dynamic event.

The two examples of the geomechanical studies into the state and behavior of coal seam mining elements illustrate the general provisions of rock mass deformation modeling given in the beginning of the article.

**ACKNOWLEDGEMENTS**

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# MONITORING $CH_4$, $CO_2$ AND CO CONCENTRATIONS ON THE AIR OF THE UNDERGROUND COAL MINES IN SOUTHERN BRAZIL

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# MONITORING $CH_4$, $CO_2$ AND CO CONCENTRATIONS ON THE AIR OF THE UNDERGROUND COAL MINES IN SOUTHERN BRAZIL


## ABSTRACT

The characterization of air in underground coal mines is important to ensure its quality that is considered fundamental for the safety of workers daily exposed to mining process. This study aims to determine the concentration profiles of the carbon monoxide (CO), carbon dioxide ($CO_2$) and methane ($CH_4$) over the ventilation systems in one coal mine (Mine A, Barro Branco Seam, overburden 180 m, Bituminous High Volatile C coal) located in the Southern Santa Catarina Coal Field, Paraná Basin, Brazil. The samples were collected in alternative glass vials with the aid of 15 mL syringe and brought to the laboratory for analysis by gas chromatography. Were also performed measurements of the air speed, temperature, pressure and relative humidity in different points of the mine. The results indicated that the highest concentrations of $CH_4$ (3,523 ppm) were found in samples collected in areas where there is emanation of this gas. However, the verified lower concentration of $CH_4$ over the venting circuit was 115 ppm**.** For $CO_2$, the point with the highest concentration was collected after the detonation (1913 ppm), and lower along the circuit was 735 ppm. For CO, the point with the highest concentration (255 ppm) was in the area with emanation, varying over from 49 to 255 ppm circuit. As expected, there was an increase in the levels of $CH_4$ and $CO_2$ along ventilation circuit. It should be noted that the highest concentrations of $CH_4$ were found in areas already mined, near geologic layer failures. The $CH_4$ levels are outside the explosive limit at all mine points. The increase of $CO_2$ along the ventilation circuit is related to the exhaustion of combustion engines found on place. $CO_2$ concentrations found in the samples are within the established by Brazilian legislation (NR15) and the North American standard for coal mine (MSHA). However, CO levels in some mine points exceeded the values established by those standards. The determined mass flow rates have higher flows of $CH_4$, $CO_2$ and CO at the outlet of the ventilation system and these and 20, 9 e 154 kg / h respectively. From these results, a first estimate of emissions of greenhouse gases (12,226 t $CO_2$ equivalent per year ) was made. This study indicates the need for a more comprehensive and systematic assessment of air quality of coal mines in the country, aiming at a better assessment of the risks involved.



## KEYWORDS

Coal, concentration, gas, ventilation


## INTRODUCTION

The coal originates from decomposition of organic and inorganic waste, whose disposal has undergone diagenesis processes, compaction and changes because of increases of pressure and temperature. (GWPRF, 2003).

In underground mining environment, various gases are liberated during the coal extraction process. Gases as hydrocarbons (methane, ethane, propane, butane and n-propane) and non-hydrocarbons (carbon dioxide, nitrogen, helium, etc.) are generated from two cases coming from geological formation. These processes can be biogenic (gas generated from biological systems) and thermogenic (generated from temperature and pressure). (Levandowiski, 2009). Moreover, the gas composition in the mine atmosphere is related to various factors including blasting rocks, the decomposition of organic matter, groundwater, diesel engine operation, coal extraction and the ventilation system (Torres, & Da Gama, 2005).

Methane ($CH_4$) is a colorless gas, its molecule is tetrahedral and nonpolar, low soluble in water and when added to the air it becomes a highly potential flammable mixture. This gas can be released from various sources in a coal mine. As the methane emerges from coal seams and cracks, it is progressively mixed with the ventilation air and diluted (Ju *et al.*, 2015). Due to its potential flammability, the methane concentration in a coal mine must be continuously monitored (McPherson, 1993). Many studies are conducted in order to monitor the concentration of this gas. For instance; Bi, Ishihara and Matsumoto (2008) conducted tests with different types of electrolytes and electrodes aiming to develop an amperometric sensor for identification of $CH_4$. Also, the synthesis of $SnO_2$ nanoparticles is being studied seeking to produce solid state sensors for detection of the methane gas with higher sensitivity (Abruzzi, Dedavid, & Pires, 2015). Moreover, technologies are being developed in order to take advantage of this energetic gas. According to Su, Beath, Guo and Mallett, (2005), three forms can be applied for this use: through the air vent mines, the gas drained from the wells before the mining and gas existing in mines already operated.

Carbon monoxide (CO) is a colorless, odorless and tasteless gas having density too close to the air, easily mixing with it (Xuehai, Aihua, Kexin & Jian, 2011). Studies conducted in China indicate that the level of this gas in coal underground mines is linked to the incomplete oxidation process generated from organic compounds coming from the coal matrix (Liu Jiang, Shen, & Zhang, 2014). Workers' exposure to CO can lead to many health problems according to McPherson (1993). When it reaches the saturation level in the range 70-80% in the blood, it can cause death.

Carbon dioxide ($CO_2$) is an odorless and colorless gas, originated from three processes related to adsorption of carbon, namely through osmosis of the magma effect and effects on structural seals (McPherson, 1993). Moreover, this gas is heavier than oxygen tending thus to accumulate at the bottom of the mines (Xuehai et al., 2011). At very high concentration CO2 also present risks that are associated directly to the worker's health.

Regulatory Norm of the Ministry of Labor in Brazil (NR15, 2014) sets the limits of tolerance for unhealthy activities and operations in which consistent with exposures of workers to these environments. In other countries, there are specific regulations for mining processes as the North American standard Mine Safety and Health Administration (MSHA, 2001). So, monitoring the concentration of these gases is important as it allows guaranteeing the work security of people who frequent these places.

In general, the gases present in these places have peculiarities that can directly affect the safety of workers, structural stability and the mine environment. Therefore, this study aims to monitor the air quality in a coal mine located in Southern Santa Catarina Coal Field, Brazil, with a focus on $CH_4$, CO, and $CO_2$. Thus help to establish a low-cost protocol aimed at environmental control for national coal mines.

## MATERIALS AND METHODS

### Study area

For the development of this work, a study was conducted at an underground coal mine, namely Mine A located in southern Santa Catarina coal field, belonging to Paraná Basin and Bonito formation (Figure 1). The overburden ranges from 150 to 180 m.

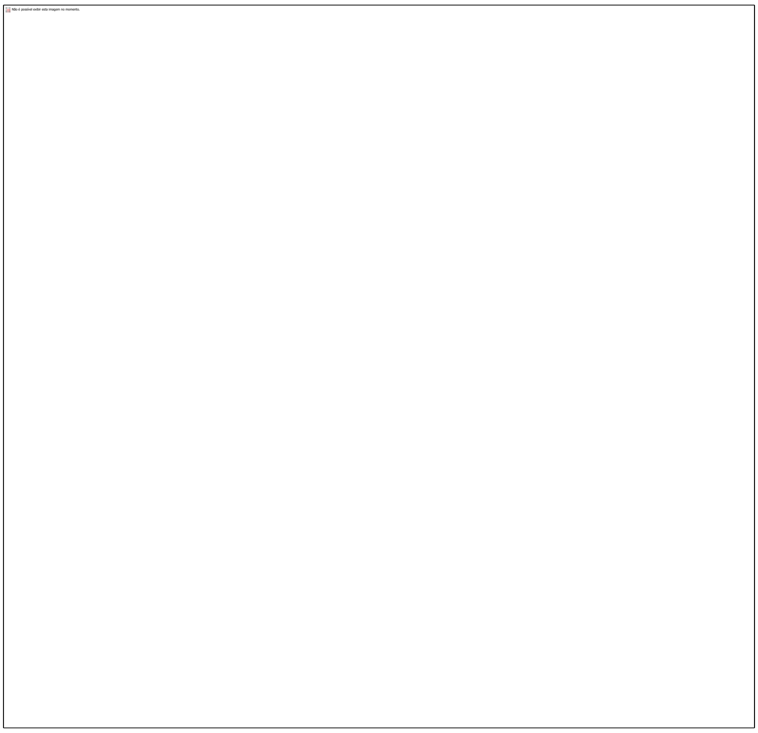

Figure 1- Main Coal Fields in southern Brazil and location of Mine A. Adapted from Serviço Geológico do Brasil (2003).

The gases sampling was performed at strategic points that are associated with the ventilation system, consisting of a main fan, a secondary fan in front of extraction and an exhaust fan. Thus, the samples were taken at the main entrance and the return of ventilation (before and after detonation events) and in places that occur higher methane emanations (Figure 2).

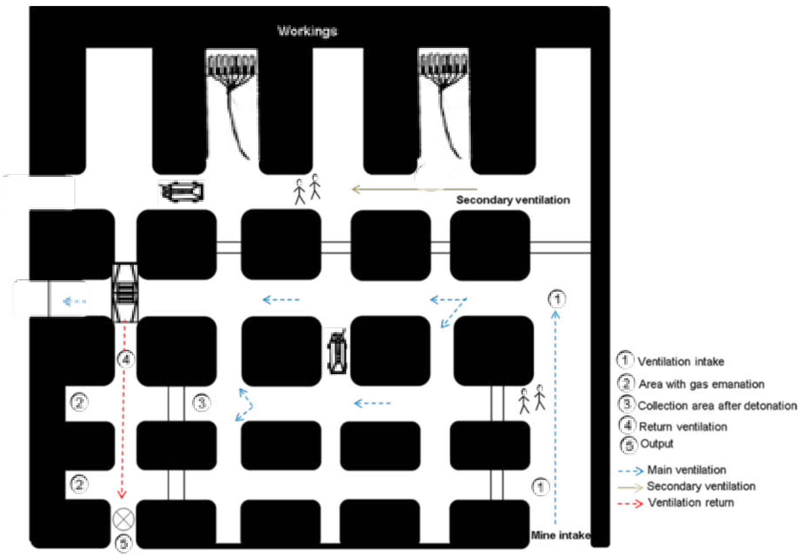


Figure 2-Scheme of collection points in Mina A.

Also during the air sampling various measurements were conducted to determine the mass flow rates of the gases at each point. Temperature, humidity, pressure and speed of the air flow was measured in each point using an anemometer (Kestrel® 4000NV) following standard procedure (Pinto et al.; 2003) A digital Trena (BOSCH GLM80 Professional) was also used to measure the area in each collection point.

**Collectors**

In order to ensure the storage and transport of gases and enable/allow reuse and reduction of costs, and alternative collection systems (AV_BR) were used. The AVBR borosilicate vials produced have plastic screw cap and butyl rubber septa (Supelco) with a Teflon septum (PTFE) / silicone (Supelco) used as a protective cover. Commercial vials (Exetainers®, LABCO, England) were also used for comparison (Figure 3).

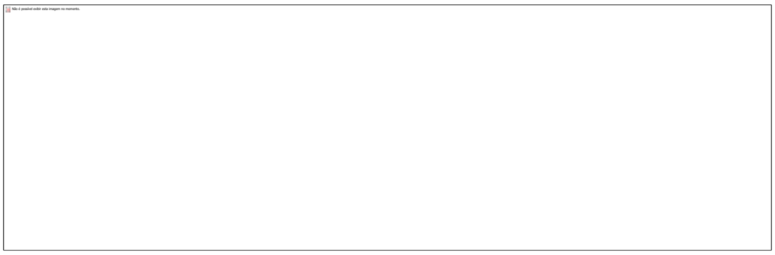


Figure 3 - Alternative Bottle AVBR and commercial vials Exetainer® (LABCO) and their respective septa.

The AV_BR vials were previously validated with different samples (real and synthetic) compared to usual Exetainer® systems of collection and storage (Abruzzi, Da Costa, Bonetti, Pires, & Silva, 2015). Before the collection, the alternative vials (AV_BR) were washed with deionized water and detergent (Extran), dried (oven, 3 h, 100°C) to ensure that there were no contamination on the gas sample. Vials were subsequently evacuated with the aid of a vacuum line (T-Station75 pump, Edwards). Gas samples were collected to vials using a 15 mL plastic syringe, and sampling was performed in triplicate.

**Gas analysis**

To determine the concentration of $CH_4$, a Gas chromatograph (PerkinElmer, Clarus 580) with detector FID (flame ionization detector) was used. The separation occurred in a PlotQElite column (Ø 0.53 mm, 20 μm thick film stationary phase, 30 m long). To increases limit detection of CO and $CO_2$ a methanator was placed between column and detector (Kuckartz, 2014). The temperatures of the injector, detector and the oven were 200, 350 and 50 °C, respectively, and Helium was used as carrier gas (110 ml $min^{-1}$). Fixed volume (300 μL) of the samples was injected into chromatograph using a microsyringe gastight. All measurements are performed in duplicate.

**Calculations**

The estimation of the mine $CH_4$ and $CO_2$ emissions was performed considered total gas flow and the net concentration of each gas at the exit point of mine ventilation (Harpalani e Prusty, 2009). The methane emission (Gg $CH_4$ / year) was also made following the methodology established by the IPCC (2006) and described by equation 1. In this calculation considers the ROM coal production mine methane depending on the coal characteristics (gassy or not) and the conversion factor ($6x10^{-7}$ Gg / $m^3$). The Mine A was considered as low emission mine and the lowest factor was used (10 $m^3$ $CH_4$ / ton coal produced).

$$E_{CH4} = 10\ m^3\ CH_4/ton\ X\ coal\ production\ (ton)\ X\ 6{,}7x10^{-7}\ Gg\ /\ m^3 \qquad \text{(Equation 1)}$$

The emission results are also expressed $tCO_{2eq}$ per year using equation 2. For this was made a stoichiometric calculation based on the mass flow rates taking into account the Global Warming Potential for a time horizon of 100 years, for each Greenhouse Gas (Environmental Resources Management, 2010).

$$ECO_{2e} = ECO_2 + 25 \times ECH_4 + 298 \times EN_2O \qquad \text{(Equation 2)}$$

In this study, he nitrous oxide values ($N_2O$) was not considered because this gas is not detected by the method used. However, the concentrations of the $N_2O$ are not expected to be significant in in coal mine air.

## RESULTS AND DISCUSSIONS

In Table 1 the results for concentrations of $CH_4$, CO and $CO_2$ present in the ambient air, collected at different points within the Mine A, are showed. The concentrations vary from 115 to 3,523 ppm for $CH_4$, 735 to 1913 ppm for $CO_2$ and 49 to 255 ppm for CO. The highest measured concentrations for the three gases were observed in the areas with gas emanation.

Unfortunately there are very few literature data about air composition of the coal mine in Brazil. Pires et al. (2015) reported methane concentration of 124 ppm in the return air of this same mine in a study performed in May 2015. The actual measured concentrations of $CH_4$ in return air of Mine A (115-171 ppm) ranging within that value. Silva et al. (2010) also reported high methane concentration (1.5-20%) in emanation area and next to mining front (3,414 ppm) of the Mine A in early study (December 2009). This high value could be due proximity with to freshly mined layer. Anyway, these concentrations, unlike those of the area of emanation, are well below the explosion limit.

Lloyd and Cook (2005) report concentration of Methane in return air of six South Africa coal Mines range from 21 up to 427 ppm. Studies developed by Harpalani and Prusty (2009) in two coal mines in India reported that methane levels along the ventilation circuit of 0.11-0.22% and 0.01-0.03%. The methane concentrations on return air were 0.12% (1,200 ppm) and 0.03% (300 ppm) for gassy and no gassy mines, respectively. The $CH_4$ levels in return air of Mine A is within the range of values observed in South African coal mines and in non-gassy Indian coal mine.

CO in coal mines is generated from the oxidation of coal, and its content increases exponentially as the temperature of coal rises(Liu, Jiang Shen, & Zhang, 2014). The existence of CO may increase the risk and consequence of gas explosion Deng et al. (2015). Olive (2009) also reported the occurrence of oily sandstones next to coal seams, which are responsible for the generation of gases such as CO. This gas may migrate to coal layers through fractures on the rocks. In addition, CO could also be formed by incomplete combustion of the diesel in engines present inside the mine. Pinto (2006) reported high levels (up to 250 ppm) and large dispersion in the concentration of CO in a Brazilian coal mine. The observed levels of CO on Mine A (49-255 ppm) are in agreement with those reported by Pinto.

Increased levels of $CO_2$ on coal mine air can occur from: seam gas, mine fires, blasting operations, diesel emissions, oxidation of coal and timber, action of acid waters on carbonate rocks, and planned inertisation (coal mines). To the best of our knowledge, the measurements of $CO_2$ in the air coal mines of return are not reported in the literature. Because of this, it is not possible make a comparison of our data with others.

The high concentrations for the studied gases could be attributed in part to the faults and porosity of the coal seam. These result in a greater flow of gases consequently in the increase of their concentration in the underground environment. In addition, it should be noted that changes in concentrations can also be linked to anthropogenic factors (workers and equipment) that are critical in the process of exploitation.

From a security point of view, only the CO concentrations are worrisome. Despite relatively high methane concentrations, they are far below the explosion limit. CO2 levels also do not indicate warning values. $CO_2$ level is within the limits established by Brazilian NR15 (2014) and North American (MSHA, 2001) safety standards. The high observed concentration (1,913 ppm) was reported after the detonation.

Table 1 - Concentration of $CH_4$, CO and $CO_2$ in coal mine air, collected at different points in the mine and permissible exposure.

| Ventilation Circuit | $CH_4$ ppm[c] | $CO_2$ ppm[c] | CO ppm[c] | Description |
|---|---|---|---|---|
| Intake air | <LOD | 793 ± 4 | 49 ± 1 | 1º entrance Point |
| | <LOD | 735 ± 2 | 79 ± 3 | 2º entrance Point |
| | 1,122 ± 13 | 1,669 ± 43 | 62 ± 8 | 1ª emanation area |
| | 3,523 ± 2,171 | 1,339 ± 502 | 255 ± 91 | 2ª emanation area |
| | 669 ± 314 | 1,913 ± 414 | 249 ± 30 | After detonation |
| Return air | 115 ± 2 | 1,219 ± 20 | 87 ± 2 | Ventilation return |
| | 171 ± 3 | 1,292 ± 65 | 73 ± 2 | Main output |
| Safety Standard | n.p. | 3,900 | 39 | NR15[a] |
| | n.p. | 5,000 | 50 | MSHA TLV[b] |

[a]- Tolerance limit for the workplace in Brazil (NR15, 2014); [b]- Permitted Values Limits (TLV) by MINE SAFETY AND HEALTH ADMINISTRATION (MSHA, 2001) in the United States. n.p. – not pertinent; [c]-Gas concentration in ppm; [d]-LOD – Limit of Detection 0.1 ppm for $CH_4$.

Methane concentrations at all points are below its explosive limit (5,000 ppm). The area with the highest emanation of the gas was in the place where there is no mining activity, with a concentration of 3,523 ppm. As a result, it was installed at this location secondary ventilation in order to decrease the concentration of this gas to ensure that possible accidents will be avoided. Carbon monoxide concentrations have exceeded the values established by Brazilian standard (NR 15, 2014) and American (MSHA, 2011) standards at all collection points

The mass flow rate calculations are important because through this it is possible to correlate the data of gases concentration with the ventilation system. It is believed that the variation of these flows at each point is related to the operational activities at the mine for coal mining. From geologic issues, to operating systems such as number of employees, vehicles, equipment or the use of coal extraction techniques, in the case of the mine of this study is conducted through explosions with the assistance of dynamite.

The higher flow rates are, as expected, on the ventilation outlet. This is due to the forced system that is composed with fans and exhaust fans in which ensure that fresh air reaches the most extreme points of the mine, ensuring in this way that there is a dilution of gases.

Comparing Tables 1 and 2 at the entry points (1 point) and output is noticed that the points where there are higher emanations of gas, the mass flow rates are higher. As mentioned earlier, this is probably due to geological features. Pan, Wang, Hou, Niu, Wang, & Ji (2016), explain that the fractures found in coal provide increased release of gas, because the space on that site is larger, thereby facilitating the passage and infiltration mainly of $CH_4$.

Table 2 – Estimated emissions of gases greenhouse $CH_4$ and $CO_2$ at different points of mine A.

| Gases | Location point: Input (kg/h) | Output (kg/h) | Input (tons/year) | Output (tons/year) |
|---|---|---|---|---|
| $CH_4$ | <1 | 53 | <1 | 465 |
| $CO_2$ | 121 | 401 | 1056 | 3514 |
| **Emission estimation** | | | | |
| $CH_4$ (Equation 1 ) | 3.618 tons/year | | | |

| | |
|---|---|
| $CH_4$ ( by Harpalani e Prusty, 2009) | 477 tons/year |
| Total ($CH_4$ + $CO_2$) | 12.226 t($CO_2$)eq / year |

In the mine A operating conditions, it is estimated to be annually emitted 12.226 t $CO_2$eq. This value is equivalent only to an activity involving the exploitation of coal. Larger studies, such as comparative study of greenhouse gas emissions made by the Brazilian Association of Coal (2013), include all power generation parameters from coal, pointing so that the generation of electricity should involve all value chain related to fuel (coal) and the impact that this causes to the environment.

## CONCLUSION

The gas sampling and analysis of underground coal mine ambient air through the proposed method proved to be suitable for determining the presence of CO, $CO_2$ and $CH_4$. The storage conditions used were maintained on the unique characteristics of the samples. The presence of $CH_4$ was higher in areas with gas emanation, even below the explosive limit this concentration is an alert to the need for periodic monitoring. High CO concentrations at these points also lead to devote special attention to ensure safety in the mine. The mass flow rates are greater at the outlet of the ventilation system, because this exhaust system intensifies the flow of gases in this environment. Related emissions of greenhouse gases, it appears that according to the activities carried out on the day of collection in the mine is issued on average 12.226 t/year of $CO_2$.

## ACKNOWLEDGMENTS

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# OPTIMIZATION OF DRILL BIT REPLACEMENT TIME IN BENCH DRILLING

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# OPTIMIZATION OF DRILL BIT REPLACEMENT TIME IN BENCH DRILLING


## ABSTRACT

Cost is the main concern for the mining industry. System aging and resource degradation are the main reasons of increasing operation costs in mining activities. Thus, it is necessary for mine management to pay attention in order to reduce operation costs through operation rationalization and continuous improvement. In this frame, reducing drilling cost must be the priority so as to help the sustainability of the mine because drilling operation is often a high cost activity. The most important cost associated with drilling operations is drill bit consumption. This is mainly because the continuous contact between rock and bit rapidly decreases the bit performance, and requires replacement. Therefore, monitoring drill bit performance, which requires advanced technical expertise and high technology, and its optimization with mathematical models are required to maintain productivity and efficiency of this mining operation. This paper presents a model to determine the optimum drill bit changing time for rotary drilling operations. The full factorial experimental design method was used to analyze parameters and then the problem is formulated by mixed – integer programming to solve by CPLEX software. The results show that the approach is very promising and it can be used to determine the optimum replacement time of rotary blast hole drill bits while keeping bit costs minimized.



## KEYWORDS

Open-pit mining, drill bit wearing, experimental design, mixed integer programing.


## INTRODUCTION

Open pit mining is a method to extract ore from rock bodies that are close to the surface of the ground. Geological aspects and topography of the area play a key role to decide minerals to be extracted by open pit mining techniques. Large scale equipment, such as drilling machines, trucks and loaders, are used to mine minerals effectively and efficiently.

Rock drilling is a primary activity in mineral extraction. Drill holes are opened with a certain geometry in the rock masses to charge explosives as a first step of production (Jimeno et all., 1995).

Although the systems of drilling can be classified with tremendous variety of possibilities such as percussion, high frequency vibration and dissolution, according to their applicability, rotary drilling which transmits mechanical energy is mainly preferred in open pit mines (Jimeno et all., 1995). It can be used for all types of rocks based upon strength properties such as soft, medium and hard. It makes rotary drilling the most frequently used method particularly for open pit mines. In open pit operations to create benches, blast holes are commonly drilled by rotary drilling machines with tricone tungsten carbide drill bits. They are considered as the most widely used bit type particularly in harder and abrasive rock formation because of the wear-resistant material (Kricak et all. 2015). It is also easier to handle tricky situations with these bits than other bit types (Atlas Copco, 2009).

Rotary drilling with tricone tungsten carbide bits requires advanced technical expertise and high technology. Over the past two decades, many studies have examined the importance of rotary drilling factors and performance issues to optimize the rotary bit selection and operation for the project conditions that significantly affect the completion of the drill holes. However, the performance prediction and the determination of optimum operational parameters of bits for different rock conditions are not explained in a viable scientific manner at this time because they are extremely theoretical and they need more experimentation to explain the relationship between the rock and the drill bit design.

The research activities and some methods have been developed and tested over the last 20 years. However, the current studies were limited with some drilling operations in the field and some laboratory experiments. Therefore, index values and some regression analysis have been identified to explain the drilling mechanism and these are insufficient to show the whole process (Ersoy & Waller, 1995). In order to explain drilling mechanisms, information is needed to fill the gap between the small-scale laboratory tests and actual-size of the field operations. In addition, the interaction between the rock and the drill bit is needed to optimize bit performance.

Moreover, rotary drilling with tricone tungsten carbide bits is a significant component of operational cost particularly for open pit mines. Unfortunately, this essential operation is a high cost activity. One of the most important factors which makes this activity costly is drill bit consumption. The main reason for the bit consumption is the bit deterioration associated with the interaction between rock and the bit. As the worn bit penetrates into the ground, penetration rates decrease (Peck, 1986). The drill bit changing time is the time when drill operators feel the high vibration (Ghosh et all, 2016). Hence, it all depends on the experience of the operator. It might not be the right time to change the expensive part of the drilling operation. On the other hand, if the bit is changed before its beneficial life, the cost of drilling increases unnecessarily. As a result, there is a trade-off between bit wearing and cost increase. Therefore, drill bit monitoring and optimization of the drilling parameters are crucial for mining operations.

In the literature, drilling is affected by several factors which can be classified as uncontrollable and controllable. The uncontrollable factors are basically physical and mechanical rock properties of the formation (Kricak et all, 2015). The effects of formation hardness, mineral composition, structure and binding properties have been investigated by several researchers. Generally, it is accepted that the hardness of the rock affects drillability inversely proportional. However, some soft rocks are more difficult to drill than hard rocks (Bilgin, 1977). Therefore hardness is not a reliable scale to assess drillability. However, binding force has a closer relationship with drillability (Koronka, 2009). Furthermore, the relationship between texture properties of the rock and rock drillability shows that there is a statistically high correlation which is demonstrated by analysis of rock's texture (Koronka, 2009). In addition, uniaxial compressive strength (UCS) and quartz content of the rock mass are one of the most important parameters which affect penetration rate of the drilling operation because these factors directly affect drill bit wear (Bilgin, 1977).

The controllable factors are the drilling machine parameters which can be controlled by the operator of the drilling machine. These controllable factors can be categorized as independent and dependent (Peck, 1989). The independent parameters are weight on the bit (W) and rotary speed (R). The drill bit needs a sufficient rotation speed in order to make a drill hole. Lower rotary speed is needed for hard rocks because teeth of the bit need time to create sufficient stress to drill properly. On the other hand, higher rotary speed can be used for softer rocks effectively (Atlas Copco, 2009). The rotary speed is the main reason for the bit wear which is also related to pulldown force, bailing pressure and temperature (Peck, 1989). The weight on the bit which depends on the compressive strength of the rock is necessary to have a successful drilling operation. The feed force which is obtained by weight on the bit must be adequate to overcome the strength of the rock. A breakage of an insert on the bit can be produced by high thrust force. Therefore, weight on the bit must be determined cautiously. The dependent parameters which are related to rotary speed are rotary torque (T) and bailing air pressure (P). The torque is defined as a force which is required to calculate power which rotates the entire drill rod and drill bit. The bailing pressure is a pressure to evacuate the drilling chips which are created during the process. The drill hole cleaning by air bailing pressure is a crucial activity to have an accomplished drilling operation because drilling chips in the drill holes are causing decreased penetration rate, increased bit wear and the necessity of increased weight on the bit and higher torque to rotate the drill bit (Peck, 1989).

Experimental design is playing an important role for optimization of controllable factors. Many experiments are conducted in a series of trials to produce quantifiable results which can be analyzed to understand the interaction between the key input variables and the output performance. When a lot of factors affect an outcome, the most effective, efficient and economical way to interpret data from the experiments is statistical experimental design (Myers et all. 2009).

Experimental design is used to evaluate the effects of several different independent factors on a response variable. Multiple input factors are considered and controlled simultaneously to ensure that the effects on the output responses are statistically significant. The most crucial reasons for statistical experimental design are to minimize the cost of obtaining usable data and to use time effectively and efficiently (Montgomery, 1991).

Factors or variables can be not only qualitative (categorical), but also quantitative (continues). Rock types, machine types or raw materials are some examples of qualitative factors. Examples of quantitative factors are rotation speed and temperature (Montgomery, 2009).

It is widely accepted that the most extensively used designs in particularly manufacturing companies and scientific research is full factorial design at two levels. It is an orthogonal type of design. It can analyze all possible levels' combinations of factors for all trials or the replications of experiments. In other words, the experimenter can investigate all possible combinations for all factors. The impact of factors on dependent variables can be the main effect or the interaction effect. At full factorial designs, $X^k$ shows the observations of experiment. X and k represent levels and factors respectively (Myers et all. 2009).

This research focused on determination of optimum drill bit changing time for open pit mines. First, experimental design was used to evaluate the effects of several different independent factors on responses. Then multiple input factors were considered and controlled simultaneously to ensure that the effects on the output responses were statistically significant. This supports the reasons for statistical experimental design which are to minimize the cost of obtaining usable data and to use time effectively. Therefore, a full factorial experimental design at two levels method was used to investigate the effects of all combinations to design field tests. Rotary drilling was selected to drill blast holes because it is a widely used method in the mining industry. The data was collected from open pit mines from the drilling machine which worked with tricone tungsten carbide drill bits. Following data collection, a mixed - integer programing (MIP) model was developed. The problem was solved by CPLEX software.

## MODEL OPTIMIZATION

Optimization of systems is one of the hardest real world problems. It is a tough process to solve maximizing or minimizing problems systematically and to choose the best combination from a large group of datasets. The main aim for drilling operations is to optimize drilling parameters in order to minimize drilling cost with maximum penetration rate. Drilling operations face environmental hurdles to reduce cost and probability of encountering failures. Hence, it is important to keep in mind that formation features which are uncontrollable are one of the most critical factors in drilling performance determination (Eren, 2010). Therefore, the optimization process must be considered for a specific formation and the formation must be assumed homogeneous.

There are three key parameters which affect drilling performance and cost significantly; rotary speed, weight on the bit and bailing pressure. They have a direct effect over penetration rate and bit performance particularly. There is a linear relationship between these parameters and penetration rate (Atlas Copco, 2009). High level of pulldown force and revolutions per minute (rpm) generally increase penetration rate. However, they also produce high vibration and cause low drill bit life. Wear and tear of the drill rig is caused by the high vibration (Atlas Copco, 2009). Moreover, increased pulldown force might result in overloads to the rig and drill bits (Atlas Copco, 2009). Therefore, these three parameters must be optimized to have an effective and efficient drilling operation. The main objectives to optimize drilling operation are having high penetration rate and low operation cost, also long service life of drilling machine.

## PROBLEM FORMULATION

The objective of the problem is to find optimum drill bit changing time in the specific time limit with constraints in order to specify rules for the data which is collected from the field in such a way as to minimize the operation cost. The model is given below.

| | |
|---|---|
| b = 1, 2… B | B denotes the number of drill bits |
| h = 1, 2… H | H denotes the number of drill holes |
| f = 1, 2… F | F denotes the number of slices (a drill hole has slices) |
| r = 1, 2… R | R denotes the level of rotary speed (rpm) |
| w = 1, 2… W | W denotes the level of weight on the bit (Pulldown Force - kN) |
| p = 1, 2… P | P denotes the level of bailing air pressure (psi) |

Decision Variables

| | |
|---|---|
| $x_{bhfrwp}$ | binary variable (if the cost is minimum in period of time, variable is 1. Otherwise, it is zero.) |
| $y_b$ | binary variable (if the bit must be changed, variable is1. Otherwise, it is zero.) |

Parameters

| | |
|---|---|
| D | the total depth of a hole (m) |
| Dbit | the diameter of the drill bit (inch) |
| Tmax | the maximum allowable time for drilling operation (min) |
| NS | the number of slices per hole |
| Bcost | the drill bit cost ($) |

I. Objective Function

$$Min \sum_{b=1}^{B}\sum_{h=1}^{H}\sum_{f=1}^{F}\sum_{r=1}^{R}\sum_{w=1}^{W}\sum_{p=1}^{P} C_{bhfrwp}x_{bhfrwp} + \sum_{b=1}^{B} y_b\ Bcost \tag{1}$$

Subject to

II. All holes must be drilled.

$$\sum_{b=1}^{B}\sum_{r=1}^{R}\sum_{w=1}^{W}\sum_{p=1}^{P} x_{bhfrwp} = 1, \forall h, \forall f \tag{2}$$

III. A hole must be drilled by the same bit.

$$\sum_{r=1}^{R}\sum_{w=1}^{W}\sum_{p=1}^{P} x_{bhfrwp} = \sum_{r=1}^{R}\sum_{w=1}^{W}\sum_{p=1}^{P} x_{bh(f+1)rwp}\ , \forall b, \forall h, \forall f \tag{3}$$

IV. The maximum allowable drilling time cannot be exceed.

$$\sum_{b=1}^{B}\sum_{h=1}^{H}\sum_{f=1}^{F}\sum_{r=1}^{R}\sum_{w=1}^{W}\sum_{p=1}^{P} t_{bhfrwp}X_{bhfrwp} \le T_{max} \quad (4)$$

V. Unless the previous slice is drilled, the slice under consideration cannot be drilled.

$$\sum_{r=1}^{R}\sum_{w=1}^{W}\sum_{p=1}^{P} x_{bhfrwp} \le \sum_{r=1}^{R}\sum_{w=1}^{W}\sum_{p=1}^{P} x_{bh(f-1)rwp} \text{ ,} \forall b, \forall h, \forall f \ (f > 1) \quad (5)$$

VI. If a bit removed, it cannot be used again.

$$if \sum_{b=1}^{B}\sum_{h=1}^{H}\sum_{f=1}^{F}\sum_{r=1}^{R}\sum_{w=1}^{W}\sum_{p=1}^{P} X_{b(h-1)frwp} \ge 1 \ and \ if \sum_{b=1}^{B}\sum_{h=1}^{H}\sum_{f=1}^{F}\sum_{r=1}^{R}\sum_{w=1}^{W}\sum_{p=1}^{P} X_{bhfrwp} \le 0, \sum_{b=1}^{B}\sum_{h=1}^{H}\sum_{f=1}^{F}\sum_{r=1}^{R}\sum_{w=1}^{W}\sum_{p=1}^{P} X_{b(h+1)frwp} \le 0 \quad (6)$$

VII. There must be an order to use drill bits.

$$\sum_{h=1}^{H}\sum_{f=1}^{F}\sum_{r=1}^{R}\sum_{w=1}^{W}\sum_{p=1}^{P} x_{bhfrwp} \le \sum_{f=1}^{F}\sum_{r=1}^{R}\sum_{w=1}^{W}\sum_{p=1}^{P} x_{(b-1)hfrwp} \text{ ,} \forall b \quad (7)$$

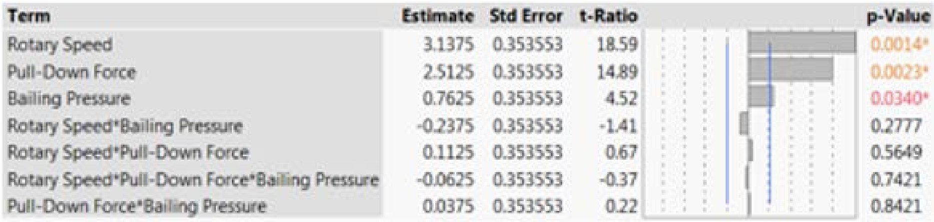
## CASE STUDY

First part of the case study is based on data coming from an open-pit iron mine. The full factorial experimental design method at two levels was selected to collect data from the field. All possible combinations of the controllable factors, which are rotary speed, pull down force and bailing pressure, were investigated by experimental design methods so as to monitor drilling operation and drill bit wear. Equation 8 shows the regression equation of full factorial design with interactions.

$$y = \beta_0 + \beta_1 a + \beta_2 b + \beta_3 c + \beta_{12} ab + \beta_{13} ac + \beta_{23} bc + \beta_{123} abc \quad (8)$$

As can been from the Figure 1, all interactions can be ignored because of the statistical significance against the response.

| Term | Estimate | Std Error | t-Ratio | p-Value |
|---|---|---|---|---|
| Rotary Speed | 31.1125 | 0.353553 | 8.87 | 0.0076* |
| Bailing Pressure | 6.6375 | 0.353553 | 1.89 | 0.1804 |
| Pull-Down Force | 5.2625 | 0.353553 | 1.50 | 0.2548 |
| Rotary Speed*Bailing Pressure | 2.4875 | 0.353553 | 0.71 | 0.5423 |
| Rotary Speed*Pull-Down Force*Bailing Pressure | 2.1875 | 0.353553 | 0.62 | 0.5883 |
| Pull-Down Force*Bailing Pressure | 1.3375 | 0.353553 | 0.38 | 0.7349 |
| Rotary Speed*Pull-Down Force | -0.4875 | 0.353553 | -0.14 | 0.9005 |



| Term | Estimate | Std Error | t-Ratio | p-Value |
|---|---|---|---|---|
| Rotary Speed | 3.1375 | 0.353553 | 18.59 | 0.0014* |
| Pull-Down Force | 2.5125 | 0.353553 | 14.89 | 0.0023* |
| Bailing Pressure | 0.7625 | 0.353553 | 4.52 | 0.0340* |
| Rotary Speed*Bailing Pressure | -0.2375 | 0.353553 | -1.41 | 0.2777 |
| Rotary Speed*Pull-Down Force | 0.1125 | 0.353553 | 0.67 | 0.5649 |
| Rotary Speed*Pull-Down Force*Bailing Pressure | -0.0625 | 0.353553 | -0.37 | 0.7421 |
| Pull-Down Force*Bailing Pressure | 0.0375 | 0.353553 | 0.22 | 0.8421 |

Figure 1: Statistical analysis of the controllable factors (made by JMP) (different time intervals)

Penetration rate is reduced by time because of the bit wear which is the conclusion of the interaction between the drill bit and the rock formation. Rate of penetration can be a beneficial signal of drill bit changing time (Ghosh et all, 2016). Therefore, penetration rates were recorded every 2 hour-period of time. Table 1 shows the parameters and their levels.

It can be seen from Figure 2 that the importance of the rotary speed is decreasing by time. At a certain point, the importance of the pull down force is more than the importance of the rotary speed for the drilling operation.

Table 1: Full factorial design with three factors at two levels.

| | **Rotary Speed** | **Pull-down Force** | **Bailing pressure** |
|---|---|---|---|
| | (revolution/min) | MPa | bar |
| **1** | 40 | 100 | 10 |
| **2** | 40 | 100 | 16 |
| **3** | 40 | 150 | 10 |
| **4** | 40 | 150 | 16 |
| **5** | 80 | 100 | 10 |
| **6** | 80 | 100 | 16 |
| **7** | 80 | 150 | 10 |
| **8** | 80 | 150 | 16 |

It can be seen in Figure 2 that after 8 hours operation, rotary speed loses its importance and pull down force must be increased to achieve penetration to the ground. The main reason for increasing pull down force is the drill bit wear. When the bit is worn, rotary speed doesn't affect the penetration. This is the time to change a drill bit. It is also seen that during the drilling operation, certain levels of the pull down force and bailing pressure are needed in order to maintain equal penetration rate. Peck (1989) stated that in order to maintain penetration rate, it is necessary to increase pull down force so as to compensate for wear of the drill bits. The regression equation is also modelled by the recorded data. It is easily seen from Equation 9 that all parameters have direct proportion with penetration rate, thus inverse proportion with drilling operation time.

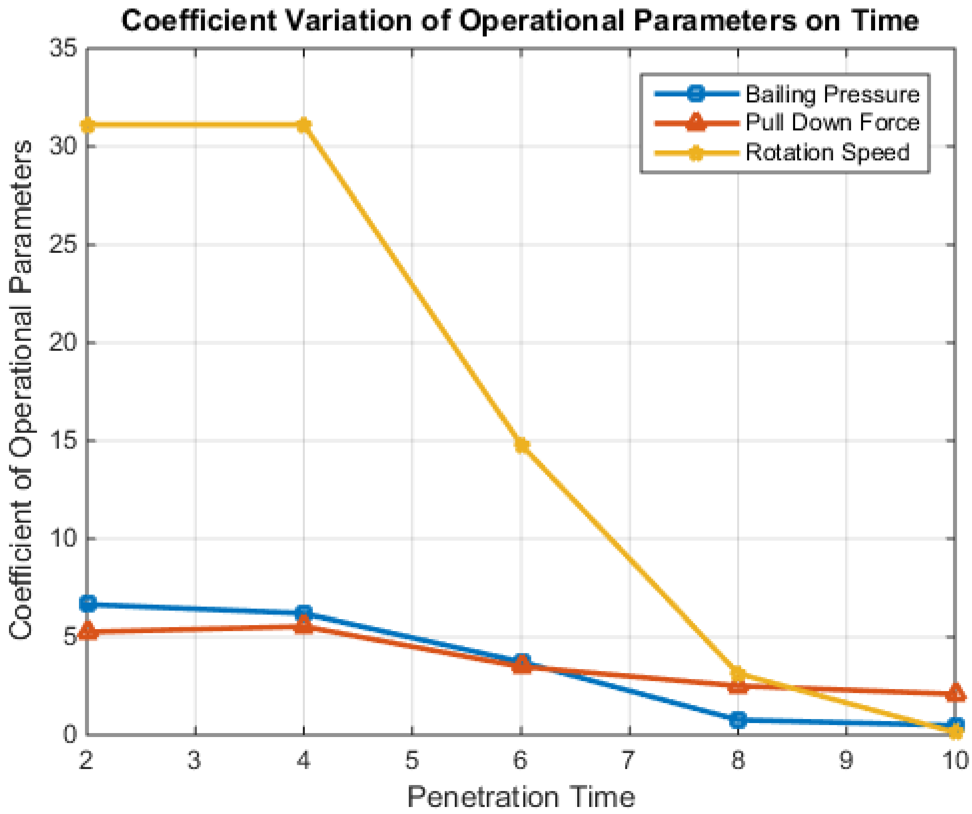



Figure 2: Coefficients of the parameters versus operation time (hour)

$$t_{min} = 3.93 - 0.02R - 0.003F - 0.0027P \tag{9}$$

where t represent the minimum drilling time (minute), R is the rotary speed (rpm), F is the pull down force, and P is the bailing pressure (bar).

The second part of the case study is based on a simulation. The simulation is used to determine drill bit changing time with the best combination of the controllable parameters. The parameter file of the simulation used in this research is given in Table 2.

In this case study, there are 32 000 decision variables. It is a relatively large cost minimization problem and has to be solved using a computer. This is the main reason behind using the mixed - integer programming. First of all, energy consumption of the drilling operation was calculated by Equation 10 for 8 different combinations.

$$e_s = \frac{W}{A} + \frac{2\pi\, R\, T}{A\, u} \tag{10}$$

where $e_s$ is the specific energy (psi), T is the torque (lbs.inch), A is the area of the hole (inch$^2$), and u is the penetration rate (inch/min). After calculation of energy consumption, the cost of the energy was calculated. Then, IBM ILOG CPLEX Optimization Studio was used to develop the model which minimizes the operation cost. According to the results, the most influential parameter is rotary speed. The importance of pull down force increases with time and a certain level of bailing air pressure is needed for the drill bit penetration. However, when rotary speed is increased, the needs of the bailing pressure is increased as well. The results show that the minimum operation cost is obtained when the rotary speed is at its high level and the other two parameters are their low levels (Combination 5 at Table 1).

Table 2: Parameter File

| | |
|---|---|
| Number of Drill Bits | 10 |
| Number of Holes | 420 |
| Number of Slices | 1680 |
| Number of Rotary Speed Level | 2 |
| Number of Weight on the Bit Level | 2 |
| Number of Bailing Air Pressure Level | 2 |
| Total depth of a hole (m) | 20 |
| Diameter of drill bit (mm) | 165 |
| Number of slice per hole | 4 |
| Drill bit cost ($) | 5000 |

## CONCLUSIONS

This paper presents an approach including statistical analysis to (1) determine parameters affecting drill bit performance and (2) optimize drill bit changing time. Decisions based on experience can lead to poor performance of drilling or unnecessary bit consumption. The first task is to analyze variables affecting drilling operations. For this reason, experimental design was conducted based on controllable factors. Full factorial design at two levels was selected to analyze parameters statistically. After the investigation of all possible factors, a regression equation was fitted. It was observed that rotary speed is the most influential factor for drilling operation and tooth wear. Then, optimal replacement time was formulated as a mixed integer programming problem. The objective function was minimization of the drilling operation cost under the constraints of maximum allowable time and inventory size. The optimization matrix was created by OPL and problem was solved by CPLEX software. The results of the study showed that the proposed approach can be used as a tool for drill bit management in open pit mining operations. Further field studies are needed to determine the exact time to replace a drill bit economically. Future research will be the effect of system aging and the reliability of the drilling machine for drilling operation.

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# PARTIAL DEACTIVATION OF MARBLE QUARRY IN OUROLANDIA – BA DUE TO ENVIRONMENTAL CONSTRAINTS

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# PARTIAL DEACTIVATION OF MARBLE QUARRY IN OUROLANDIA – BA DUE TO ENVIRONMENTAL CONSTRAINTS


## ABSTRACT

The purpose of this paper is to serve as sugestion for a partial deactivation plan for a marble quarry located at Ourolândia – BA, Brazil using both collected data from the area and previous works on mine closure. In the particular case, the closure plan is required due to environmental constrains, and its development will follow the PRAD (Recovery Plan of Degraded Areas) guidelines. In order to fulfill the constraints listed in the environmental licence of the subject areas as issued by the responsible environmental agency. The paper suggests filling the pit with waste material and a layer of soil and giving a future use to the area analogous to agriculture with native species or conditions to run livestock, in order to provide in the future an activity to replace the mining for the local community.



## KEY WORDS

Partial deactivation, closure plan, marble, quarry.


## INTRODUCTION

After a FPI (Preventive Integrated Inspection) in 2011, a portion of Ourolândia mining companies had their activities suspended for lack of environmental license; in order to rectify their legal situation the companies provided studies requested by the environmental organ, INEMA, and conduct adjustments required by Prosecutor's Office of Bahia (MP-Ba).

The studies have shown that a part of the quarry in question is inside the area of influence of cave zones (Permanent Protection Areas - APP), and for this reason, they should end their activities in that place as soon as possible and recover the area with a schedule that should be started immediately after the study was presented. They could restore the mining activity in other economic interesting locations inside the total area and out of the range of APPs.

This area was degraded by long-term intensive marble extraction, by previously people and companies that had insufficient knowledge and techniques for sustainable management of karstic areas. This paper will provide options for the recovery of these lands in an environmentally acceptable way according to the constraints proposed by INEMA related to the mine closure and the area recovery.

The ideal is to start the closure plan from the begining of quarry operations, and perform the recovery plan in parallel to the activities, so that the cost dilutes over the years by being included since the initial accounts. Unlike from the ideal, the quarry had to take forced recovery measures, due to a delayed environmental education and years of negligence. Therefore, to the partial closure of the quarry and subsequent recovery of these areas the implementation and maintenance costs of the adjustments will not suffer budgetary damping.

## CHARACTERIZATION OF THE PROPERTY AND LOCATION

The quarry is located in the county of Ourolândia (10°58'3" South, 41°5'12"), in the center-north of the State of Bahia in the Chapada Diamantina, a brazilian national park, Figure 1. The county area is 1,333 km², and is surrounded by the counties of Jacobina (east), Morro do Chapéu and Varzea Nova (south), Sento Sé and Umburanas (west) and Mirangaba (north). Ourolândia is 363 km away from Salvador (the state capital) paved highways BR-324 and BR-116. The *Pietrine Serviços em Pedras Ornamentais Ltda* operate the quarry whose case number DNPM (National Department of Mineral Research) is 872.899/2009.

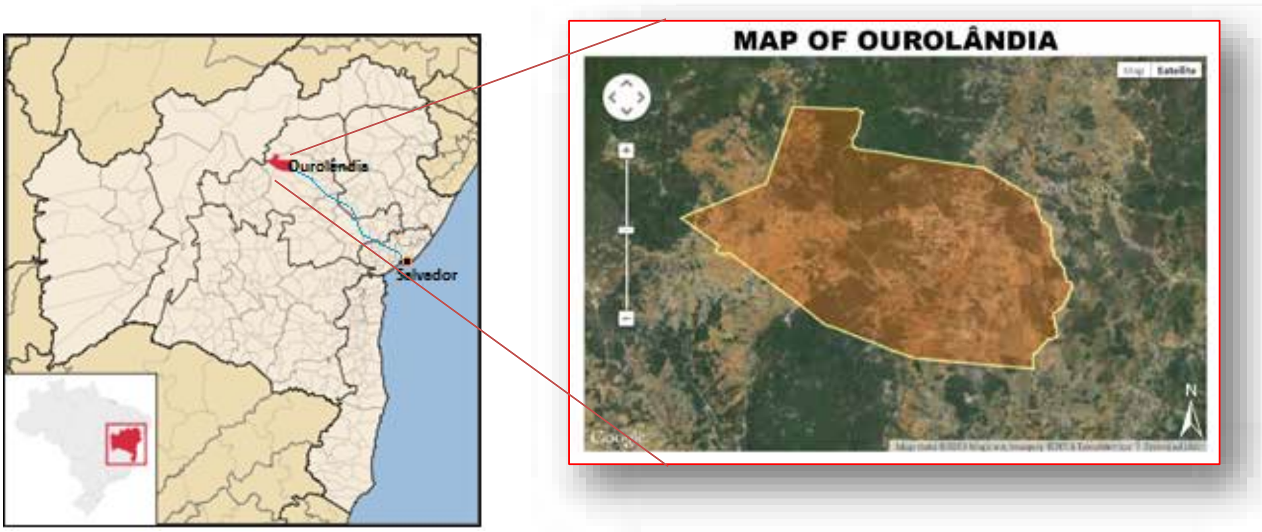


Figure 1 – State of Bahia with the detail of the city of Ourolândia and the access to Salvador (the capitol of the state).

## DESCRIPTION OF THE INFLUENCE AREA OF THE QUARRY

### The Quarry

The company pertforms the extraction of marble "Bege Bahia" in two mining fronts 1 and 2 at the Fazenda Cais – Ourolândia through an open pit mining design with descendant benches and ditches shape. In the original design, the height of countertops is 1.60m for both pits. The pits 1 and 2, once separated, are now intertwined with a depth of 9.0m. On these pits are blocks waiting to classify, others ready to shipment, defective ones and the mining waste. The slope of the countertops in all pits is 90°.

**Mining Waste**

Are considered waste, the marble blocks with very low economic value in domestic and/or international market, blocks with imperfections, and residue of limestone that do not form square blocks. We can find these materials arranged in disorderly piles behind armholes and along the access roads in the mining area. The quarry removes the material provided along the access roads after reduced to small sized blocks of 0.50 m³ for the confection of floors. It is worth remembering that the marble waste from the mining does not interfere with the site drainage.

Figure 2 – Waste disposal inside pit 1.

Figure 3 – Waste disposal inside pit 2

## DESCRIPTION OF THE DEGRADED AREA

The upwelling of the Rio Salitre located in geographic coordinates (UTM SAD69): 274289 – 8791095 and 274331 – 8791169; covers a part of the river bed which is in the region of Permanent Preservation Areas (APP) and are under the domains of three companies: Imegra, Icesa and Pietrine cited above. This area presents a complex picture of environmental degradation. Garbage litters the sites of upwelling, material silt (mud) in the bed of the Salitre River. Non-native vegetation species at the riverbancks, such as cattail (*Typha domingensis Pers)* that are pollution indicators. The area is environmentally unsuitable habitat for the existence of fish and organisms that are usually present in the beds of pollution-free rivers. It is important to note that, although mineral extraction is responsible for much of the degradation to the riverbed, other anthropogenic activities are also contributing factors.

### Environmental Impacts

Overall, the region itself has a landscape eminently marked by interference on land cover, with the suppression of vegetation and replacement by agroecosystems. Regarding the quarry, it operates on karst terrains without cover crops and therefore no vegetation cover.

The area of indirect influence of the project lies in the field of agroecosystems, which suggests that even the supporting facilities and infrastructure are in areas already deforested before.

Therefore, through the quarry lifetime it will not be necessary to deforest the area. Assuming only a cleansing of the areas of expansion, there are few vegetables that they could remove as gameleiras and cacti diffusely distributed, wich offers no greater significance to the ecossystem. Revegetation actions at the end of operation (deactivation), may contribute to the formation of a new vegetation cover.

It is worth emphasizing the importance of the restoration of riparian vegetation along the banks of the river Salitre, at least in the trail crosses the boundaries of the quarry, although this has not been the cause of degradation.

## RECOVERY OF THE DEGRADED AREA

### Quarry

The pits 1 and 2 have walls formed of limestone with less than 12.0 m height and slope of 90°. Therefore, it requires physical treatment such as stabilize the slopes and install fences on the surounding area, with the goal of increasing safety of people and animals that may circulate in the quarry after exhaustion. This care reduces acidents and not only increses the good relationship between the quarry and the surrounding community, but also softens the closure process.

**Waste Marble Piles**

The waste rock piles disposed on the deactivated pits and its suround area are disorganized, and the waste located along the access roads to the quarry are organized in rows. There is no need to retrieve the wase alongside the road, although the rest of the material is destined to recompose the quarry area mostly to fill the deactivated pits and the armholes around it.

**Current Legal Situation of the Quarry**

The two pits: 01 (with an area of 6,300m²) and 02 (with an area of 2,800m²) under the responsibility of Pietrine Company are curently with suspended activities, due to being above the caverns. The area also features an advanced process of environmental degradation requiring an environmental recovery plan. At the Figure 4 is possible to see the DNPM areas in Ourolandia as well as the projects installed and the geological features. Figure 5 shows in detail this particular quarry area.

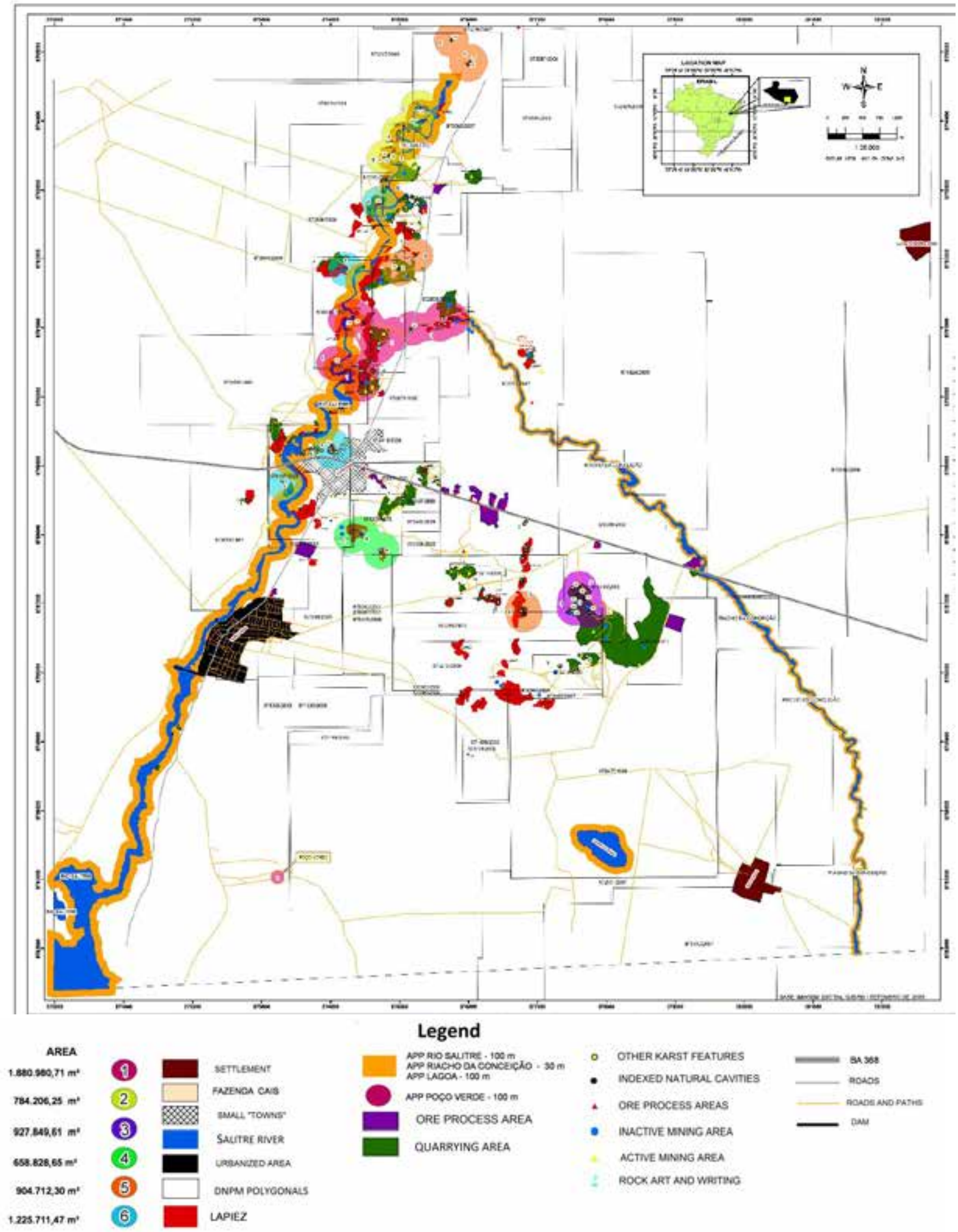


Figure 4 – DNPM areas in Ourolandia as well as the projects installed and the geological features.

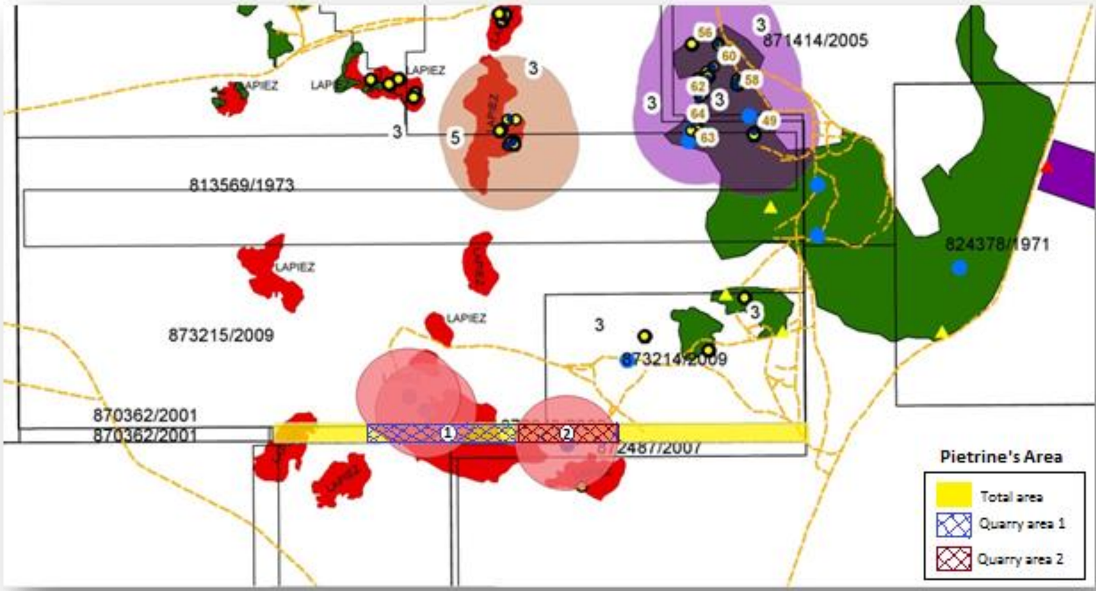


Figure 5 – Highlightened are the limits of the quarrying areas 1 and 2 inside the APPs related with caverns.

**Recovery Strategy**

The recovery of the quarry considers the environmental impacts, and focuses in measures to minimizing or eliminating them, as well as the preparation of the area according to Future Use Plan. This will help reinstate characteristics and properties of soils that will provide it with conditions to grown vegetation cover around the armholes and alongside the marginal areas of Salitre River.

Its development should take place throughout the quarrying period itself, focusing, however, on the end of exploitation. Some activities during recovery will take place simuntaneously with their own quarrying activities for preventive recovery, involving actions such as the removal of vegetation, removal of topsoil, drainage control, and erosion.

The recovery, often considered the corrective actions developed at the end of mining, will in fact involve two groups of actions: Restoring the physical profile of the area (filling of pits and artisanal use of sterile) and revegetation. A specialized professional must follow all recovery actions.

**Filling the Pit with Waste Rock Piles**

The material from the waste rock piles will be filling of the pits, these materials can be imperfect blocks, and debris from hand cut blocks for the manufacture of tiles, and remnants of mining. The company's own loaders will execute the transport of these materials. The disposal of this waste material will be in an organized manner, avoiding risks to workers. That provision may occur during quarrying operations and after the end of operations.

**Destination of imperfect blocks to the community**

They will be arrange, along the access roads for use of the local community, the blocks that do not meet the company's standard, even though they are still viable for other purposes. Placing these pathways facilitates the handling of the local community that divides these blocks manually into "*bloquetos*" or small blocks with volume of around 0.50 m3. They sell the blocks to third parties, and have lower cutting equipment that are availed to manufacture tiles. The weekly production is 10 *bloquetos*/man. Its commercial value is R$3.00/bloqueto. This operation works as a source of income for the local community during the dry season; as well the production of *esparcatos* that can be made with a machine or manually; the *esparcatos* are handmade ornaments for residences walls, that has excellent market acceptance and may serve as complementary income.

Figures 6 – Manufacturing and use of *Esparcato* (handmade ornaments for residences walls)

**Future Area Use**

There is the confirmation that the project falls in the region where agriculture is the remarkable economic activity and almost solely by the absence of the development of other economic sectors. Despite the limitations of climate, the sector has developed using adapted species.

The presence of the Salitre River cutting through the perimeter until towards northwest / southwest is a very important factor that we cannot overlook in the recovery and disposal area. The micro Salitre basin is already involved with several irrigation projects, and maintenance of these depends on the very maintenance of the environmental qualities of the river, avoiding degradation processes along its banks. The karstic geological environment prevents their use as deposits for long-term stormwater.

After analyzing the above issues, it is possible to conclude and establish the following Plan of Future Use:

- ✓ The armholes will serve as deposits of waste material produced from the quarrying. They will have a revegetation process on the surroundings areas, and should remain as areas geared towards the maintainance of wildlife, and, in the future, may become regarded as part of the legal reserve areas as the law demands. (Article 16 of Federal Law No. 4771/65 – BRAZILIAN FOREST CODE).

- ✓ The marginal band of the Salitre River, a width of 30.0 m (each side according to the law), is already established as permanent preservation area, and should pass through a restoring process (Article 2 of the Federal Law No. 4771/65 – BRAZILIAN FOREST CODE).

- ✓ The other areas of the perimeter will reinstate into farming. One of the vocations of regional agriculture is the cultivation of fibers (*sisal*), which can be a great option for economic occupation of the area in the future. Several aspects pointing out the importance of driving the area for future use with the agriculture. The area can also be prepered to receive livestock farming.

**Revegetation**

Revegetation is an important treatment for a vast majority of environmental problems, consisting of the deployment and or adapting of plant cover, which will operate as one of multiple roles in the environment. The nature of the problems, the objectives of the recovery, and even setting trends for future destination of the quarry are crutial to determinate the revegetation characteristics. In the specific case, the objectives are to reduce environmental impacts and to indicate a future use to the area.

Through the planing and execution of revegetation, some aspects have to be clear, such as the profile of the vegetation on the subject area as well as the kind of plant they will use, which type of culture they will develop (i.e. agriculture, permaculture, a preservation park, farming to provide for livestock), and the basic steps of its operation.

Revegetation and restoration of the part of the quarry area will be given in the form of permaculture, which according to the book Permaculture One (1987), is a construction of a consciously designed landscape that reproduces patterns and relationships found in nature and at the same time produce food, fiber and energy in abundance and sufficient to supply local needs.

**New Perspective for Pietrine's Quarry**

The delimitation of the future areas designed for extraction considered a topography and geophisics that excludes cave zones, with the goal of not affecting the structure of the floor covering the underground cavities, as not to affect the behavior of the karstic environment. The new pit fronts, 3 and 4, are two new extraction targets; its polygonal are on the Figure 7.

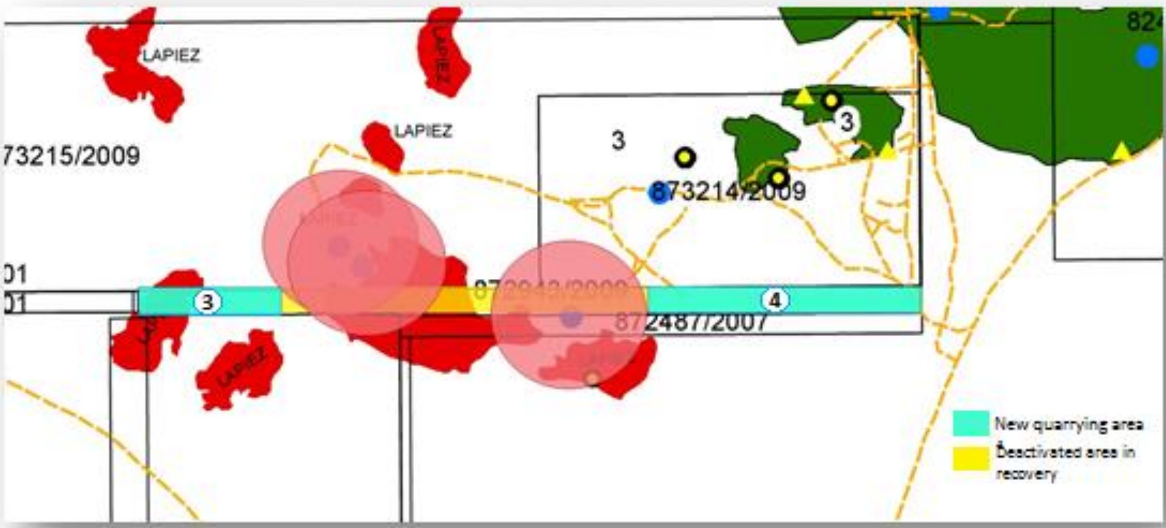


Figure 7 – Highlightened are the limits of the new quarrying areas.

## CONCLUSION

The closure of the two pits will not bring impacts to the socio-economic environment, because it does not create unemployment at the local labor, since other two mining fronts will be open outside of the APP zone of influence. Meanwhile the new pits, 3 and 4, start to operate, the recovery activities of pits 1 and 2, post mine closure, will start to implement the project, with the comunity attendance, which will ease the transition once the quarry is exhausted.

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# PARTICIPATORY LAND USE PLANNING FOR SAFEGUARDING ACCESS TO MINERAL DEPOSITS IN EUROPE

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# PARTICIPATORY LAND USE PLANNING FOR SAFEGUARDING ACCESS TO MINERAL DEPOSITS IN EUROPE. APPLYING THE QUICKSCAN TOOL IN THE MINATURA2020 PROJECT.


## ABSTRACT

The sustainable extraction of minerals in Europe is an indispensable activity to ensure that the present and future needs of the European society can be met. This means that sufficient access to land is required to explore for new deposits and ensure the future development of known ones. Such access may often be hindered due to legislative, environmental or social opposition constraints. This indicates the need of a participatory land use planning and of tools which can integrate multiple criteria to identify constraints and options to overcome them. The QUICKScan software tool is a fast, simple and transparent spatial modelling environment which allows the integration of data reflecting multiple criteria. The tool is appropriate for multi-stakeholder settings and it creates in situ and real-time multi-criteria maps. Our paper presents the results of applying this tool during stakeholder meetings within the European Commission-funded MINATURA2020 project in which we aimed to display suitable areas and areas with different degrees of restrictions to develop mineral exploration or mineral extraction. Several European case studies show that the QUICKScan tool is suitable for participatory land use planning in the mining business and that it can identify the geographical areas and the type of interaction with other land uses that restrict mining activities.



## KEYWORDS

Land use planning; Europe; multi-stakeholder; mining; exploration; mineral deposits


## INTRODUCTION

Demand for land in Europe is high. Europe is a mosaic of landscapes, reflecting the evolutionary pattern of changes that land use has undergone in the past, and is one of the most intensively used continents on the globe, with several land functions all competing for space: food production (cropland, grassland), biomass production, housing, infrastructure, natural and cultural conservation, water provision, tourism and recreation. Overall the highest share of land (up to 70%) is used for production systems (agriculture and forestry), with around a 5% destined to settlements (residential, recreational, etc.) (European Environment Agency, 2013). Land use for mining and quarrying, together with industry and transport use is only a 3.4% (Eurostat, 2015); land used only for minerals extraction typically occupies less than 0.1% of the European Union (hereinafter EU) Members' land areas (Montan Universität Leoben, 2010). Despite this, a key characteristic of mineral deposits is that they are not ubiquitous, i.e. they are found in certain places and cannot be moved. They need to be mined where they are found, in contrast to uses such as housing which is much more flexible.

The European Commission has now for long been acknowledging that access to (mineral) raw materials from domestic sustainable extraction is one of its priorities. This has been clearly indicated as a goal in the Raw Materials Initiative (RMI) and the European Innovation Partnership on Raw Materials (EIP-RM), both initiatives which seek to reactivate the minerals industry in Europe via technological and non-technological research and innovation programs and via continental and international cooperation. On the other hand, the European minerals industry faces social opposition to new projects due mainly to fears of environmental pollution based on some notorious negative experiences in the past. Other constraints to the activity are derived from inefficient, costly, elongated and complex permitting procedures and from legislation which restricts the activity at different degrees (e.g., in protected natural areas), all of which make the sector less competitive and discourage exploration. New exploration activities, expansion of operating quarries, new projects or the resuming of old ones may involve the origin of land use conflicts with communities living nearby (not-in-my-backyard NIMBY issue), and often entail difficult decision making processes for authorities.

Decisions about land use involve trade-offs between diverse sectoral interests, including industry, transport, mining, agriculture, and forestry. Managing these trade-offs in a way that maximises society's wellbeing requires integrated policies which include raising the public awareness to the importance of mineral raw materials for society and land use planning in participatory settings, i.e. open to a large part of the general public and their qualified representatives (e.g., NGOs) who become part of the planning process at early stages. For this, often policy makers are in need of an easy to handle research tool that is fast, simple and transparent, requires little data and can be carried out in a multi-actor setting. The QUICKScan (Verweij et al., submitted) (http://www.quickscan.pro/) is an example of this as it is both an *approach* and a *software tool* that is applied in group processes with policy makers and experts to develop and explore potential policy options and assess likely impacts of those options through data integration. The QUICKScan software tool encompasses a spatial modelling environment with functionalities to assess societal and environmental conditions, diagnose patterns and interactions and uncertainties thereof, implement alternative responses (e.g., spatial scenarios) and evaluate the impacts of those responses. It allows combining tacit expert knowledge with available spatial and statistical data, and it is easy to use in workshops providing real time results.

In this paper we present selected results of a series of workshops carried out within the **MINATURA2020 project** (http://minatura2020.eu/), an EU-funded project formed by a Consortium of 24 partners from 19 European countries representing multiple sectors (public authorities, universities, research centres, industry and geologists associations, geological surveys) and supported by an Advisory Board of experienced experts and by policy officers from the European Commission. The project aims at developing a concept and a harmonized framework for safeguarding European non-energy (metallic, industrial, construction minerals) 'mineral deposits of public importance' (acronym MDoPI) for their 'best use' in the future. In other words, we aim at avoiding unnecesary sterilization of mineral potential areas by safeguarding access to such areas via a balanced and fair land use planning procedure. The project is currently discussing via national and regional stakeholder workshops the different qualifying conditions for a mineral deposit (or an area with mineral potential) to become an MDoPI. The exploration of land use conflicts and challenges, i.e. some of the work introduced in this paper, is only one necessary input to understand the qualifying conditions which is rather a more complex on-going process. Out of 8 case studies, we present the results for an area with mineral potential in the Norrbotten County in Sweden and an offshore mineral potential area in the Celtic and Irish sea (an area shared by the UK and Ireland). The paper is surely of interest to land use planning authorities and those officers within mining companies or associations working with stakeholders.

## METHODOLOGY

The methodology employed followed three phases. First, during the early stages of the project, all project partners with an interest in specific areas in their countries were asked to fill a questionnaire proposing a mineral area to become a case study, explaining why the area is of importance for extracting non-energy minerals, and informing on the availability of digital spatial data that represents the selected case study. The work was coordinated and led by Alterra Wageningen University and Research Centre´s group in the Netherlands. Alterra´s team gathered all data and created an inventory (overview) out of which a selection of 8 case study areas (seven onshore, one offshore) was done. The onshore areas were: Hungary (Tállya village and surrounding Zemplén-Tokaj hills), Italy (Emilia-Romagna Region), Poland (Dolnośląskie Province), Portugal (Codaçal local scale area in the Serras d'Aire e Candeeiros site of the Natura 2000 Network), Slovenia (whole territory), Sweden (Norrbotten County), and United Kingdom (South West England and South Wales), the offshore area the Ireland/UK (an area shared by the Irish and Celtic Sea with mineral potential). All the case studies are of economic importance at the local and regional level (except Slovenia which includes the whole country).Second, partners prepared the digital data for the selected areas including GIS-prepared layers (linear or polygon shape) of areas holding: i) minerals (critical, industrial minerals, deposits of aggregates, mineral deposits of national interest), ii) biotic and abiotic factors, i.e. biophysical constraints (hydrology including areas prone to be flooded, slopes, elevation, land use, land cover, transport infrastructure, urban areas, etc.), and iii) planning categories or legislative constraints, i.e. areas subject to spatial planning by regulations (e.g., Natura2000 Network areas - the principal network of protected natural areas in Europe, RAMSAR sites, national parks, national, regional and local spatial plans, etc.). For the offshore case study additional data was required for activities which may hinder exploration or extraction activities such as shipping routes, oil pipelines and platforms, offshore wind farms, others. All data maps elements in two dimensions (2D).

Third, with the data gathered, three 2-day workshops were organized at Alterra´s venue in Wageningen, the Netherlands, during the second half of 2015. Representatives with expert knowledge on each case study attended the interactive workshops which were led by Alterra in developing and using the QUICKScan software. The main aim of the workshops was to investigate how the spatial data can be combined to detect mineral resource areas with few or minimal restrictions to conduct mining activities and areas more prone to face substantial competition by other land uses and severe restrictions for mining. During the workshops the most important issue was the creation of knowledge rules which form a structure to process the data. A knowledge rule captures the causal reasoning of participants and encrypts it in a conditional, mostly qualitative form, like: 'IF the aggregate deposit = holocene sandy AND the depth < 2m THEN the potential extractability = high'. Putting it more abstract: 'IF a AND b THEN c'. Rules may be chained, i.e. the result of a knowledge rule can feed into a consecutive rule. QUICKScan applies knowledge rules to GIS raster maps. The rule is applied for every location -cell out of the GIS raster map- to create an output map (see Figure 1).

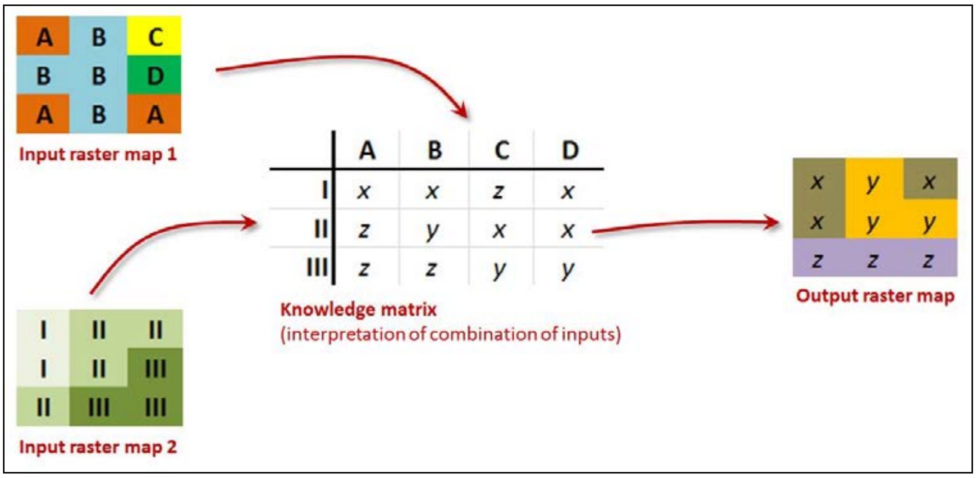


**Figure 1 –** QUICKScan matrix concept. The exercise starts by classifying each raster map according to criteria agreed during the workshop. Then, a knowledge matrix is created in which criteria (knowledge rules) are again agreed on how to combine the inputs of the raster maps. By applying the knowledge matrix, the two raster maps are combined and an output raster map is produced. This output raster map may become an input raster map for the next knowledge rule.

A basic example of how two input raster maps are combined is shown below for an area of the Netherlands, working with the availability of sandy aggregates and the accessibility of the deposits. First, GIS raster maps with spatial information were obtained. These maps consist of a geological map showing the spatial distribution of sandy aggregate deposits (input raster map 1), and a map showing the depth to these deposits (input raster map 2). To combine these maps, we created a knowledge rule which determines the relationships between both variables (depth to deposit layer vs aggregate deposit type, scale of 'no potential', 'a little potential', 'medium', 'high', and 'very high potential'). Applying this rule led to a map for Extraction Potential based on deposit availability (Figure 2). Red colour show areas of 'no potential' for extraction (due to e.g., lack of deposits or deposits too deep to be attractive), orange shows a 'little potential', and dark green areas are those with the 'highest potential', i.e. deposits available and closer to the surface.

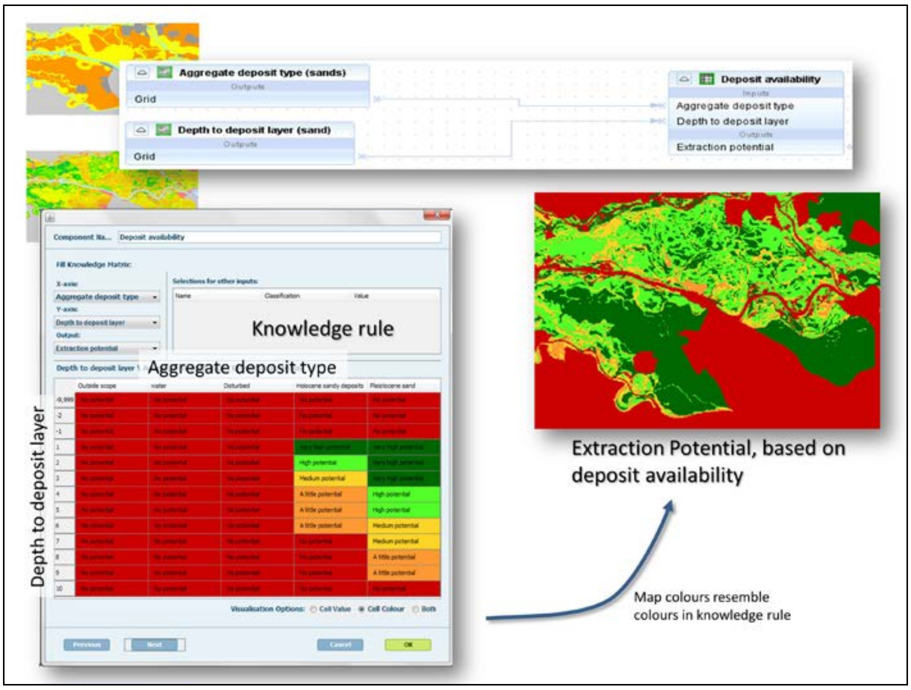


**Figure 2**. Screen shots of the QUICKScan tool exercise. The exercise starts by populating the system with spatial data and then by creating a knowledge rule (quantitative or qualitative) to define how variables interact with each other. The knowledge rule allows the combination of both variables and the creation of a new map such as the one on Extraction Potential based on deposit availability.

This is a basic example with a simple knowledge rule. The map showing Extraction Potential (Figure 2) can be further fine-tuned (filtered) by overlapping it with other GIS raster maps showing zones were potential extraction can be restricted due to policy plans, e.g., important cultural landscapes, zones of expected archaeological importance, groundwater protection zones, nationally designated quiet areas, nationally protected nature areas, etc. Moreover, given that the restrictive power of these plans varies, a weight can be assigned to them, and actually various weights can be assigned if different scenarios are constructed (e.g., a more pro-mining vs a more pro-conservationist scenario). This exercise of ‘playing’ with the raster maps by changing the layers of information analysed, applying ‘filters’ and the knowledge rules (created by the participants in situ during the workshops) allows creating different scenarios and results to scan the alternatives available. Given that the rules are created during the workshop and can be traced back with the software, it becomes a transparent tool for the whole process and the results.

## RESULTS

### Norrbotten Area, Sweden

The Swedish Norrbotten County takes up 25% of Sweden’s total area and has about the same size of Austria. However, only 250,000 people live there, of which 170,000 people live close to the coast. If the population density of Norrbotten would be the same as the EU average, 12 million people would live there. So one could think there could not be any issues on competing interests on land in this area. However, some of the biggest iron ore (e.g., Kiruna, Malmberget) and copper (e.g., Aitik) mines in the EU are located in Norrbotten.

Moreover, there are vast deposits of e.g. base metals and precious metals such as silver and gold. Potential competition with mining activities on land appear from nature conservation (national parks, Natura 2000 areas which make 25% of the area of Norrbotten), cultural heritage and reindeer herding by the Sami population (an indigenous people inhabiting the Arctic area of Sápmi, which today encompasses parts of far northern Norway, Sweden, Finland, the Kola Peninsula of Russia). Reindeer herding areas are occupying most of Norrbotten, as different parts of land are used in different parts of the seasonal life cycle (nursing areas, mating areas). During the workshop, potential competition zones were mapped, indicating the size of the constraints (see Figure 4).

A comparison shows that the Sami reindeer herding is 'always' an issue in Norrbotten, i.e. has the areas with the largest constraints (areas in red colour) (Figure 4, Figure 5); however, is not an impossible obstacle. Clearly, there is a need for negotiation here, perhaps including some kind of compensation. Cultural heritage seems to represent the least obstacle for mining activities (in areal terms, Figure 4).

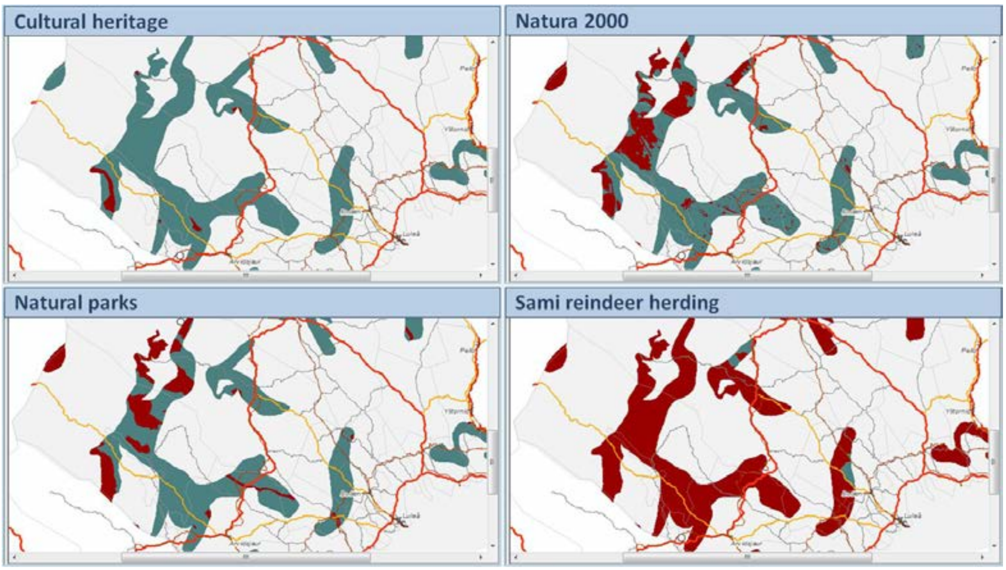


**Figure 4 -** Screen shots of QUICKSCan. Mineral resource constraints in the Norrbotten area, Sweden. In red areas of land use competition between mineral deposits and different restrictive land uses (natural parks, cultural heritage, Natura 2000 areas, and Sami reindeer herding areas), in blue areas without constraints

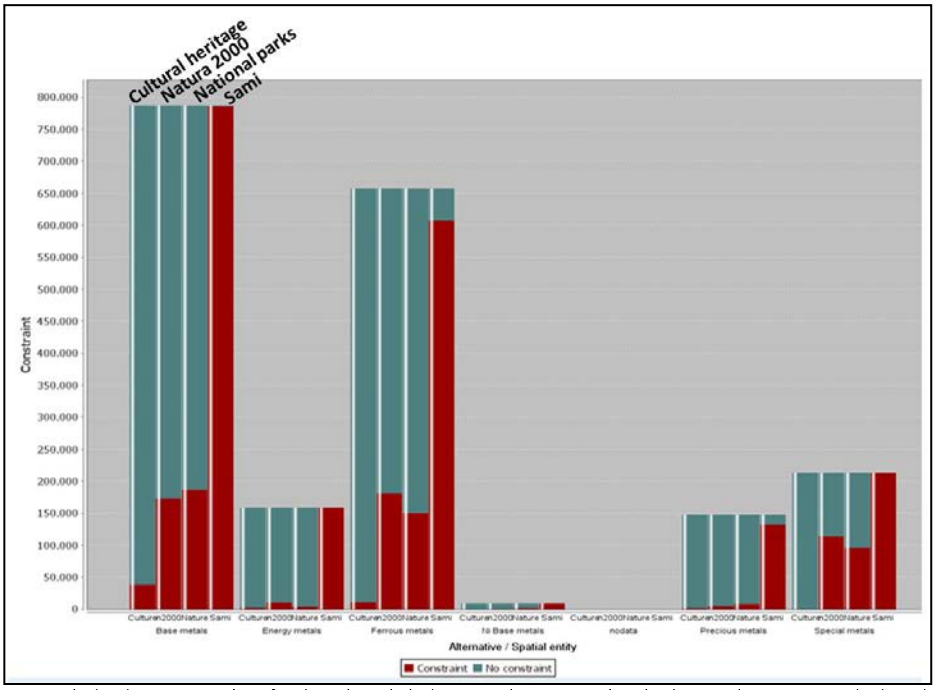


**Figure 5 -** Main land use constraints for the minerals industry and no constraints in the Norrbotten area. The bar charts show the areas of the specific mineral groups, indicating the different constraints (in red) and areas with no constraints (in blue)

**Irish and Celtic Sea: one sea, two countries, different datasets**

The case study of the Irish and Celtic Sea is unique in several aspects: it is the only offshore case study area, and two countries (United Kingdom and Ireland) are involved. As a consequence, the work during the workshop started with sorting out the spatial data that were relevant to use. As a basis, we compiled a map showing the position of the aggregate resources (see Figure 6, upper left corner, the area in white colour represents the shared Celtic and Irish sea, the line in blue the border, the areas in grey are the onshore ones). This map was based on both an Irish map, classifying 'sand', 'gravel' and 'sand and gravel', and a British map with a different classification, indicating 'fill aggregates', 'fine sand', 'coarse sand' and 'gravel'. The compiled aggregates map was overlaid with maps indicating the position and permit status of wind turbine farms, marine nature conservation areas and main fishery interest areas (in the latter case via proxy data on the value of the catch) (Figure 6). The latter map is a UK map, and although the catch value areas in the Irish part of the sea are indicated, the accuracy of this data has not been verified.

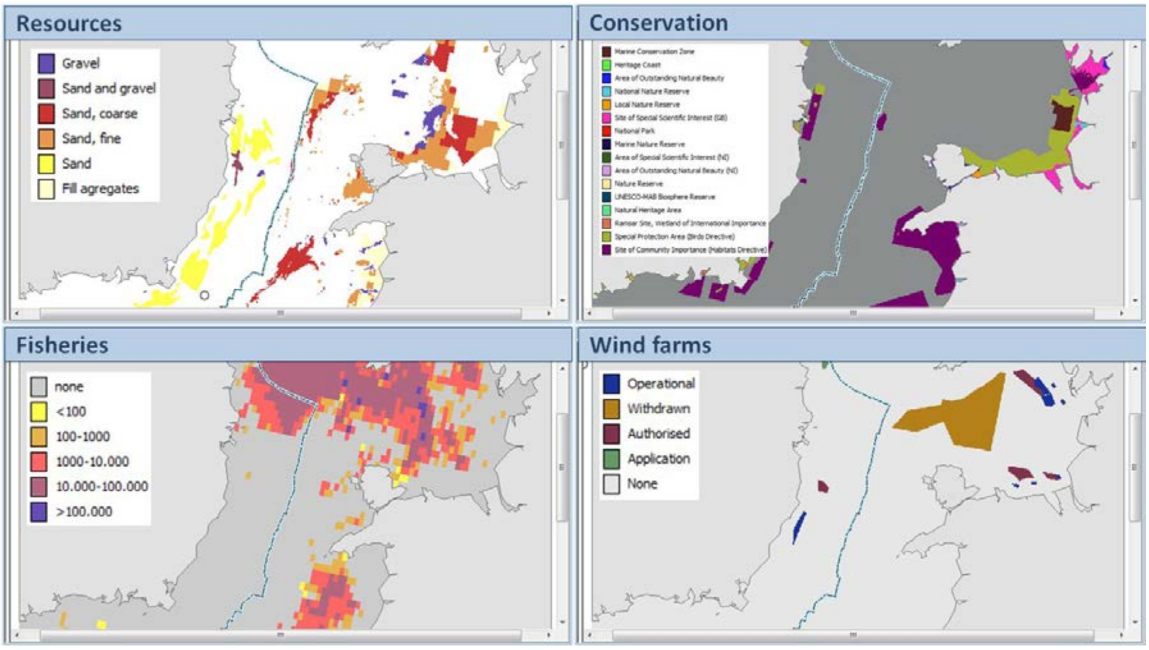


**Figure 6 -** Snapshots for the Irish and Celtic Sea between the United Kingdom and Ireland. Maps show aggregate resources (compiled map, upper left corner), marine nature conservation areas (upper right corner), wind turbine farms (lower right corner), and main fishery interest areas (lower left corner). The unit of the Fisheries map´s scale is economic value (British pound sterling) of live weight fish landed with gear type.

This led to a map indicating the possible interactions with other 'land use' (or: 'sea use'; Figure 7). The colours of the map belong to three categories depicting whether there is an overlapping of the map with aggregate resources and the other considered sea uses: 'yes', 'no', or 'may be'. Green colours in the map show the areal locations which have the lowest potential for conflict; in contrast, red colours show the areas with the most likely chance of being restrained for mining by other land uses, e.g. nature conservation in the coast of UK (the coast appearing on the right side of the figure with grey colour).

The bar charts in Figure 7 indicate the relative amount of interactions per theme and per country. Bar charts need to be used with care as different data has been combined. Having said this, they show that in Ireland's offshore area there exist only interactions with protected areas and almost no meaningful interactions with fisheries or wind farms. In the UK offshore territory there exists more potential for use conflicts with fisheries and protected areas.

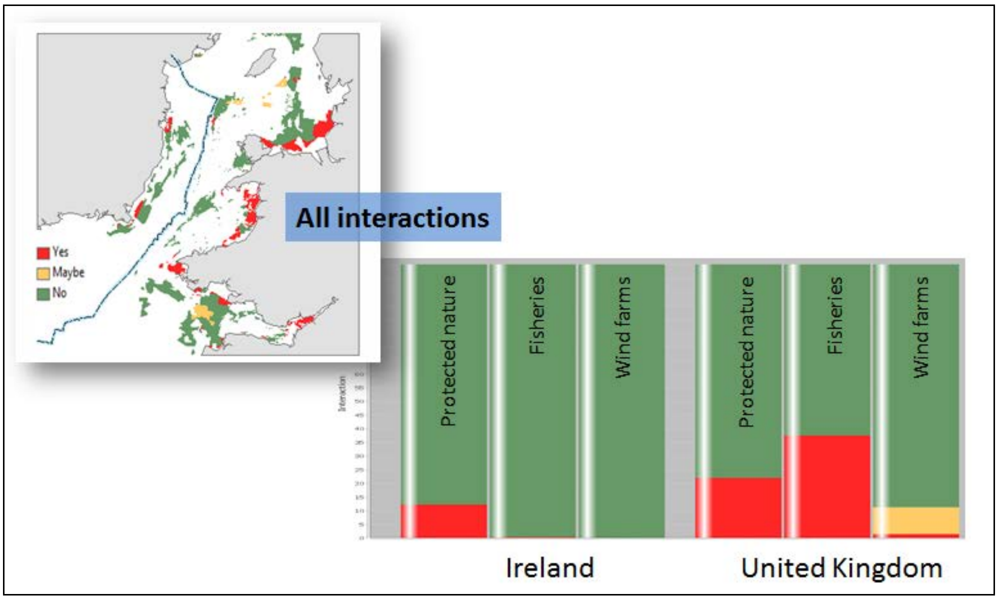


**Figure 7 -** Combining four maps in Figure 6 leads to the map showing all interactions. The bar charts give the relative amount of interactions per theme and per country

**Approach delimitations**

The selection of case studies was delimited first by the availability of specific digital spatial data, e.g. on the occurrence of particular minerals, which varies among countries and minerals. Due to for instance strategic importance, not all mineral deposits have publically accessible data, only those of major availability (e.g., Slovenia). In some other cases, only analogous spatial data is available (paper maps but no digital files). The downloadability may be limited to single (local) map sheets, downloadable one at a time or in non-GIS formats (like PDF) only. Often the use of the data is limited to just viewing the maps at a portal using WMS/WFS format (e.g., Sweden, Portugal, Slovakia, EU data). The analysis of the data available allowed concluding that, given the currently known EU datasets, it is impossible to map extraction suitability for various minerals purely based on the available EU scale maps. The conclusion was therefore drawn that it is more worthwhile to map extraction suitability based on (predominantly) Member State information, using maps on a local to regional scale.

Other delimitations have to do with the fact that all maps and graphs are simplifications of reality, with many underlying assumptions which lead us to make several ‘health warnings’:

- ***Not all factors are able of being mapped*** (or some are very difficult to map): we have often worked with nature conservation areas, but not with species presence and distributions. When species that are protected under the Bird or Habitat Directive are present in a certain area, this may limit further development of this area. These species continuously disperse to and colonise areas outside the mapped nature conservation areas, and will do so in the future. The same applies to marine fisheries which often move within an area difficult to map. Moreover, species distributions may be more dynamic (due to e.g., climate change) than the conservation areas are now. Local consultations could therefore include specific species presence and not conservation areas as such.

- ***Accuracy of geological information:*** The accuracy of the geological information is crucial, as this is the base map in all cases. During the workshop, we discussed various types of geological information. One could work with maps that show the outcrops only, or with maps that show the resource as a whole (3D maps), including e.g. sub crop and vein mineralisation. The latter is often unknown, or partially known or estimated. Moreover, the quality of the mineral is often not indicated on geological maps. Therefore, in some cases the maps will differ from existing national mineral inventories. We could even add a time dimension, as mineral resources availability may 'expand or shrink' according to improvements in knowledge (more drilling, better evaluation) or value (price falls/increases).

- ***Land use conflict areas***: The competition between mineral extraction and other land uses is not restricted to the boundaries of the case study areas, but is a factor relevant to decisions on mineral development in adjoining areas. For example, reindeer herding is not limited to the Swedish borders, but also affects policy making in Norway and Finland. And, as another example, heathland species conservation concerns large parts of Western Europe, from Denmark to the UK and then to Spain. This asks for a Pan-European approach of trade-off options.

- ***2D and 3D issue for mineral deposits***: the third dimension of mineral deposits is a crucial issue when visualizing and managing two-dimensional competition for the use of land. Near the surface, non-outcropping mineral deposits are covered by overburden that will be removed during exploitation. This overburden cannot be classified as a mineral deposit, but the area must be safeguarded for mining, avoiding other land uses to sterilize that deposit or, at least, must be considered for conflict management. During the workshops only 2D geological data was used, but 3D is expected to be used in coming QUICKScan workshops.

- ***Data and working scale***: for the purpose of providing a broad comparison on constraints or interactions with other land uses between countries or minerals, working on a scale 1:100,000 or even smaller would be fine. However, when the objective is to determine location specific policies or decisions, a large scale of 1:5,000 or even larger would rather be required. Fuzzy borders or buffer zones can possibly be used in case of inaccuracy.

- ***Classification issue***: Currently, classifications used vary per country (see e.g., the aggregates classification differences between the offshore parts of Ireland and the United Kingdom). Before producing pan-European policy frameworks, there is a clear need for a common, harmonised classification. A possible hierarchy for such classification could be like the Corine land use classification, with a broad base level and a stepwise detailing of each class. The common terminology of Minerals4EU could also be used as a starting point.

- ***Extent of marine areas***: There is perhaps a greater degree of mobility in the 'value' or 'significance' of marine competition. The marine system is perhaps more dynamic that land systems in both the value of cropping (fish catch) and the location of that crop. There may be major changes in size of catch in particular locations over a cyclical or non-cyclical base. The defined extent of marine conservation areas tend to be regular polygons unlike onshore designations and extend beyond the physical boundary of the actual area of interest. The apparent constraint may, in practice, not be an issue.

## CONCLUSIONS

Land use planning policies and instruments are nowadays necessary in Europe (but not only in Europe) if the access to land for the mineral raw materials industry is to be secured. Participatory land use planning, e.g. via interactive workshops with experts, planning authorities, industry representatives and other interested stakeholders, seems necessary to find common grounds on competing land uses and the necessary trade-offs. The QUICKScan software has proven to be a simple tool to work with 2D digital spatial data allowing the participatory creation of live, in situ knowledge rules and different scenarios. It has also proven useful to detect areas of potential conflict (interactions with other land uses) for the minerals industry as well as areas free or minimal conflict potential (according to the data employed for the analysis). Results from the analysis can become valuable input for policy makers in terms of detecting which zones should be subject to careful planning in order to start early with the aim of avoiding land use (or sea use) conflicts and mineral sterilization. The tool has large potential to be useful also for 3D analysis but this has yet to be tested in future workshops.

## ACKNOWLEDGEMENTS

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# PRESENT ASSESSMENT FOR MINERAL RESERVES IN MONGOLIA AND ECONOMICALLY VIABLE POTENTIAL PROJECTS


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# PRESENT ASSESSMENT FOR MINERAL RESERVES IN MONGOLIA AND ECONOMICALLY VIABLE POTENTIAL PROJECTS


## ABSTRACT

In the recent decades, the mineral reserves of Mongolia has ten-folded for copper, increased by 8 times for gold and tripled for iron ore and doubled for coking coal. It is related to the extensive mapping and exploration activities implemented. Oyu Tolgoi and Tsagaan Suvarga copper mines, Energy Resources and Erdenes Tavan Tolgoi coking coal mines have been commissioned in the newly discovered mineral properties. Besides the mining conventional resources, deposits for base metals, gold, iron ore and tungsten have being substantially investigated and prepared to be invested. The importance of the mining industry in Mongolia which currently accounts for 40 percent of the whole economy is progressively increasing by the further development of processing mineral resources including operation of copper smelters and ferrous metallurgical plants.



## KEYWORDS

Mineral reserves, projects, mineral extraction, investment, new mineral properties


## INTRODUCTION

In respect with major mineral resources and reserves in Mongolia, it can be estimated as follows: gold - 2.9 thousand tons, copper - 60.4 million tons, coal - 32.9 billion tones, iron ore - 1.8 billion tones and fluorspar ore - 82.6 million tons. Thus, it takes the 8th place, accounting for 6% of the world gold resources, the 3rd place, accounting for 9% of the world copper resources, the 10th place, accounting for 4 % of the world coal resources, the 12th place, accounting for 1.2 % of the world iron ore resources and the 4th place, accounting for 17 % of the world fluorspar resources.

In the recent 15 years, the mineral resources of Mongolia has been significantly increased as results of the foreign investment attracting in mineral exploration. For example, copper resources increased by 10 times, coking coal resources - by 1.5 times, gold resources - by 8 times and iron ore resources – by 3 times. The growth of the identified resources of Mongolia is shown in Table 1.

Table 1 – The growth of the identified resources of Mongolia

| *Types of minerals* | *Before 2010* | *2010* | *2011* | *2012* | *2013* | *2014* | *2015* | *Total* |
|---|---|---|---|---|---|---|---|---|
| *Gold, primary deposit, ton* | *82.3* | *307.1* | *55.7* | *41.1* | *30.1* | *2008.0* | *28.0* | *2553.2* |
| *Gold, placer deposit, ton* | *303.5* | *8.264* | *4.0* | *7.7* | *4.7* | *4.8* | *-* | *339.1* |
| *Polymetal, thous.ton* | *4087.2* | *480.3* | *239.9* | *-* | *212.6* | *433.5* | *-* | *5453.6* |
| *Copper, mln.ton* | *12.8* | *0.79* | *0.41* | *0.12* | *0.34* | *45.9* | *-* | *60.4* |
| *Iron, mln.ton* | *670.5* | *155.3* | *80.1* | *122.2* | *464.4* | *151.6* | *202.5* | *1846.5* |
| *Molybdenum, thous.ton* | *394.1* | *198.0* | *89.0* | *54.0* | *-* | *22.0* | *287.0* | *1044.2* |
| *Tungsten, thous.ton* | *261.3* | *2.7* | *1.2* | *-* | *103.6* | *235.6* | *2.9* | *607.2* |
| *Rare earth, thous.ton* | *1541.5* | *45.0* | *-* | *-* | *52.0* | *245.5* | *268.2* | *2152.2* |
| *Fluorspar, thous.ton* | *47.6* | *6.0* | *1.9* | *3.1* | *4.2* | *-* | *-* | *62.8* |
| *Coal, mln.ton* | *7634.7* | *349.7* | *7067.2* | *2376.2* | *4405.2* | *6822.3* | *4254.3* | *32909.6* |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| *Limestone, сая т* | *641.1* | *35.5* | *289.1* | *273.5* | *6492.7* | *1916.6* | *5.8* | *9654.6* |

It is resulted in the significant exploration works conducted in the territory of Mongolia, moreover, the availability of the vast lands in which the geological and exploration surveys had not ever been completed. It shows that there are high probabilities for discovering new mineral properties.

Oyu tolgoi copper mine and processing plant, Erdenes Tavan tolgoi and Energy Resources coking coal mines have been put into operation relied on newly discovered mineral resources.

Except of conventional mineral resources, new projects for uranium, base metals, gold, iron ore and tungsten are being intensively investigated and prepared for attracting foreign investment.

Based on the newly discovered mineral resources, giant plants has been commissioned and put operational including Oyu Tolgoi and Tsagaan Suvarga copper plants, Energy Resources coal plant and Tavan Tolgoi mines.

Except of those conventional mining operations, many projects are being developed and the relevant investment are being considered for uranium, base metals, gold, iron ore and tungsten.

The extractive industry of Mongolia currently accounts for 40 percent of Mongolian economy. Furthermore, the construction of the mineral processing plants including copper smelters and steel mills would significantly increase the shares of extractive industry in Mongolian economy.

## MAJOR MINING PROJECTS

### Major and potential mining projects

Oyu Tolgoi: In 1999, Oyu Tolgoi deposit was firstly discovered by Ivanhoe Mines. The deposit is located in the southern Mongolia, 80 km north of the Mongolian-Chinese border. The combined resources of the deposit, including adjacent deposits are estimated at 45 million tons of copper and additional exploration indicates that there are 5 deposits in the vicinity of the deposit. Mine life is over 110 years, assuming the current annual production capacity as 35-45 million tons.

The Oyu Tolgoi project has been financed since 2009 and major mining and infrastructure facilities have been commissioned and start operation since 2013. The project includes the construction of ore open-pit with annual production capacity of 35 million tons of ore, processing plant, water supply system, high-voltage power transmission lines, heating plant, tailing dam, airport facility and employees camp. At present, approximately 7 million US$ has been invested for the project.

The Government of Mongolia and Rio Tinto has signed the agreement on the development of the underground mine in 2005. The underground mine with the depth of about 1500 m in where the rich ore occurred would be constructed in a period of 5 years commencing from 2022. Oyu tolgoi project having annual production capacity of 0.8-1.5 million tons of high quality copper concentrates will export its products to Chinese smelters.

### Smelters project

One of the significant projects associated with Oyu Tolgoi project and Erdenet copper-molybdenum plant is a smelter.

The Government has resolved that the copper smelter should be constructed in Bor-Undur soum, Khentii province. Bor-Undur soum, a small town with 10,000 residents is located in the industrial region having well developed infrastructure including 380 km railway access to Ulaanbaatar in which a fluorspar mining and processing plant with an annual capacity of 0.6 million tons is operating.

A project working unit, set up in 2015 under the Ministry of Industry in order to prepare the feasibility study and furnish the preparatory works for the construction of the smelter is still working. The Government of Mongolia is preparing to sign the agreement in cooperation with the interested parties. According to the prefeasibility study, the project require investment of USD 1.5-2.0 billion. The annual production capacity of the smelter is estimated at 120-150 thousand tons of copper cathode.

Development project of Burenkhaan phosphorus deposit: the importance of the project interconnected with the copper production of Mongolia. The project comprises of the development of phosphorus deposit, construction of processing plant and chemical plant of superphosphate fertilizer and by products.

For the production of 1 ton of cathode copper, 3.7-3.9 tons of sulfuric acid is produced. Based on the assumption, sulfuric acid in quantity of 450 thousand tons is produced annually in Mongolia. Upon the consideration of ore reserve of the deposit that was outlined at 35 million tons (P2O5) of phosphorous, the plant is planned to have an initial capacity of 1.5-2.0 million tons. Estimate on the production of phosphorous ore, phosphorous concentrates and final products is shown in the following Table 2.

Table 1 – Volume of production and required phosphorus concentrate which depend on neutralizing sulphuric acid

| Neutralizing sulfuric acid thous.tons | Required | | Production | | |
|---|---|---|---|---|---|
| | Concentration, thous tons | Ore, thous tons | Double super phosphate,thous.tons | Gypsum, thous.tons | $Na_2SiF_6$, thous.tons |
| 400-450 | 1054.0 | 2000.0 | 728.0 | 566.0 | 5.7 |

Phosphorous ore in quantity of 1.2 -2.2 million tons is processed in order to output 400-450 tons of superphosphate fertilizer. The total reserves amounted 120.9 million enables the plant operation more than 55 years at its maximum production capacity as 2.2 million tons. The project is considered as mining and chemical complex and to be implemented promptly with investor, once its reserve was outlined.

**Coal projects**

Mongolia has vast coal resources, contained within 15 large-scale coal bearing basins. There are around 320 coal deposits and occurrences (80 deposits and 240 occurrences), according to Geological Information Center of Mongolia.

Tavantolgoi coal project: Tavantolgoi project area or basin is located in the Ulaan nuur valley in Tsogt tsetsii soum of Umnugovi province in southern Mongolia, 540 км south of Ulaanbaatar city and 270 км north of Mongolian – Chinese border. There are several coking coal deposits or fields in the basin, covering total 68.5 thousand hectares area.

Geological coal resources and reserves of Tavantolgoi coal basin is estimated to over 6 million tons of coal, of which 1,5 billion tons belong to high quality coking coal. Small mine operation with annual production capacity of 50 thousand tons of coal had started in 1965 for local need. Only since 2005, mine capacity has increased significantly for the purpose of coal export.

Presently, 4 coal mines, each of 10-15 million tons of designed capacity, managed by 3 different companies are in operation in the basin.

The area offers several infrastructure advantages: paved road, connecting coal deposit and Mongolian – Chinese border points, high power transmission line, water supply system, coal washing plant etc. Railway, connecting coal deposit and Mongolian – Chinese border points is under construction.

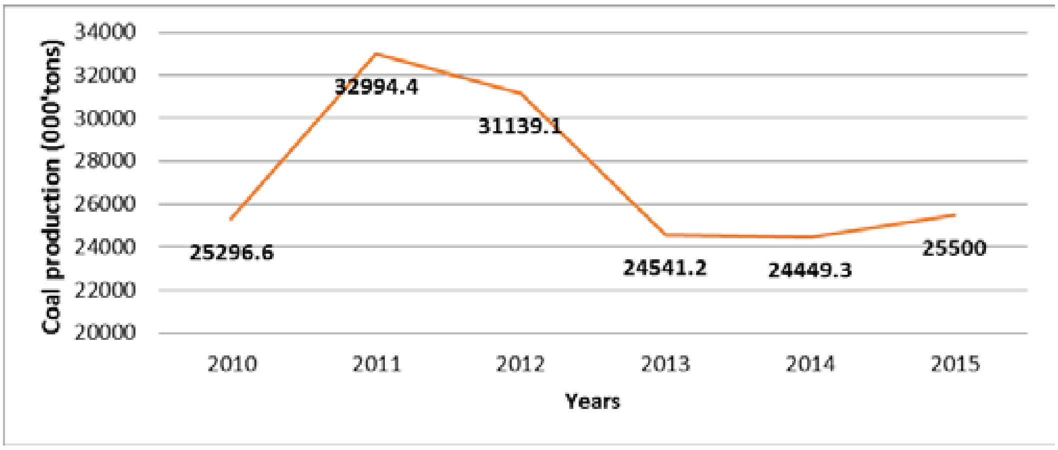


Figure 1 – Recent coal production in Mongolia for 2010 -2015 (000'tons)

**Uranium projects**

Mongolia holds 1.5 million tons of uranium resources, including 145 thousand tons of mineable reserves. Largest uranium project is implemented by Areva Company of France, which identified 70 thousand tons of mineable uranium reserves at Zuuvch –Ovoo and Dulaan-Uul deposits. The company finalized feasibility study of the plant to produce 2 thousand tons of yellow cake annually since 2017. Now, pilot testing and other preparation works are under progress. The deposits are located 420 км south of Ulaaanbaatar city and 300 км of north-west of the Zamyn-Uud, Mongolian –Chinese border port. Investment for the plant is estimated to be 2 billion US$. The deposit belongs to low content, sandstone deposit and in-situ leaching (ISL) technology is proposed to be used.

Another reasonable project is Mardai uranium project for developing primary deposits, located at Mardai ore knot. In the area, there were discovered primary uranium deposits with 40 thousand tons of reserves in the 1980's. The feasibility study for developing Gurvanbulag deposit in the Mardai area by underground mine with ore processing plant has been developed by Emeelt Mines LLC, invested by PRC. Mardai ore area in the territory of Dornod province is located at 150-160 km distances from Russian and Chinese borders and includes Dornod, Mardain gol and Narst deposits, closely located each to other. Reserves of the deposits are identified and possible to be invested and developed with increase of uranium price at world market. Dornod deposit with 28 thousand tons of uranium reserves is biggest among the deposits, which was explored by Khan Resourse LLC, Canada. There were occurred some disputes between the company and the Government of Mongolia in connection with revocation of exploration license. The dispute was resolved by paying compensation to the company.

**Projects of ferrous metallurgy**

Mongolia's export of iron ore is 6-8 million tons per annum and domestic iron demand 1,5-2 million tons.. There is certain demand for iron products in case of establishing metallurgical plant in Mongolia, also some portion of the products can be exported to PRC. Currently, metallurgical plant for producing 100 thousand tons of iron products with use of scrap iron in Darkhan and small plant of Beren Company for producing 50 thousand tons of cast iron from iron ore are in operation. However, plants of larger capacity for processing iron ore not yet established in Mongolia. Preliminary studies indicate that it will be possible to built metallurgical plant for producing metal billets, smelting 1-2 million tons of cast iron in Darkhan city, where closely situated operating iron ore mines. Investment for the plant is estimated to 1.5 billion US$, including cost of necessary infrastructure facilities.

**Projects for smelting and refining of base metals (Polymetals)**

Nowadays, plant of Tsairtmineral LLC for producing 50-60 thousand tons of zinc concentrates is operating in Eastern Mongolia. At the same time, numerous mineral processing plants with foreign investment were established in this area, developing several zinc, lead and other base metal deposits. Further development of base metal processing plants in the area based on resource potential may create possibilities of producing value added products and establishing high efficiency production. Moreover, eastern region possesses tungsten and molybdenum deposits, apart from base metal deposits. Therefore, establishment of processing and refining plants with universal technologies should be considered from the point of view of long term operation.

## CONCLUSIONS AND SUGGESTIONS

1. Increased reserves of some minerals in Mongolia by 1.5-10 times for recent 10 years show reliable mineral potential for developing large scale mining and mineral processing projects.

2. Mongolia promises opportunities for discovering new large mineral deposits, so far about 10% percent of total territory is currently investigated under the exploration licenses.

3. Mining sector of Mongolia is dominated by mineral extraction industry. Therefore, Government of Mongolia is being paid attention to mineral processing and refining to produce value added products and achieve more high level of efficiency. Large mineral markets in the two neighboring giants - China and Russia and other region has increased demand of mineral supply.

4. The major mining projects in Mongolia are largely based on copper, gold, coking coal etc. In the further, large mineral processing projects, such as copper smelting plant, phosphate mining and processing plant, nonferrous metallurgy plant, polymetals processing plant etc. require new investment and international cooperation.

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# REDUCING ENVIRONMENTAL IMPACT THROUGH THE RECOVERY OF IRON ORES ULTRAFINES

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# REDUCING ENVIRONMENTAL IMPACT THROUGH THE RECOVERY OF IRON ORES ULTRAFINES


## ABSTRACT

The greatest and noblest challenge of mining engineering for the present and the future of the treatment of iron ore could be considered as the pursuit of optimizing the use of the mineral resources. The need for obtaining adequate places for tailings disposal, reducing waste volumes sent to the tailings dams associated with the growing difficulty in obtaining environmental licenses, are some of the factors that make the processing of slimes a real alternative for increasing the iron and mass recoveries. This environmentally correct option has an enormous potential for achieving the rational use of the available natural resources in a profitable way. Currently, the tailings dams are a fundamental condition that makes possible the installation and operation of the concentrators for processing the iron ore. Even when considering all the specific characteristics of each mine and iron ore type, there exist studies that indicate the technical feasibility for recovering millions of tons of ultrafine iron oxides that are discarded at the tailings dams every year. Systematic mineral processing investigation developed in some mines of the Iron Quadrangle in Minas Gerais, during the last decades, presented results that indicate a great potential for recovering the ultrafine iron particles from the discarded iron ore slimes.



## KEYWORDS

Ultrafines, iron ore, tailings dam, slimes


## INTRODUCTION

The growing market demand for iron ore associated with the scarcity of rich deposits and the need for processing sophistication propitiate the exploration of marginal ores with low grade of iron and great quantities impurities e.g. the ones disposed in tailing dams (Nascimento, 2010; Rocha, 2008).

The production of concentrates from these low-grade ‘ores’ involves a very important aspect: the huge volume of waste created. A study carried out by Jones and Boger (2012) claims that the mineral industry is the biggest world tailings producer, producing about 65 billion tons/year of which 14 billion are waste majorly consisting of fine particles (smaller than 120 µm).

Azcue (2012) emphasizes that, from that waste, the solid waste is one of the main characters in the environmental impact of mining companies’ activity. The treatment and storage of these tailings aim to optimize costs and maximize the operational safety. Both these factors compose one of the main goals of those companies to meet environmental requirements once waste disposal is classified as additional cost with no return in the project.

The late accidents related to tailing dams that have happened in Minas Gerais show the tragic environmental and social impacts related to these constructions break besides the knowledge and control their technical aspects. Among the damages it is highlighted the vegetal suppression, water supply compromise to thousands of citizens, irrecoverable loss of fauna and flora, displacement of people, local economy impact, and even human losses.

This article focuses in the scenario of raw material demand, amount of waste generated, and current environmental concerns aiming to exemplify successful practices of reuse of tailings from dams, as well as show the current landscape of iron ore tailing dams in the state of Minas Gerais.

## MINING WASTES

There are two types of waste created by the mining industry: the sterile material and the tailings. Concerning the first one, during the stripping of the deposit it is produced material with no economic value to the enterprise that will be disposed in dumps called waste dumps. Concerning the tailings, they result from processing plants and may contain high levels of toxicity, besides having particles dissolved and in suspension, heavy metals and reactants.

In ore treatment processes the quantity of tailings created is great and their final destiny is under the economic goals of the company.

Abreu (2012) remarks that both sterile and tailing are disposed on pre-selected places over the ground surface where there is no ore underground. The mining companies are responsible for their tailings disposal, regardless of the project being an open pit or underground mine.

The National Council on Water Resources (Conselho Nacional de Recursos Hídricos - CNRH), when addressing the law N. 12.334 from September 20th, 2010, defines the sterile disposal system as a projected structure deployed to accumulate materials temporally or permanently in a planned and controlled geotechnical manner protected against erosive actions. It also defines the tailing disposal as an engineering structure to hold and dispose residues originated from ore processing, water catchment and chemical correction of effluents.

Therefore, the tailing dams are structures constructed in order to hold the waste produced by the beneficiation process. These structures represent a pollution source and are governed by specific environmental rules concerning their location, building, and geotechnical, structural, social and safety aspects.

For Campos, Castro, Vidal and Borlini (2009), the main environmental impact associated with the iron ore production is the construction of tailings dams. For the authors, the main preventive actions of this damage are the registration of these structures both in operation and abandoned, the technological characteristics of the material disposed there and the maintenance of stability.

Edraki, Baumgartl, Manlapig, Bradshaw, Franks and Morgan (2014) point out that solid waste can contain fine and sludge that affect and damage the stability of the facilities of its own storage, and reagents used in the flotation as collectors, flocculants, or other from the steps of concentration, which can increase the risk of contamination of soil and water.

## NEEDS FOR ORE FINES RECOVERY

The best way to preserve a non-renewable resource is its rational consumption. However, the population size and current life standards make a consumption drop almost utopic. This article considers the reprocessing of fines through reuse or recycling as one way to value these materials, which are being classified as tailings.

Once the reprocessing of fines prolongs its useful life, these material cannot be classified as waste, since that nomenclature is intended for materials that have no other destination than their final disposal.

Over the years, the dams have attracted attention in the national scenario through different types of rules aiming the regulation and inspection of these constructions. In these laws, the National Policy for Dam Safety (Política Nacional de Segurança de Barragens - PNSB) is highlighted, which was stablished by the CNRH 2010 and says the entrepreneur is legally responsible for the dam safety, should guarantee the forecasted inspections, periodic revisions, and the organization of related documents.

The registered dams in the PNSB are classified according to two parameters in high, medium and low levels, as shown in table 1. It is explained in the CNRH (2010) that the “associated risk parameter” includes technical characteristics and aspects that influence in accident probability, such as conservation state and the dam safety plan. Secondly, the “associated potential damage” concerns the environmental, economic and social impacts the rupture, leakage or infiltration can cause, regardless the occurrence probability.

Table 1 - Risk Category Classification and Potential Damage Associated (Adapted from DNPM, 2012)

| Associated Risk | Potential Damage Associated High | Medium | Low |
|---|---|---|---|
| **High** | **A** | **B** | **C** |
| **Medium** | **B** | **C** | **D** |
| **Low** | **C** | **D** | **E** |

Concerning the structure classification, table 2 identifies and classifies the tailing dams in general and the specific iron-ore-tailing dams in the state of Minas registered in 2014.

Table 2 - Mining Tailing Dams in Minas Gerais Classification (Adapted from DNPM, 2014)

| Classification | Number of Dams | Iron- Ore- Tailing Dams |
|---|---|---|
| A | 2 | 0 |
| B | 4 | 3 |
| C | 114 | 49 |
| D | 63 | 29 |
| E | 61 | 20 |
| **Total** | **244** | **101** |

Duarte (2008) points out that as in Brazil, most countries have active laws for mining waste disposal and tailing dams. However, it is not rare for accidents to happen involving these structures and the economic, social and environmental losses connected to them. Despite the law and the available technology, some dams are built with failed project, operation or maintenance criteria.

Lozano (2006) enforces that the accident costs (e.g. properties damage, studies and reports, indemnity and legal taxes, employees time and salary losses) is notoriously higher than prevention costs, which covers preliminary studies, project engineering, construction, operation and maintenance supervision.

Duarte (2008) claims that despite the specific legislation, few are the countries that have real control over the number and condition of tailing dams in their territory. One of the first actions to minimize the accidents risk would be an efficient management of the structures, a complete inventory on the specific dimensions of the projects (height, volume, dam's crest length, deposited mass, and others), characteristics of operation and monitoring. Having the data correctly collected and organized, there should be the classification of the dam according to its risk parameter, therefore defining its level and type of inspection to be carried out.

It is also observed that although the National Department of Mineral Production (Departamento Nacional de Produção Mineral - DNPM) is responsible for the authorization and supervision of tailing dams, and the State Environmental Foundation (Fundação Estadual do Meio Ambiente - FEAM) for environmental licensing of these structures, information regarding technological and mineralogical characterization of these wastes, as levels of the main elements, particle size, solids percentage of pulp and tons / hour of solid are unknown. The data attached to dams are basically related to structural and geotechnical issues such as bus and height of the reservoir volume, for example.

Subrahmanyan and Forssberg (1990) have discussed the large quantity of mineral goods that were classified as tailings mainly because of their size, and defended their re-processing as a manner to reduce the dams' volume.

Table 3 seeks to illustrate the quantity of tailings generated by year by the main companies in Minas Gerais. The data is an estimation done through information from the magazine Minérios & Minerales (2014), from DNPM and active iron-ore-mining professionals.

According the Informe Mineral, by DNPM, in 2014, approximately 290 million tons of iron ore were produced in Minas Gerais. The estimation carried out covered 94% of the mentioned production, which considered over 100 million tons as tailings.

## EXAMPLES OF FINE IRON ORE RECOVERY

In order to demonstrate the feasibility of ore tailing recovery, there are some example below of successful practices in mining companies located in Minas Gerais in the last decade.

Before the selected examples it is important to point out that Samarco pioneered the iron ore tailing recovery in Minas Gerais. In 1994, the company studied and implemented an ultrafine processing plant. The millions of tons of fines recovered by this process yearly represent a bold environmental impact reduction as otherwise they would be disposed in tailing dams (P. R. M. Viana, personal communication, March, 23, 216).

The ore coming from the milling went through cyclones in order to separate ultrafine material – below 10 μm – potentially harmful to flotation circuits. These cyclones underflow fed the regular flotation circuit while the overflow fed the fine iron ore recovering circuit (Mapa, 2006).

At this fine ore recovering plant, the pulp went through a cyclone circuit. The overflow was the final sludge that would feed the thickeners. The underflow went to a conditioner tank where starch was added, then feeding a rougher and cleaner stage of flotation in columns. Picture 1is a simplified flowchart of the process (Mapa, 2006).

Recently Rocha (2008) investigated the economic appreciation of ultrafine tailings (slurries) through reverse cationic flotation of iron even despite the traditional view that fine particles do not float. After technologic characterization of the material, reactants dosage was analyzed and due to the good results from bench tests, pilot tests were carried out. The study points a favorable financial delta for the company, because of the ultrafine extra ore.

Gomes (2009) investigated the tailing stocked in the dam that was produced by the ore processing plant of the Córrego do Feijão Mine, in Brumadinho – MG, which processed hematite and limonitic itabirite. After sampling and technologic characterization of the dam, parameters for concentration through magnetic separation were adjusted. The results demonstrated the possibility to produce iron ore concentrate with chemical specifications of pellet feed for blast furnaces.

Table 3 - List of the main mines and amount of tailing in the state of Minas Gerais. Data obtained from Minérios & Minerales magazine (2014), DNPM and professionals working in the area: Base year: 2014

| Base year: 2014 | | | | | |
|---|---|---|---|---|---|
| **Mine** | **Company** | **Location** | **ROM (Mt/2014)** | **Final product (Mt/2014)** | **Tailings (Mt/2014)** |
| Itabira | Vale | Itabira | 60,7 | 35,5 | 25,2 |
| Minas Centrais | Vale | São Gonçalo do Rio Abaixo | 47,8 | 33,0 | 14,8 |
| Minas Itabirito | Vale | Itabirito | 46,1 | 33,0 | 13,1 |
| Alegria | Vale | Mariana | 16,3 | 11,0 | 5,3 |
| Capão Xavier | Vale | Nova Lima | 33,0 | 22,0 | 11,0 |
| Paraopeba | Vale | Nova Lima | 30,3 | 28,2 | 2,1 |
| Vargem Grande | Vale | Nova Lima | 30,2 | 25,0 | 5,2 |
| Pico | Vale | Itabirito | 28,5 | 20,0 | 8,5 |
| Casa de Pedra | CSN | Congonhas | 25,9 | 18,0 | 7,9 |
| Fábrica Nova | Vale | Catas Altas | 16,4 | 13,7 | 2,7 |

| | | | | | |
|---|---|---|---|---|---|
| Capitão do Mato | Vale | Nova Lima | 16,0 | 11,0 | 5,0 |
| Fazendão | Vale | Catas Altas | 13,2 | 10,2 | 3,0 |
| Oeste | Mineração Usiminas | Itatiaiuçu | 10,7 | 6,4 | 4,3 |
| Pau Branco | Vallourec Mineração | Brumadinho | 6,0 | 4,3 | 1,7 |
| Serra Azul | ArcelorMittal Mineração | Itatiaiuçu | 3,6 | 1,8 | 1,8 |
| Total | 15 mines | | 384,7 | 273,1 | 111,6 |

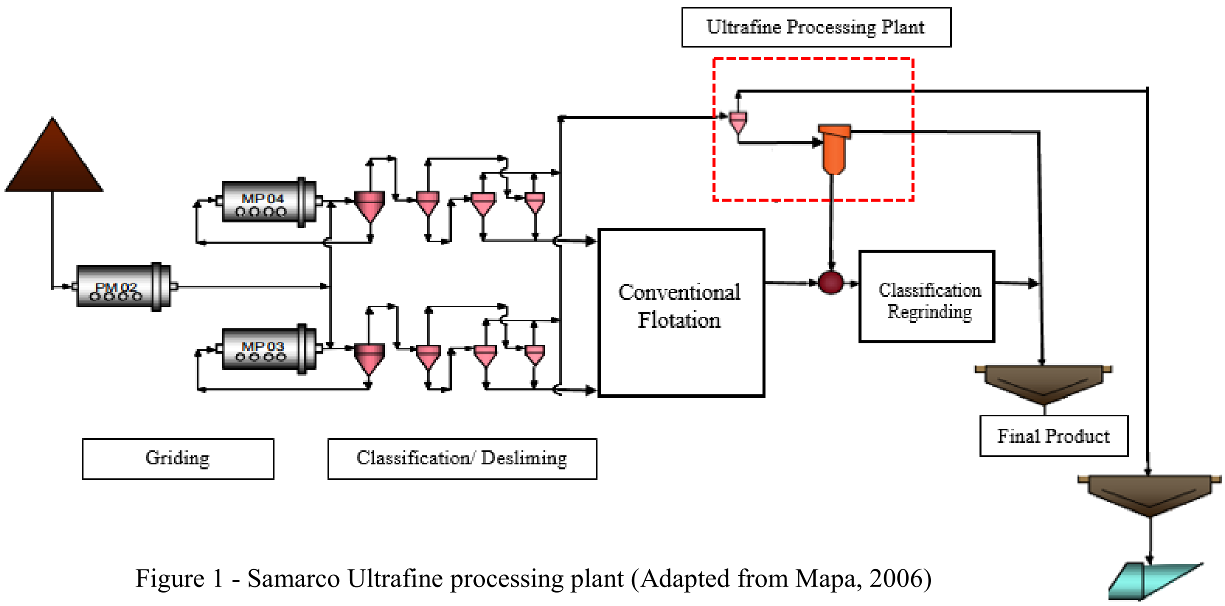


Figure 1 - Samarco Ultrafine processing plant (Adapted from Mapa, 2006)

Table 4 - Examples of fine iron ore recovery in Minas Gerais

| Examples of Fine Iron Ore Recovery in Minas Gerais | | | | |
|---|---|---|---|---|
| **Author/ Source** | **Company/ mine** | **Fine material origin** | **Steps** | **Results** |
| Rocha (2008) | CSN/ Casa de Pedra | Slimes thickener underflow | Technologic characterization, desliming cationic Reverse Flotation (mechanical and column cell) | Grades in the concentrate: 66,8% Fe, 0,51% $SiO_2$ Slurries treated separately float |
| Gomes (2009) | Vale/ Corrégo do Feijão | Cyclone overflow | Technologic characterization, desliming, classification flotation and magnetic concentration | Grades in the concentrate: 67,5% Fe, 1,5% $SiO_2$ The best results were obtained by magnetic concentration |
| Santos (2010) | Vale/ Pico mine | Cyclone overflow | Technologic characterization, desliming and Flotation (column cell) | Grades in the concentrate: 64,0% Fe, 1,8% $SiO_2$ The best results were obtained by cationic reverse flotation |
| Sales (2012) | Vale/ Brucutu | Slimes thickener underflow | Technologic characterization and magnetic concentration (cleaner, scavenger and cleaner from scavenger) | Grades in the concentrate: 66,8% Fe, 0,76% $SiO_2$ |
| FEAM (2013) | Minerita | Processing plant | Technologic characterization, silicate concentration, mechanical strenght and water absorpyion tests | Production of industrial sand to be employed in civil constructions |
| Costa, Gumeri and Brandão (2014) | Company not identified in Quadrilátero Ferrífero | Ore processing plant not identified | Technologic characterization, magnetic concentration, compressive strenght and absorption tests | The sinter feed waste after concentration was considered satisfactory for concrete production |
| Andrade (2014) | 4 iron tailings dams in Quadrilátero Ferrífero | Tailing stocked in the dam | Technologic characterization | The four tailings dams contain high grades that justify advanced studies |

Santos (2010) studied the flotation for slurries after two cyclone system stages in Pico Mine of Vale. For such, the material was characterized and direct and inverse flotation in column routes were analyzed. The ore, containing hematite, goethite, caulinite, quartz and gibbsite, presented satisfactory grade for Fe (64%) and $SiO_2$ (1.80%) in the concentrate of the reverse flotation system.

Sales (2012) stablished parameters for the magnetic concentration of fines from the underflow of slurries thickener in the Brucutu Plant of Vale. Firstly dumped as tailings, it was found the material contained grades that justified it undergoing processing; Fe and $SiO_2$ grades in the concentrate were up to 66.8% and 0.76% respectively.

The company Minerita (Minérios Itaúna Ltda.) was awarded the 'Good Environmental Practices' by FEAM with the support of the Secretary for Environment and Sustainable Development of the State of Minas Gerais and SENAI (National Service of Industrial Training/ Serviço Nacional de Aprendizagem Industrial). The company extracts iron, but aims the usability of silicates, and characterized the waste, therefore, designing a concentration route for industrial sand production. After some tests, such as mechanical strength and water absorption, the sand was considered of excellent quality for cement artifacts construction to be employed in civil constructions. A new company, BLOCOITA, was created to make business with the new product.

Costa, Gumieri and Brandão (2014) studied the feasibility of reusing the sinter feed waste as aggregate for concrete production for pre-modeled elements. After technologic characterization and magnetic separation, the waste performance according to its physical, technical and environmental properties was considered satisfactory for its use as paving concrete. However, due to the elevated density of the product (because of the iron presence) it is recommended the production to be performed in loco, avoiding extra transportation costs.

Andrade (2014) characterized the waste of four dams in the Iron Quadrangle, determining the size distribution of particles, the chemical composition, the mineral phases identification, and morphology of grains. The results presented satisfactory characteristics for deployment of these tailings in civil constructions, such as concrete, mortar, and ceramics production and paving works. The author endorse that each dam presented distinct grain size and iron and silica grades. Mechanical tests must be carried out to confirm the feasibility of use for the tailings.

Table 4 illustrates the examples above in simplified manner.

## CONCLUSION

This article approached the environmental impact reduction through the recovering of iron ore fines due to the increasing frequency of the theme in scientific and academic papers, and its relevance concerning the raw material demand, the quantity of waste created and the environmental concerns.

The fact that the ore reserves are non-renewable goods alone justifies the necessity of a better use method. Environmental and economic factors endorse the recovery of fines relevance, as once they are used the ore extraction is reduced, the sterile and tailing piles sizes reduce, allowing revenue stead of costs, and extended mine activity.

Nowadays, tailing dams are the biggest impact associated with iron ore processing, and at the same time are considered indispensable for the feasibility of the processing plants.

The state of Minas Gerais has over 200 dams registered in the PNSB, being almost 40% from the iron ore industry. Even though among this total just a few are classified with high potential associated damage or in a risk category, the mining industry, especially the iron ore mining deposits millions of tons of waste in dams every year.

The estimation presented in the table showing the relation between the main mines and tailing quantities in the state of Minas Gerais do not show exact values, due to the difficulties to obtain the information, which does not consider production or stock selling, nor the re-processing of the waste. The data collection endorses the great mass movement, ROM, production, tailings and waste generated every year.

Other important aspect is the real control number, register and condition of every tailing dam in the state, which also includes the non-operational dams. Further specific data, as solids percentage and grade, are of great importance for future fines recovery.

The studies mentioned on this paper are successful examples of iron-ore tailings reuse in Minas Gerais in the last decade. It is observed high grades of iron in the slurries. The authors have shown that for a reuse study it is essential the ores technological characterization, once it studies specific aspects of mineralogy providing information for the development and optimization of the beneficiation processes. Through the technological characterization parameters were stablished for concentration routes that could reach satisfactory grades of Fe and $SiO_2$ in the concentrate.

Finally, due to particularities of each ore, it is recommended to every mining company to invest in means to reuse the tailings as the ones that applied a valid waste management policy, contributing to a better sustainable development of the community they are inserted in, showing environmental and economic advantages especially because of the volume reduction in tailing dams.

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# REMOTE SENSING APPLIED TO DETECTION OF MINING DEGRADED AREAS IN SOUTHERN BRAZIL BETWEEN 1985-2011

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# REMOTE SENSING APPLIED TO DETECTION OF MINING DEGRADED AREAS IN SOUTHERN BRAZIL BETWEEN 1985-2011

## ABSTRACT

The multi-temporal image analysis is one of the most convenient and useful ways to determine how specific attributes of a particular area have changed between two or more regular intervals, comparing aerial photographs or satellite images of the study area taken at different times. This study examined the impact of the expansion of degraded areas through the mineral production and subsequent changes in natural vegetation after leaving the area over a period of 26 years in a region affected by copper mining over a century generating environmental, social and economic impacts in Minas do Camaquã in southern Brazil, using geographic information system (GIS) and remote sensing (RS) techniques. A series of Landsat images were classified by normalized difference vegetation index (NDVI) to produce three land cover maps of the region. From comparisons between these maps and areas with no vegetation cover, it was possible to quantify the variation that occurs in the landscape, identifying the evolution of changes in natural vegetation area. It has been observed that between 1985 and 1996 the degraded area has increased 8%, however, in 2011 (the last year analyzed), there was greater vegetation cover than in the first reporting period resulting in vegetation recovery of 26% when compared to 1985.

## KEYWORDS

Remote Sensing, GIS, Mining, Degraded Areas, NDVI.

## INTRODUCTION

After the advent of the first remote sensing satellite (Landsat 1), in 1972, the preparation of accurate reports about the use and land use, changes in vegetation cover, environmental monitoring, natural resource management and urban development have become relatively simple, enabling the making of numerous studies combining field research and satellite data in many areas, such as urban and agricultural areas. In the case of inaccessible areas, the only method of obtaining data for the application of geographic information system (GIS) and remote sensing (RS) techniques in the observation of periodic changes on the surface of the Earth.

Although this technology has been available for many years, the use of remote sensing for monitoring of mining activities has rarely been applied, although, according to K. Koruyan et al, this tool has been proven valuable in the management and planning of some aspects in the operation of mining projects.

Change detection (se change detection nao for um defined term, e melhor dizer the detection of changes) in remote sensing is described by Singh (1989) as "the process of identifying differences in the state of an object or phenomenon by observing it at different times", determining how specific attributes of a particular area changed between two or more regular intervals, comparing aerial photographs or satellite images of the area taken at different times. In general, the detection of changes in the characteristics of the earth's surface, according to Lu et al, provides the basis for a better understanding of the relationships and interactions between human and natural phenomena, assisting in the management and use of resources; and invariably this involves the application of multi-temporal image analysis.

In this case study, we have examined the impact of expansion of degraded areas for mineral production and subsequent changes in natural vegetation over a period of 26 years in a region affected by copper mining for over a century, causing environmental, social and economic impacts in Minas do Camaquã, in the municipality of Caçapava do Sul, Rio Grande do Sul, Brazil (Figure 1). Using remote sensing techniques, degraded and recovered vegetation areas post-mining activity were calculated based on multispectral and sequential analysis of satellite images of normalized difference vegetation index (NDVI).

It was adopted as image selection parameter: (1) the period in which it had data availability (the Landsat 5 satellite was launched in 1984 and closed in 2013), (2) image quality that would allow the application of the vegetation index and (3) representativeness in relation to historical events in the region.

- 1985 : Four years after mining company starts modern and mechanized operation.
- 1996 : year of deactivation and abandonment.
- 2011 : one year before the start of ecotourism activities.

## MATERIAL AND METHODS

In order to check the environmental impact and detect the evolution of changes in vegetation cover in an abandoned mining area, remote sensing techniques have been applied in the analysis of a series of images over a timeframe. For the acquisition of data, the coordinates of the study area (described in Study Area topic) and satellite images Landsat 5 (which has 30 meters of resolution in the bands of visible and infrared) were collected during three different periods, August 1985, June 1996 and April 2011 and then the impact coverage zones were determined. Finally, the degraded area and in particular the changes in vegetation cover were quantified.

The Figure 1 shows a sequence of tasks applied in this study, and each step of analysis and image processing are explained in detail in the following topics.

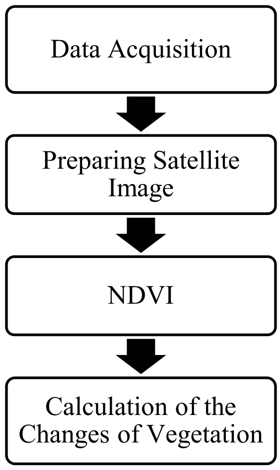


Figure 1 – Flowchart of methodology

### Study Area

The study area is located between latitude and longitude -30.908591, -53.446582 and is part of the geological unit “Escudo Sul Rio-grandense”, Caçapava do Sul district. The copper ore discovery in the region is dated 1865 and there were several cycles of operation and decommissioning until the Second World War.

In 1942, the Brazilian Copper Company (CBC) was founded, with the participation of the State Government, the National Lamination Metals and owners and concessionaires of the mines. Its foundation arose from the need to produce strategic materials, including copper, during the war. In 1952 the Pignatari Group took control of the company, selling it to the Federal Government through the National Bank for Economic and Social Development (BNDES), and in 1975 the operation was suspended given the poor conditions of underground mining, which had reached 150 meters of depth, and the deactivation of the metallurgy that used copper produced in Minas do Camaquã. In this period, the CBC has directed its activities to geological research in order to develop the characterization of the ore and expansion of reserves, thus allowing the implementation of the "Camaquã Expansion Project". Mining activities were resumed in 1981 and highly mechanized extraction techniques came to be used both in underground mines and in open-pit mining. In 1987, BNDES assumed the entire bank debt of the company and in 1988 the CBC was put up for auction and has not been sold to any of the companies qualified by withdrawal(the companies qualify by withdrawal? Consider redrafting this bit). As a workaround, the CBC has just been bought by its own employees, who have come to form a new company. The Bom Jardim SA took over the activities, paid off its debt to the BNDES, before the deadline stipulated in the Protocol of Intentions, and continued to mine copper until May 1996, when the economically viable reserves known became totally depleted.


Figure 2 – Location of the study area

**Image Data and Processing**

For this study we have used Landsat 5 satellite images, obtained at the Brazilian National Institute for Space Research (INPE) website. The images were processed in ArcGis and ERDAS software. The limits of mining and degradation were determined in the time interval using digital image processing. After delimitation and selection of the study area, the vegetation index (VI) tool available on ERDAS was applied.

**Estimation of Change in the Natural Vegetation**

The Vegetation Indexes (VI) are computed and calculated from the numerical value of brightness, this work will be used vegetation index (NDVI), which in addition to map also allows you to measure the quantity and condition.

The NDVI is calculated using the portions of electromagnetic energy reflected by the vegetation in the bands of red (wavelength = 0.6 micrometers) and near infrared (wavelength = 0.8 micrometers). It is the product of a function which takes as input parameters from the spectral bands of red and infrared. The reflectance of bands 3 (red - visible) and 4 (infrared - near) of the Landsat 5 sensor, which are determined by the following relationship:

$$\rho_{0,i} = \frac{L_{rad} * \pi}{E_{0,i} * cos\theta * d_r} \quad (1)$$

Where $\rho_{0,i}$ is the spectral reflectance in band i, $d_r$ is the inverse square of the Earth-Sun distance in astronomical unit, $E_{0,i}$ is the average value of exoatmospheric solar irradiance in the band i in $Wm^{-2}\mu m^{-1}$ (solar constant), θ the solar zenith angle (calculated from the solar elevation angle) and $L_{rad}$ is the spectral radiance in band i in $Wm^{-2}sr^{-1}\mu m^{-1}$.

The NDVI was determined by the following relationship:

$$NDVI = \frac{\rho iv - \rho v}{\rho v + \rho v} \quad (2)$$

As a result of the application of Equation 2, the product generated is stamped with the values of NDVI ranging within the range -1 to +1, with -1 representing total absence of vegetation and +1 maximum detected the presence of vegetation.

## RESULTS AND DISCUSSIONS

After the images were processed and generated the NDVI indexes, the cutoff of about 0.30 was set to vegetation and no vegetation. Thus, all above 0.30 was considered as vegetation and all below that was considered as no vegetation.

In Figure 3 you can see the vegetation dynamics of change in the study area, characterized by a contraction of the same between the periods 1985 and 1996, the mine operation lifetime, and finally, expanding the vegetated area in the period 1996 to 2011, the period after deactivating the mine and abandonment.

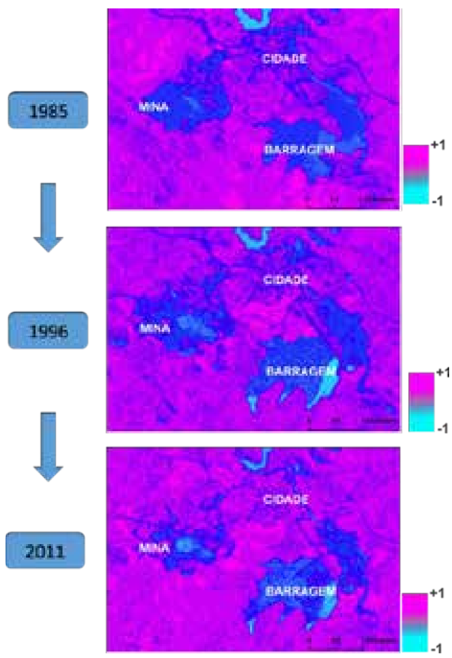

Figure 3 – An example of the expansion of the land use/cover and effect on vegetation between 1985 and 2011. A) Vegetation (pink), No vegetation (blue). B) Mine (mina), Town (cidade), Dam (barragem)
Through analysis of NDVI index, which defines the cut at 0.30 was calculated in the software ERDAS the vegetation pixel count (NDVI > 0.30) and degraded area (NDVI < 0.30), as the satellite has a spatial resolution of 30 meters, the area of each pixel corresponds to 900 m². Data presented in Table (1).

Tabble 1 – Expansion of the degraded and vegetaded area

| Área (m²) | 2011 | 1996 | 1985 |
|---|---|---|---|
| Degraded | 4,693,500 | 6,300,000 | 5,825,700 |
| Vegetation | 16,785,000 | 14,896,800 | 15,486,300 |
| | Degraded area | | |
| Period | Variation (m²) | Accumulated variation (m²) | Variation (%) |
| 1985 - 1996 | 474,300 | 474,300 | 8% |
| 1996 - 2011 | -1,606,500 | -1,132,200 | -26% |

Below Figure 4 shows a graph with the evolution of degraded area in the analyzed period, in which there is a clear recovery of the vegetation on the degraded area between the period from 1996 to 2011.

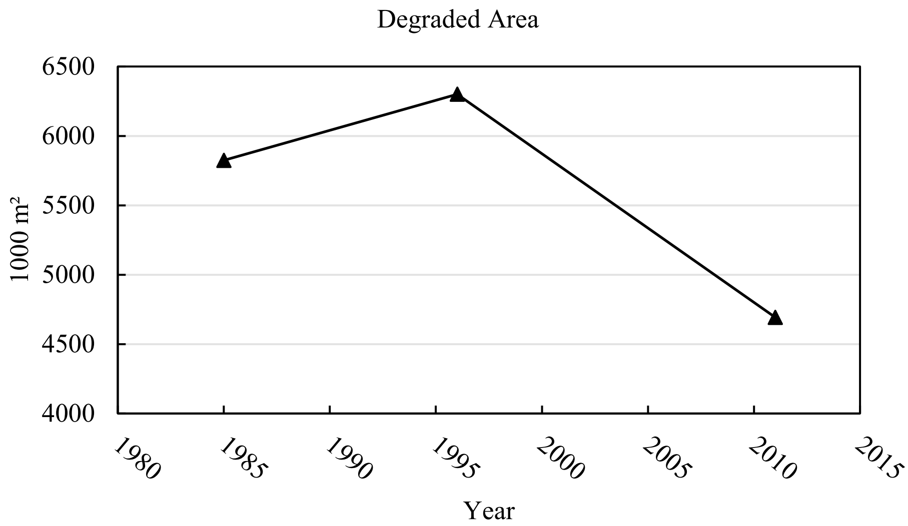


Figure 4 – Expansion of degraded area between 1996 to 2011

Figure 5 shows the area corresponding to the open pit mine in isolation from other structures, this analysis is the vectorization of the area marked as degraded from NDVI. This corresponds to the color composition of the year 2011 (RGB 542), in which are represented in yellow the degradation boundaries of the year 1996 and in black the boundaries of the year 1985.

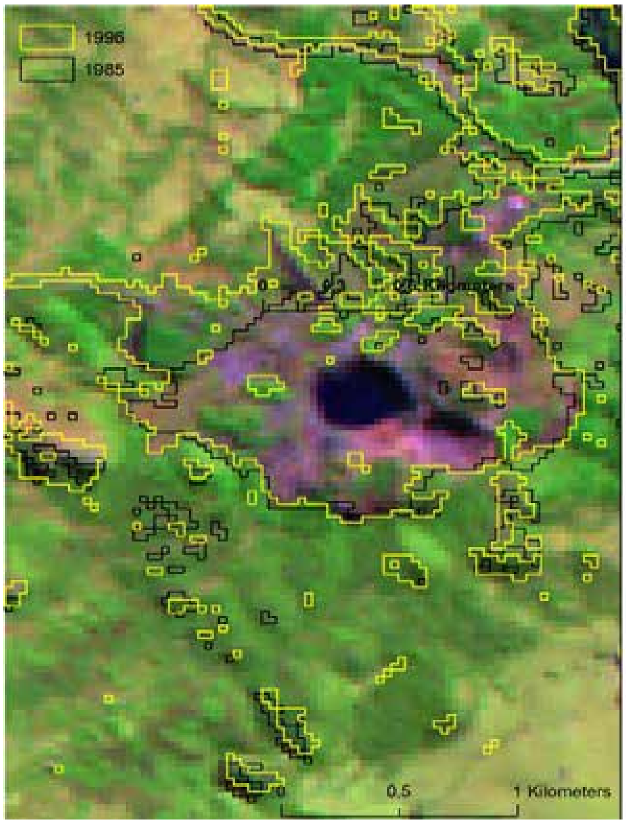


Figure 5 - An example of the expansion of mining activity between 1985 and 1996 (different colours represent mine boundaries related to the years).

**CONCLUSIONS**

A quick review of the literature shows that remote sensing methods can be used to classify the types of land use in a practical, economic, repetitive and large areas. Although change detection techniques have been widely used in multidisciplinary scientific studies to monitor and evaluate the impacts of natural processes and human activity on the environment, few studies using these tools have been conducted to evaluate changes in areas affected by mining activity.

In this research, the authors presented an estimate of the expansion of the degraded area and the changes in vegetation associated with mining activity through multi-temporal analysis of the years 1985, 1996 and 2011, applying the NDVI index.

It was observed that the area without vegetation cover increased between 1985 and 1996 and that there was a great expansion of vegetation after the closure of operations and abandonment of the area in 1996, advancing over 26% of the area characterized as degraded, and in 2011 the area with greater vegetation cover the first analyzed date. Totaling an area of about 113 ha. It should be noted that this data is from the area affected by mining as a whole, including the construction of the mining town (urban sprawl), tailings dam and open pit. By only analyzing the influence of the open pit region, visually it is possible to notice a big vegetable recoating.

The depletion of mineral resources has been a common event throughout world history, but neglect and impoverishment of these regions is not an inevitable consequence. The use of remote sensing and geographic information system have an increasing role in the management of mining areas. Together, they provide information and statistical data for the evaluation of habitat diversity and changing land cover while the mine is in operation, which may be used to formulate policies and guidelines for the management post-mining and in planning the closure of the mine, environmental reclamation, monitoring, characterization of the landscape and socioeconomic alternatives for rehabilitation of the area in the production system. In this study area, the municipality adopted in 2012 ecotourism as an alternative to use the area.

As future work, we suggest (1) the classification of different types of vegetation occupying the area, for example: dense vegetation, grassland, scrub, native vegetation and exotic vegetation, etc; (2) multi-temporal analysis in stream subbasin João Dias, in order to identify changes in drought conditions and contamination of sedimentation, as it received the solid waste and liquid effluents from the treatment of copper ore since the nineteenth century until the construction of the tailings dam at the end of 1970; (3) identification of the variation in average vegetation index only in the mine pit area and (4) inclusion of images from different periods in the analysis.

## ACKNOWLEDGEMENTS

We wish to express our profound gratitude and indebtedness to Professor Rafael Ribeiro, of the Department of Geodesy, Federal University of Rio Grande do Sul, for introducing the present topic and for his inspiring guidance, constructive criticism and valuable suggestions throughout this project.

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# REMOVAL OF METALS OF ACID MINE DRAINAGE BY PRECIPITATION AND BY ION EXCHANGE WITH ZEOLITE NaP1

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# REMOVAL OF METALS OF ACID MINE DRAINAGE BY PRECIPITATION AND BY ION EXCHANGE WITH ZEOLITE NaP1


## ABSTRACT

The mining of fossil coal generates large volumes of waste that may be responsible for serious environmental damage, including the acid mine drainage (AMD) resulting from oxidation of pyrite ($FeS_2$) in the presence of water and air. This percolated has a low pH, rich in sulphate ions and iron as well as other soluble metals such as aluminium, manganese and zinc. Nowadays the most common treatment for this wastewater is precipitation/neutralization. However, this process is inefficient for the removal of manganese. Thus the general aim this study was the treatment of acid mine drainage, aiming the removing metals, with special focus on removal of manganese ion, using the steps of precipitation and after the ion exchange with synthesized zeolites from fly ash coal. The methodology of this work included two steps: 1°) synthesis zeolite NAP1 from fly ash coal of Candiota by hydrothermal process and their characterization, 2°) characterization of AMD treatment followed by precipitation/neutralization and ion exchange-zeolite. The study was applied for a AMD from the coalfield of Santa Catarina. The results of the characterization tests of the synthesis product showed the formation of the zeolite NaP1, CEC from 2.3 meq $g^{-1}$. The AMD showed typical results with low pH, high concentration of Fe and sulphate and manganese values 45.15 mg $L^{-1}$. The results of the initial treatment from precipitation/neutralization showed that treatment of effluent by precipitation/neutralization at pH 6.0 with $Ca(OH)_2$ promotes complete removal of Al, Fe e Zn, however the concentration is still in the manganese 28.24mg $L^{-1}$. In the treatment by ion exchange, the zeolite NaP1 was used for the remaining manganese removal in wastewater. The contact time was 30 min, the ratio S/L 10 g $L^{-1}$. The use of zeolite promoted the complete removal of manganese from AMD. The manganese removal by ion exchange mechanism occurs in the neutral range and surface precipitation in values above 8.5. In laboratory conditions, the cost of treatment with zeolite was double treatment by precipitation/neutralization. The treatment with use of zeolite would be an alternative aiming to decrease consumption of hydrated lime with increased pH and removing the residual Mn.



## KEYWORDS

AMD, $Ca(OH)_2$, Zeolite NaP1, Manganese.


## INTRODUCTION

Coal is a fossil fuel formed by organic matter buried of vegetable pressure and high temperature in absence air, has been transformed physical-chemical and geological changes over time (Araújo, 2007). Its main application is in the generation of electricity by burning. The use of coal corresponds to 41% of all energy generated electricity, in the words the second source primary most used (IEA, 2009). However in Brazil, only 2.36% of the energy produced in through coal (ANEEL, 2015).

The main problems related to the exploration an use of fossil coal are: geomorphological terrain changes, vegetation degradation, disposal of large amounts of waste, formation of acid water, gas emission and the generation of ashes after burning the coal in power pants (Monteiro, 2004).

Coal waste generated in the mining and processing steps, when disposed incorrectly, causing the acid mine drainage (AMD). The AMD is nothing more than an extremely high acidity percolated, formed by the oxidation of metallic sulphates, for example, pyrite ($FeS_2$), through joint water and atmospheric air action (Kontopoulos, 1998). With high acidity occurs the solubilization of metals, with as Fe, Zn, Al e Mn.

The conventional treatment of the AMD is performed by neutralization and precipitation of metal as hydroxides and/or oxides. The practice is generally and meets most of the emission standards required by Brazilian law – CONAMA 430/2011 (Ministry of the Environment). However, often the standard emission is not achieved because high concentrations of Mn. Because of this it is necessary that the water manganese removal acid is improved. The alternatives are based on the elevation of pH for more alkaline tracks (with a higher consumption of alkali) or application different materials.

This works aims to use materials, zeolites, synthesized from fly ash coal to complement the treatment of neutralization/precipitation. The polishing steps, by ion exchange aim removal of manganese still present in the treated effluent in the first stage.

## MATERIALS AND METHODS

The acid mine drainage (AMD) was collected in the B module output of waste Unidade de Mineração II (UM II), the Carbonífera Criciúma S/A, localized in the city of Forquilhinha, SC, Brazil. The zeolite NaP1 was synthetic hydrothermal treatment from coal fly ash. The ash was collected electrostatic precipitator, Unidade B, Usina Termoelétrica Presidente Médici (UTPM), in Candiota, RS, Brazil. Methodological approach of this study was divided into two stages. The first stage with the synthesis and characterization of zeolite NaP1 and second stage characterization and treatment of AMD.

Zeolite NaP1 was synthetized from coal fly ash by hydrothermal treatment, we used a ratio 6 S/L, or 15 g ash and was added 90 mL de solution of 3 mol $L^{-1}$ NaOH, heated at 105 °C for 24 hours (Cardoso, 2012). The suspension was filtered and the solid washed and dried at 105 °C for 2 hours. The morphological and qualitative elemental characterization of the particles was realized by Scanning Electronic Microscope coupled to an energy dispersive spectrometer (SEM-EDS). The chemical tests were cation exchange capacity (CEC), with the ion exchange $NH_4^+$, XRF (x-Ray Flurescence) and residual alkalinity.

The AMD after characterization, was treated by precipitation/neutralization in the pH range between 4 and 12, with two alkalizing agents, NaOH and $Ca(OH)_2$, step 1. The samples were allowed to stand for 24 h and filtered after, the supernatant was submit to step treatment polish, by ion exchange, with the use of zeolites NaP1 with contact 30 min, ratio of 10 g $L^{-1}$, step 2. Characterization before and after step 1 e after step 2, were FAAS (Fe, Al, Zn and Mn) e pH. It was also performed Mn behaviour studies in different pHs after step 1.

## RESULTS AND DISCUSSION

### Characterization Zeolite NaP1

Figure 1 shows typical morphology of the Zeolite NaP1 by SEM and qualitative analysis of chemical composition by EDS. The results of EDS were identified elements Na, Al e Si to be majority in the composition zeolite.

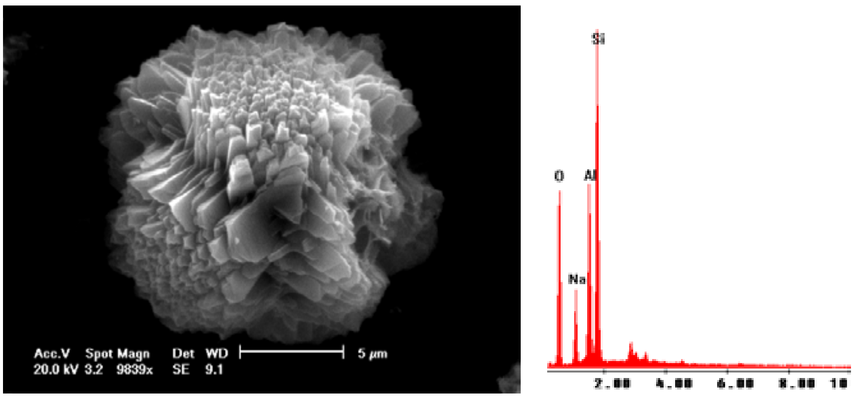


Figure 1- Image and EDS Zeolite NaP1 obtained by Scanning Electronic Microscope (SEM).

Table 1 show the characteristic parameters ratio Si/Al, CEC and alkalinity residual, compared with the commercial zeolite NaP1 (IQE- Industria Química del Ebro S/A).

Table 1- Results of the characterization of the zeolite NaP1 and Zeolite NaP1 commercial

| Zeolite | Ratio Si/Al XRF | CEC meq $NH^{4+}$ $g^{-1}$ | Alkalinity Residual % $Na_2O$ |
|---|---|---|---|
| NaP1 | 3.5 | 2.3 | 2.18 |

| | | | |
|---|---|---|---|
| Commercial (IQE) | 2.8 | 4.7 | 0.35 |

The ratio of Si/Al was obtained by XRF analysis and showing values 3.5 characterizing it as zeolite with content Si intermediate that according Auerbach et al (2003) must have values between 2 and 5 to be characterized as zeolite NaP1.

The CEC testing, used measure the ion exchange capacity, showed a value lower than commercial zeolite (Table 1), probably is due zeolite synthesized in the work is derived from a by-product, coal ash, generating product with impurities.

Residual alkalinity presented a significant value if purchased with commercial, 2.18 and 0.35 % $Na_2O$, respectively. The demonstrates that a significant amount of free OH in structure, which causes the pH change of the aqueous medium is in contact with zeolite.

**Step 1 – Treatment by Precipitation/Neutralization**

Were analysed some parameters in the AMD and after step 1 treatment, such pH, metals (Fe, Al, Mn, Zn), these parameters were compared with the environmental regulations in Brazil (CONAMA 430/2011). The AMD was submitted to precipitation/neutralization treatment, with alkalizing agents NaOH and $Ca(OH)_2$, between pH 4 to 12 and their behaviour were followed, after 24 hours of rest was filtration and analysis. Table 2 show the results of tests of AMD and the values established by CONAMA 430/2011.

Table 1. Results of the characterization of AMD and values established by CONAMA.

| | pH | Fe (mg $L^{-1}$) | Al (mg $L^{-1}$) | Mn (mg $L^{-1}$) | Zn (mg $L^{-1}$) |
|---|---|---|---|---|---|
| AMD | 2 | 1476 | 286 | 45,1 | 17,4 |
| CONAMA 430/2011 | 6 a 9 | 15 | n.a. | 1 | 5 |

n.a. There isn't an emission limited established in the Resolution.

Observing the above results it can be seen that the AMD used in this work presents pH 2 and high concentrations of Fe, which are typical characteristics of a AMD formed from the oxidation of pyrite.

Figures 2, 3, 4 and 5 show the behaviour of AMD treatment after step 1, analysed for metals Fe, Al, Mn and Zn, according pH variation and alkalizing agents.

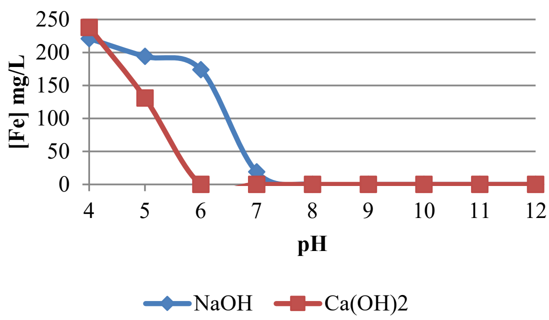


Figure 2- Comparison of alkalizing for Fe precipitation.

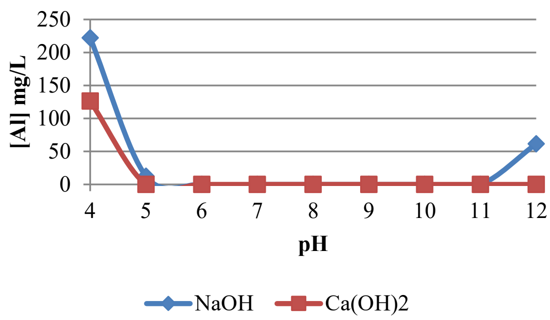


Figure 3- Comparison of alkalizing for Al precipitation.

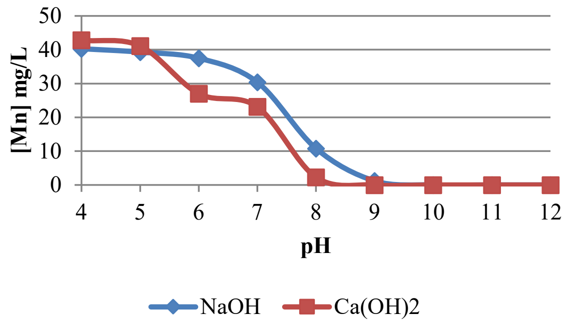


Figure 4- Comparison of alkalizing for Mn precipitation.

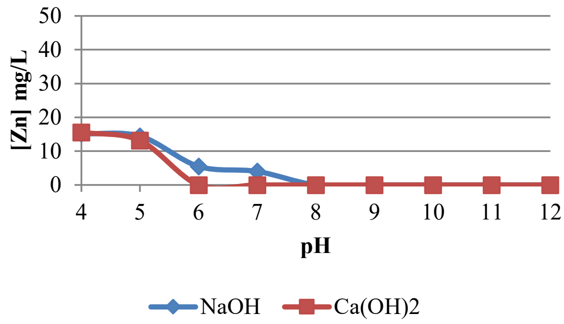


Figure 5- Comparision of alkalizing for Zn precipitation.

The graphs of Figures 2, 3, 4 and 5 it can be seen that the Fe precipitations at pH 6 around, may be explained by the presence of $Fe^{2+}$ , wherein the precipitations takes place at pH between 6 and 8, unlike that $Fe^{3+}$ precipitates at pH 3. The Al from pH 5 and Zn from pH 6, Mn was removed only from pH 8. Their behaviour was similar alkalizing, however there was a tendency of $Ca(OH)_2$ slightly larger promote removal rates and range slightly wider pH. The necessity for high pH to occur the precipitation of Mn, even if some has been removed by coprecipitation with iron.

Based on these results, it was decided that the best precipitant was the $Ca(OH)_2$ and the pH precipitation AMD would be 6. Several factors led to the choice: (a) the pH was less consumption of $Ca(OH)_2$ ; (b) $Ca(OH)_2$ is usually employed in the AMD reactant treating stations; (c) there was a greater concentration of residual manganese, toxic metal of interest in this work.

**Mn behavior present in the AMD**

Once established that the condition would be: pH of precipitation/neutralization 6 and alkalizing agent $Ca(OH)_2$, a study was conducted to evaluate the Mn metal behaviour without the action of the Fe. Since, according Lovett (1997), large amounts of Fe are sufficient to co-precipitate the Mn, the ratio Fe/Mn is greater than or equal to 2, is typically what occurs in the AMD, in particular in which it was studied in this work shows the ratio Fe/Mn very high.

The study is the precipitation at pH 6 and 24 h after the separation by filtration was added Ca(OH)2 to pH 9 to 11, precipitation took place with 0.2. The results can be seen in Figure 6.

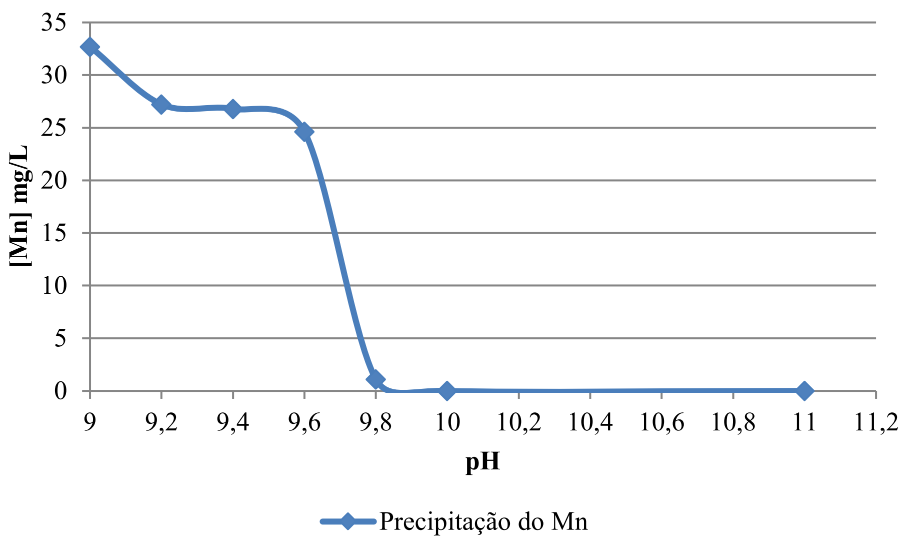


Figure 6- Variation of the concentration Mn versus pH, of the effluent after treatment precipitation/neutralization.

Complete removal only occurred from pH 9.8, at pH values much higher that allowed by law, that is, above 9. In this case the precipitated Mn most likely as oxides or hydroxide.

**Step 2 – Treatment by Polish**

The treatment by polish was carried out after step 1 with synthetic zeolite type NaP1. This step tests were conducted by varying the ratio S/L, contact time, and it was establish that the best contact time was 30 min. and the ratio 10 g $L^{-1}$ (Horn, 2015). The parameters evaluated before and after this treatment were pH, concentration of metals, which were purchased with the current legislation.

The synthetized zeolite from fly ash coal exhibits very high alkalinity and therefore we carried out a washing cycle in order to minimize the amount of free OH in structure, which cases the pH of the aqueous middle is changed at contact with zeolite, after which the zeolite cycle was named as NaP1 1x.

In the second step were compared with results of zeolites alkalinity removal cycle and without cycle NaP1 and NaP1 1x, respectively. Furthermore, it was also compared with alcalinizing agent precipitation with $Ca(OH)_2$, Figure 7, 8, 9 and 10.

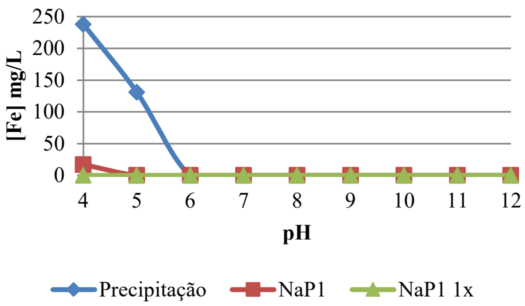


Figure 7- Comparison of [Fe] between precipitation, NaP1, NaP1 1x at differents pHs.

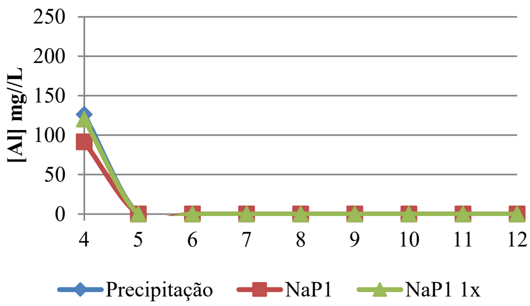


Figure 8- Comparison of [Al] between precipitation, NaP1, NaP1 1x at differents pHs.

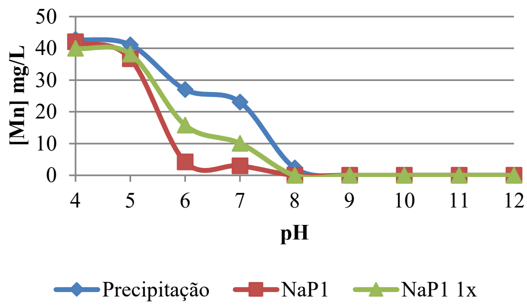


Figure 9- Comparison of [Mn] between precipitation, NaP1, NaP1 1x at differents pHs.

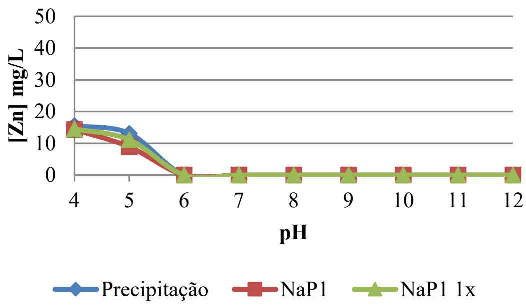


Figure 10- Comparison of [Fe] between precipitation, NaP1, NaP1 1x at differents pHs.

Can be seen that for metals Fe, Al and Zn there was no differentiation between process. The chemical precipitation process has promoted a suitable metal removal across the pH range studie. However, to Mn, the addition of the zeolite in a later step mainly made improvements in the pH range between 6 and 8, just the band greatest interest for effluent emission into the environmental.

The treatment step 1 (precipitation/neutralization), followed by exchange ion, and be sufficient specially for manganese removal maintain the pH within the specifications CONAMA 430/2011. At pH 8 regardless of the zeolite is washed or not removal of Mn was sufficient in both stages.

## CONCLUSIONS

The zeolite NaP1, synthetized from fly ash coal by Candiota, proved to be within the characteristic standard of this zeolite, with characteristic morphology and ratio Si/Al of a zeolite of Si intermediate value, with CEC 2.3 meq $g^{-1}$. The treatment by precipitation/neutralization it showed that the precipitation is faster than for the NaOH with $Ca(OH)_2$ which often because less selective step. The removal of manganese was complete above pH 8 with $Ca(OH)_2$ and 9 with NaOH. In the absence of other metals to co-precipitation, it was found that for optimal pH for removal of Mn is above 9.8, a value that is outside the emission parameter required by CONAMA 430/2011 legislation – pH 6 and 9. Due to the difficulty Mn removal, treatment consisted of an initial step neutralization/precipitation followed by a subsequent step with the use of zeolites NaP1. The chosen operating condition of the treatment by precipitation/neutralization was the use of $Ca(OH)_2$ in minimum concentration to obtain the effluent at pH 6. The best conditional for treatment by ion exchange was zeolite NaP1, in the ratio of 10g $L^{-1}$, 30 minutes of stirring. The Mn removal by ion exchange mechanism is in the neutral range (pH 6 and 7) and by surface precipitation at pH above 8.5. Thus it is possible to perform the precipitation/neutralization treatment, followed by treatment by ion exchange, aiming at the treatment of the AMD effluent, especially for removing Mn ions, thus saving parameters such as pH within the limits fixed by law (CONAMA 430/2011).

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# RESPONSIBLE MINING OPERATION

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# RESPONSIBLE MINING OPERATION

## ABSTRACT

Severoceske doly Group (SD Group) as the largest brown coal producer in the Czech Republic operates two state-of-art opencast mine sites in the densely populated region. The annual production reaches levels of 23 Mt, which represents 56% of the total domestic brown coal output. The main users of the SD´s coal production (74%) are the refurbished power stations and heating plants of the CEZ Group – the owner of SD Group. All mining activities of the socially responsible corporation SD Group are governed by strict ethical standards including responsibility toward local communities, society and the environment with respect to economic, technical and legal aspects. The priority of the Group´s corporate socially responsible strategy is positive, open, bidirectional communication with neighboring communities to build consensus. SD Group has taken some major steps toward assuring the long-term stability of both mining operations, mainly the municipalities consent for the final correction of the Bilina mine´s extraction limits, extending the mine´s lifetime by an additional period of over 20 years beyond the business current mining activity permit. At the Tusimice mine a new project of transition from surface to underground mining (Room and Pillar Technology) is prepared with the aim to minimizing losses and increasing the extraction rate of remaining future coal reserves. The provision of related information is a key factor in finding approval from the neighboring communities. The responsible communication has the potential to increase the public´s trust and the credibility of the SD Group. The acceptance of mining is one of the most important conditions for sustainable operation continuation in open and democratic society. Technology is always selected after an evaluation of the geological, economical and acceptancy factors. This is the case of the application of the Room and Pillar technology in Tusimice mine.

## KEYWORDS

Coal mining, affected communities, responsibility, acceptance

## INTRODUCTION

Mining is a complex and intensive process which effects environmental and social change, no matter where it occurs. More and more mining companies worldwide realize the shared responsibility for the state of the environment in which they operate and which surrounds them. Mining companies in democratic countries create Corporate Social Responsibility (CSR). Mining company with developed CSR respects the aspiration of affected communities, provides safe workplaces, avoids or minimizes negative impacts to the environment and leaves the positive legacies. Responsible mining companies are looking for new solutions to improve systems and cooperation. Principles of Corporate Social Responsibility (CSR) are included in their strategic planning and daily practice of all its employees, associates and suppliers. To be a responsible mining company it is imperative in a democratic society. Also, the largest Czech mining company, Severoceske doly Group (SD Company) modernizes its technology, applies innovative approaches and spends considerable amounts of financial investment in care of the environment and safety. SD Company´s corporate culture applies the principles of ethical behavior and business, creating a climate of open communication and cooperation.

## COAL AND ENVIRONMENT

All the European countries which are mining coal face together with the thermal power sector the EU aim to de-carbonize the process of electricity production according the existing EU energy policy framework - the Roadmap 2050. Locally produced coal is under big pressure of so called Renewable Energy Resources. The coal industry – which provides nearly 30% the electricity used by Europeans – is being attacked in media by environmentalists, NGO´s and public health advocates. New de-carbonization demands, the emission reduction goals and anti-coal considerations targeted to the local populations increase the costs, increase the risk for coal companies and erode the mining business ability to compete. As far as current and future mining is concerned, environmental costs have to be taken as a direct cost of coal mining. The environmental performance of mining is always assessed before granting the mining permit by the environmental audit EIA. All results of EIA process as well as the impact of the mining operations are made publicly available. To be future-proof, the coal industry in the partnership with energy sector must overcome the challenges on the road to EU Power Perspective 2030 on track to the low and/or near zero carbon Europe 2050.

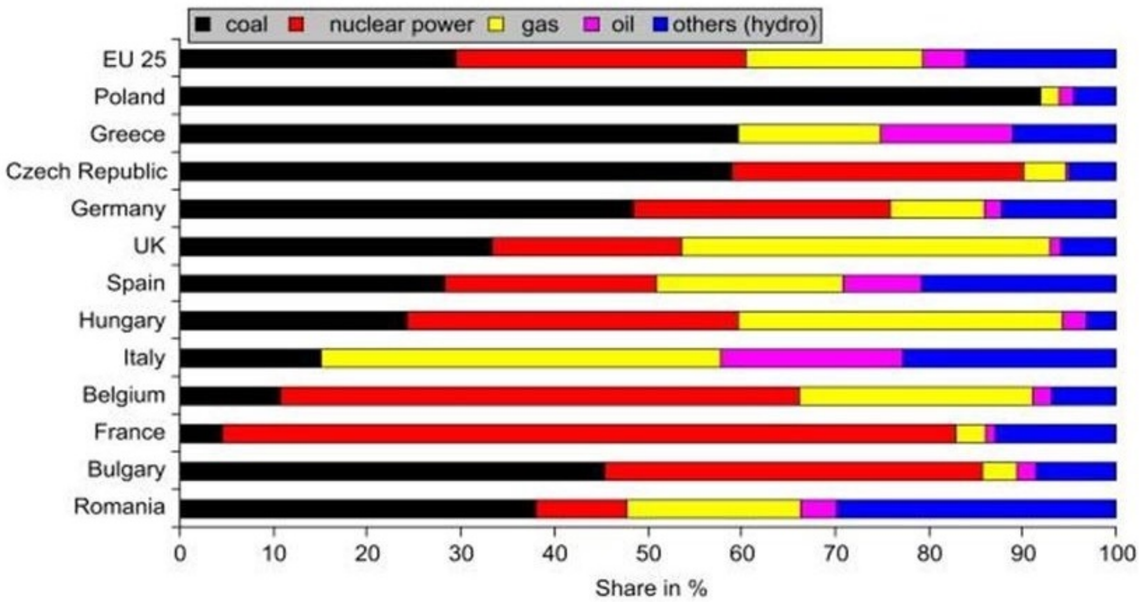


Figure 1 – Energy mix of the EU

## A CZECH PERSPECTIVE OF BROWN COAL INDUSTRY

Domestic coal, predominantly brown, accounts currently in the Czech Republic for about 60% of electricity and heat production. Some parts of potential brown coal extraction are complicated by environmental and land access issues. But, domestic brown coal will continue to play an important, although decreasing, role in the future energy mix of the Czech Republic. Ensuring self-sufficiency and security of supply is based on advanced conventional technologies and increasing proportion of gas and renewables (but green energy must be cheap energy) and secondary sources – mainly production from nuclear sources will gradually replace coal energy as the future pillar of electricity generation.

A number of new trends are emerging that reflect society´s expectations to sustainable development regarding the coal mining companies. To take proactive strategy is therefore highly important. Corporate Social Responsibility and proper communication with local as well as general public is crucial.

State energy policy of 2015 provides a proper balance between economic, environmental, local, national and European issues. It defines the basic priorities for indigenous coal as the independence base from imported energy resources and energy security, increasing environmental protection and minimizing the all possible negative impact on the future generations. Despite certain ecological aspects of coal usage, this domestic source is not fully replaceable until 2040. Securing highly-efficient technology for clean coal power and heating plants is essential as a scenario with progressively greater replacement of lower efficiency capacity with HELE (high efficiency, low emission) technology. A number of key barriers for coal are common:

- Technological: none, but the investment to mines and their operation has high risk.

- Environmental: large-scale opencast mining causes environmental local concerns (dust, noise, land use, landscape degradation); $CO_2$ emissions from coal fired power plants are target of the global environmentalists, but it is not usually the concern of the local communities.
- Political: public and political opposition to expand the coal mining areas or to build new coal-fired units.

## CAN INDIGENOUS BROWN COAL PRODUCTION IN EU SURVIVE UNTIL 2050 AND BEYOND?

The domestic both hard and brown coal production and the consumption of coal in EU as well as in the Czech Republic will gradually fall. The reduction in the share of coal used for electricity and the heat production should be a smooth process in EU in the long term. The domestic brown coal and imported hard coal can be understood as a vital bridge to the new flexible and mostly gas and renewable energy driven future. The adoption of the fundamental energy change requires for new resources the high flexibility and reliability, and the improved generation efficiency. Brown coal reserves available for mining in North Bohemian Basin are sufficient for next 40 years. The legally binding territorial-environmental limits have been valid since 1991. They guarantee existence for the municipalities situated near the coal deposits. Limits guarantee also that the environment in the mine neighborhood will not be worse and that is the reason why the existence of mining limits has long future. The limits affects together 5 major opencast mining sites in the basin, After years of negotiations, the Czech government voted in late 2015 in favor of modification of the brown coal mining limit in one mining site only – on the Bilina mine. This partial lifting of limits will not require any demolition of houses or any negative impact on the life of nearby communities. The extended coal reserves will be mined and used in the most effective and environmentally-friendly manner possible. The deposits outside the previous limit are estimated at 150 Mt and Bilina open cast mine may continue for another 40 years and by the possibility of partial underground extraction even longer.

## SD GROUP – A CZECH LEADER IN BROWN COAL PRODUCTION

Severoceske doly Group (Member of CEZ Group) operates two state-of-the-arts opencast mine sites in a densely populated region within the North Bohemian brown coal basin. The annual production reaches around 23 Mt (Tusimice mine 13 Mt, Bilina mine 10 Mt), which represents 56% of total domestic brown coal output. The main consumers of SD coal products (74%) are the refurbished power station and heating plants of the CEZ Group.

The **Bilina mine** employs 1,700 people directly and about 3,000 people in related jobs. The coal seam is located in difficult geological conditions with more than 200 m of overburden. Accordingly to the previous plan, coal mining at Bilina mine should finish by 2035, but further 15 to 20 years of opencast mining will be possible thanks to the government decision in 2015 to adjust the territorial environmental limit set in 1991. The decision opens for SD Company the way to access another 120 – 150 Mt of high quality brown coal. The issue of maintaining employment in the region with high unemployment rate played also a role. SD Company now must apply for the mining permit to perform mining activities in the given area. But, to the government resolution a condition was added: The boundaries of the Bilina mine will creep no closer than 500 m from surrounding settlements with the aim not to worsen the local living environment. The approval procedure and mining preparations will take four years. Although extended mining will not require any demolition of nearby houses or villages, the local population must be ensured that there will not be an adverse impact on their living conditions.

The **Tusimice mine** employs about 1,300 people directly and 3,000 people in related jobs. Mining operation is in relatively favorable geological conditions. The coal seam is located at varying depths, divided by clay layers. All coal production passes through a homogenization plant with a capacity of 600 thousand tons; it is used also to improve quality imbalances. In 2012, after broad public discussions on assessing the environmental impact of continued mining and on the Mining plan 2014-2029, the permit document was granted. SD Company has intention to build there a perspective low-impact underground coal mining site with discontinuous operation (Room and Pillar technology with bolter miner – shuttle car – feeder breaker – belt conveyor) for further optimal developing the potential of remaining coal deposit by minimum losses. A team of designers capable to design underground mining works were charged with drawing up the respective technical designs. The approval procedure has started and EIA process has been finalized without any conflicts between the SD Company and the community.

## ENVIRONMENTAL PROTECTION

All negative environment impacts are avoidable if mining company operates according to the state- of-the-arts technical and environmental standards. Mining operator needs to reduce the negative environmental impact and to minimize all elements of the pollution during all stages of the mine development. The long-term strategy of SD Company is to protect the environment, in order to eliminate and minimize the harmful consequences of mining activities, particularly increased levels of noise and airborne dust. Limits on environmental pollution are determined by strict European and national legislation. The mining technology employs a noise and a dust mitigation techniques and a number of anti-dust measures (effective watering of dust sources, construction of dust-free mine roads, planting of anti-dust green belts). Important protective actions in the mine site vicinity are also developed. The interests of municipalities and all questions about noise and dust pollution or water protection must be considered, various factual issues or sensitive factors had to be clarified.

For example, together with the affected towns and villages around the Bilina mine, SD participates on a STOP DUST joint initiative. Representatives of the specialist authorities and associations were appointed to an expert group charged with examining the various issues. As a result, at the coal preparation plant – one of the known sources of dust emissions - the coal storage (100 thousand tons capacity), in close vicinity of Ledvice town was closed. A new 238 m long sound wall separates the town from coal preparation plant. At Tusimice mine, neighboring municipalities concluded an agreement on the principles of environmental monitoring and oversight of the environmental performance with SD Company. The neighboring Brezno village is protected from active mining area dust and noise by a giant barrier wall 560 m long. In the system of environmental management, there is of course water control (mining and waste water are treated in modern sewage and water treatment facilities) and rational waste management.

## POST-MINING RECLAMATION AMD REHABILITATION

The reclamation and rehabilitation plans are periodically revised to update reclamation practices and costs.

The public has the right to comment on the adequacy not only of protective measures, but also on the issues of the reclamation and mine closure plans. Company is committed to offer innovative solutions and programs on the basis of a new assessment of the various reclamation options including biodiversity conservation management that supports a balance in the environment. In newly created post-mining landscapes, forest reclamation currently predominates. Areas designed for the agricultural use are also appreciated. There is a number of new smaller lakes of water in the area, also the wetlands and meadows completing both the aesthetic and the environmental function of the reclaimed area. Future large-scale water reclamation is being prepared for the residual pits of Bilina and Tusimice mine sites after mining finishes. Lake Bilina will have an area of 11.45 square kilometers and a maximum depth of 170 m, while the Dragon Lake in area of Tusimice mine will have true parameters of 10.83 square kilometers and depth 75.8 m respectively.

Depending on the progress of reclamation, optimal development of functional parameters of the landscape is monitored, as are the overall effectiveness of reclamation and environmental improvement; pedagogical and biological monitoring of the reclaimed areas is consistently performed by the specialists from the scientific institutions such as the Czech University of Life Sciences in Prague. State and regional government representatives and individual local communities are thoroughly briefed about monitored results and remedial measures during regular control days.

## RESPONSIBLE BUSINESS AS KEY FACTOR

Responsive business integrates the core strategy of the mining operation, employment practices (taking responsibility for the health and safety of own workforce), environmental issues and social dialogue. Even gaining a mining permit license to operate is s key to the development of mine site. The SD Company has demonstrated to the authorities and to the public that coal can be mined responsibly, in a dialogue with the people living in the region. Instead of waiting for the opposition to grow and, before the problem becomes critical, predictive strategy of bidirectional communications concentrates on providing communities with the real and true facts and with the advantages of the respective mining and future reclamation including the final closure projects. Early action is always crucial. In an in-depth dialogue, all stakeholders may jointly develop the concept plan in accordance with democratic principles.

The mine represents an economic boost for the vicinity and for the region, but the relationship with locals has to be very transparent to avoid possible conflicts. Historically, the mining operations in North Bohemian brown coal basin coexist with the communities many decades – in total more than 150 years. Specific local conditions and development needs identification of opportunities. Professionally managing the raised expectations (sometime also unrealistic) is key thing. Beside general environmental matters, the strategy includes different approaches for different communities to support its economic and social development. Company builds systematically trust and confidence in neighboring communities. Building trust takes years, but one single mistake can ruin everything.

## CONCLUSION

The coal industry faces a number of challenges to deliver a safe, secure, affordable and sustainable energy. Coal mining sector is finding new ways to meet its needs. The challenges are very complex, but there are many good examples from those working systematically in the industry and local community, offering new ideas to support sustainability and responsibility. Responsible behavior is reaching the increasing significance in the mining activity. Importance that Corporate Social Responsibility is done well requires the development of standards and will continue to be an ongoing challenge for all mining companies.

# SAFETY AND ENVIRONMENTAL MANAGEMENT IN OIL AND GAS MINING

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# SAFETY AND ENVIRONMENTAL MANAGEMENT IN OIL AND GAS MINING


## ABSTRACT

Recently a significant number of accidents in oil and gas mining have made us more concerned about enhancing the operational safety in oil and gas mining worldwide. Compiling and analyzing the key factors, facilitating the sharing of the learning experiences, and interacting with the industry and the government can identify the areas where industry can continuously improve the operational safety and environment management. There is an urgent need of looking into the above problems by the operators, regulators and the stakeholders of the oil and gas mining industry. Since it is difficult for any regulator to inspect the quality of the safety management system in oil and gas mining industry, the safety culture has to be inculcated within the industry to ensure safe operations under protected environment in offshore installations. In most cases, human factors in the management of emergency response are more important to reduce the risk of accidents. Lack of positive safety culture by the individuals, poor qualities of inspecting, reporting and auditing, and sharing of actual data complicate the above issue. A critical assessment has been carried out on the operational safety and environmental issues and their management systems in oil mining industry in India and abroad. Based on a few case studies, possible recommendations have been made which may be helpful for the oil and gas mining industry.



## KEY WORDS

Offshore drilling and production; Operational safety; Human factors; Oil spill; Environmental management;


## INTRODUCTION

A lot of accidents take place during oil and gas mining due to structural failure, human errors, scientific activities like seismic and extreme natural calamities like storms and hurricanes. The environmental impacts of such accidents may be severe, resulting in pollution near the shore, in shallow waters, or in deep sea. On the other hand, there may be smaller magnitude of regular spills and blowouts during drilling operations which do not have much impact on the surrounding environment. Such accidents are controlled by shutting in the well with the help of the blowout preventers and by adjusting the properties of the drilling mud. A huge amount of oil and gas is transported by tankers through sea route. Most of the accidents take place while tanker hits the shore reefs collide with other vessels, and also due to the fires and explosions of the tanker. In 1967 the tanker Torrey Canyon in the English Channel spilled 95,000 tons of oil, followed by Amoco Cadiz in 1978(220,000 tons), Exxon Valdez in 1989(40,000 tons), and Braer in 1993 (85,000 tons). Such accidents resulted in ecological disturbances in the sea and on the shore where the levels of oil pollution reached lethal limits for marine fauna, mainly for birds and mammals. It has been observed that most of the oil and gas mining accidents have been taking place in the offshore areas of oil and gas production. Offshore oil and gas production activities are prone to major accidents with possible hazards to the life and health of the personnel, resulting in environment pollution, direct and indirect economic losses, and disruption of energy supply. The offshore oil and gas industry has been rapidly developing for more than 56 years. Oil and gas production from offshore accounts for up to 30% of world's oil and gas production (Patin, S., 1999).The offshore structures have been designed to withstand the severest environmental conditions. In spite of all technological advances the industry has met serious accidents resulting in a huge loss of qualified manpower and valuable assets. The Deepwater Horizon oil spill began on 20 April 2010 in the Gulf of Mexico on the Macondo Prospect. Before that, the Usumacinta accident in 2007, the fire and explosion on board of the Piper Alpha in the North Sea in 1988, capsizing and sinking of the Ocean Ranger semi-submersible on the Grand Banks of Newfoundland in 1982, the capsizing of Alexander Kielland in 1980 in the Norwegian Sector of the North Sea, and many more such accidents have necessitated the need for a fresh look into the above important area of oil industry. In India, a high-pressure, highly inflammable gas leak occurred at an oil rig called Sagar Uday at Bombay High on 19th July, 2014 off the coast of Mumbai. The gas leak occurred at a well being drilled by Oil and Natural Gas Corporation (ONGC), India. The rig is situated about 162 kilometers off the coast of Mumbai. No deaths and no loss to property were reported in the incident so far. It was not a regular, localized pipe leakage, but something much bigger that required cemented operations.

## MANAGEMENT OF SAFETY

In any oil industry the fluids being handled contain highly inflammable paraffinic, naphthenic, resins and aromatic compounds. Gases having the low molecular weights and liquids contain higher molecular weight within the pressure ranging from 3625psi to 14500psi and temperature from $212^0$F to $392^0$F inside the oil mines. When the reservoir pressure reaches lower than the bubble point pressure in the order of 725psi, gases start to leave the solution. The gas-liquid separation process can range from 22psi to 5800psi. The gas and oil are transported through separate sub-sea pipelines where the pressure ranges from 7.25psi to 145psi. Under such operating conditions, the main hazards include release of hydrocarbons, fire and explosion after ignition of the highly inflammable gases and release of hydrocarbons to the surroundings of the sea.
According to Baker Hughes' report, the total world offshore rig counts for December 2015 was 1969, the list of onshore and offshore rigs as on January 2016 are listed in Table 1.

Table 1- January 2016 rotary rig counts (http://www.prnewswire.com).

| Countries | Onshore | Offshore | Total |
|---|---|---|---|
| Latin America | 192 | 51 | 243 |
| Europe | 73 | 35 | 108 |
| Africa | 68 | 26 | 94 |
| Middle East | 352 | 55 | 407 |
| Asia Pacific | 118 | 75 | 193 |
| United States | 627 | 27 | 654 |
| Canada | 190 | 2 | 192 |
| World Total | 1,620 | 271 | 1891 |

During any offshore accident a huge amount of manpower and money is lost. Although money could be recovered, but there is no substitute for the loss of manpower. The deadliest and the most expensive offshore accidents of the world are listed below in Table 2 and Table 3 respectively.

Table 2- Deadliest offshore accidents (http://www.oilrigdisasters.co.uk).

| Serial Nos. | Description | Fatalities |
|---|---|---|
| 1. | Occidental's Piper Alpha platform in 1988. | 167 |
| 2. | Alexander L. Kielland capsized in 1980. | 123 |
| 3. | The Seacrest drillship capsized in 1989. | 91 |
| 4. | The Ocean Ranger capsized in 1982 | 84 |
| 5. | The Glomar Java Sea capsized and sank in 1983 | 81 |
| 6. | The jack-up Bohai 2 capsized in 1979. | 72 |
| 7. | A Chinook helicopter crashed into the North Sea in 1986. | 45 |
| 8. | The Enchova Central off Brazil in 1984 & 1988. | 42 |
| 9. | The C. P. Baker drilling barge in 1962 burned and sank. | 22 |
| 10. | Mumbai High North in 2005 a fire destroyed the platform. | 22 |
| 11. | The Usumacinta jack-up blowout in 2007. | 22 |

Table 3- Most expensive offshore accidents (www.oilrigdisasters.co.uk).

| Serial Nos. | Description | Cost(2002 US$) |
|---|---|---|
| 1. | Occidental's Piper Alpha platform in 1988. . | 1,270,000,000 |
| 2. | The P36 production rig in the Campos Basin, Brazil in 2001. | $515,000,000 |
| 3. | Petrobras' Enchova PCE-1 Platform in both 1984 and 1988. | $461,000,000 |
| 4. | The Sleipner A platform in 1991. | $365,000,000 |
| 5. | The Mississippi Canyon 311 A Bourbon platform in the Gulf of Mexico in 1987. | $274,000,000 |
| 6. | The Mighty Servant 2 in 1999. | $220,000,000 |
| 7. | Mumbai High North in 2005. | $195,000,000 (2005) |
| 8. | Steelhead Platform in1987. . | $171,000,000 |
| 9. | The Petronius platform in 1998. | $116,000,000 |

Now the oil industry has moved from a reactive approach to a proactive approach to safety. The sophisticated modeling techniques are available which may be used to predict the frequency of the events and the mitigating those circumstances. Although there is a noticeable reduction in fatalities and general improvement in safety standards, Safety Management Systems need further improvement in terms of hardware and software design. The Safety Management System should be adequate enough to ensure that the design and operation of the installation's equipment are safe. Identification of the potential major hazards of the installation and the risks to personnel is carried out. In case of any emergency, there should be appropriate provision to ensure full evacuation, escape and rescue for the personnel on board, besides a temporary safe refuge.
Ismail et al. (2014) have studied more than 219 accidents in the offshore drilling operations and found that highest accidents were due to blow out (46.1%) followed by storms and hurricanes (15.1%) and structural failures ((11.4%) and the rest of the incidents were due to gas leak, towing accidents and soil failure. The major areas of weakness within failure mode are corrosion and erosion. The use of corrosion and integrity management can play a vital role in such accident prevention. Most of the accidents in oil and gas industry are fatal. Robust and reliable solutions are essential to prevent such accidents. Use of toxic and combustible gas sensors are recommended by the Occupational Health and Safety Administration, USA. Recently, uses of Wireless Sensor Networks (WSN) have been developed with a faster and energy efficient system (Aliyu et al., 2015).

**Major Health and Safety Components** (http://oilandgasuk.co.uk/Health_Safety_Report_2014.cfm**)**:
A. Hazards: The following common hazards are associated with any offshore oil and gas installation.
1. Fire and explosion: This can result from the ignition of any inflammable gas due to the hydrocarbon release from the well, the pipeline riser and the pipeline in the process plant. The causes may be mainly due to corrosion, abrasion or fracture of the pipelines.
2. Loss of stability/ Loss of station: Floating installations may lose the stability and buoyancy due to collisions resulting in loss of control of ballast systems. Anchor failures can cause the stability of the offshore installation resulting in loss of station.
3. Structural failure: Due to aging of the offshore structure, corrosion, fatigue, overloading or impact from dropped objects or any vessel structural failure can take place.
The safety and injury hazards and their possible causes are listed in Table 4.

Table 4- Safety and injury hazards and their possible causes.

| Safety and Injury Hazards | Possible causes |
|---|---|
| Contact Injuries | Persons being entangled, or struck/crushed by heavy elements, tools, machinery or other objects. |
| Fire and Explosion | Due to the presence of highly combustible hydrocarbons and oxygen along with source of ignition. |
| Slips, Trips and Falls | Frequent need to work at elevations; uneven surfaces; unavailability or improper use of fall protection systems. |
| Confined Spaces like storage tanks, pipelines and silos. | Limited opening for entry and exit; unfavorable natural ventilation. |

B. Personal health and safety: The most common hazards associated with the personnel working at oil mining installations are use of chemicals, slips and trips and manual handling of equipment. Besides the above, the following hazards are very common:
1. Noise and vibration, where noise in any onshore/offshore installation can cause hearing problem whereas hand-arm vibration can cause backache problems to the workers.
2. Mechanical handling and crane operations present a significant risk to the workers.
3. Diving or diving related problems in an offshore installation include a dropped diving bell or sudden decompression of a saturation system.
4. Personal environmental health issues which include food and water quality and other infections in the offshore installations.
The health and illness hazards and their possible effects are provided in Table 5 below:

Table 5- Health and illness hazards and their possible health effects.

| Possible Hazards | Agents | Sources | Possible Health Effects |
|---|---|---|---|
| Chemical | Toxic, corrosive, carcinogens, asphyxiates, irritant and sensitizing substances | Drilling fluid, Naturally occurring radioactive materials, Chemicals and | Dermal and eye issuses |

| | | | |
|---|---|---|---|
| | | additives | |
| Physical | Noise, vibration, radiations, extreme temperature | Drilling operations, Working under the Sun | Noise induced hearing loss, Heat stroke, Sleep deficits |
| Biological | Virus, Parasites, Bacteria | Pathogenic microorganisms | Infectious and parasitic diseases: Hepatitis A, Cholera, Typhoid. |
| Ergonomic | Manual handling activities, Repetitive motions, Awkward postures | Crane operating, Drilling and related activities | Stress, Spinal disorder |
| Psychosocial | Overwork, Odd working hours, Isolated sites, Violence | Working in shifts, Working with illiterate people | Drug and alcohol abuse |

## HUMAN FACTORS AND HUMAN ERRORS

The role of human factors may be obtained with the help of studying the interaction between man and machine. Rasmussen (1993) has described human errors as: "if a system performs less satisfactorily than it normally does, because of a human act, the cause will very likely be identified as a human error". While referring to the cause of an accident, they are often used interchangeably as general terms being related to people as opposed to a technical fault (Gordon, 1998). Human errors were mentioned by Kontogiannis and Embrey(1992) as: Action errors, Checking errors, Retrieval errors, Transmission errors, Diagnostic errors, and Decision errors. Table 6 and Table 7 provide the list of various human factors and human errors to cause accidents respectively.

Table 6-Various human factors responsible to cause an accident.

| INDIVIDUAL FACTORS | GROUP FACTORS | ORGANISATIONAL FACTORS |
|---|---|---|
| Competence | Management | Company policies |
| Stress | Supervision | Company standards |
| Motivation | Crew | Systems and procedures |

Table 7-Various human errors responsible to cause an accident.

| SKILL-BASED | RULE-BASED | KNOWLEDGE-BASED |
|---|---|---|
| Action errors | Retrieval errors | Diagnostic errors |
| Checking errors | Transmission errors | Decision errors |

According to Gordon(1998), 'action' and 'checking' may be related to skill-based slips and lapses, 'retrieval' and 'transmission' errors may be related to rule-based mistakes, and 'diagnostic' and 'decision' errors may be related to knowledge-based mistakes as described by Reason(1991). He has suggested how to improve the human factors component of accident reporting forms and the ways to reduce accidents using human factors data. He also has discussed the human factors causes which were used in the UK offshore oil industry.

## AUTONOMUS FIRE FIGHTING MOBILE PLATFORM

In any oil mining operation different types of firefighting equipment are used based on the classification of the fire materials and the fire extinguishers used to control such fires. To avoid human errors, development of an Autonomous Fire Fighting Mobile Platform (AFFMP) has been proposed by Khoon et al. (2012). The authors have shown the possibility of the fire extinguishing tasks by AFFMP. While monitoring for hazardous site via patrolling process with minimum level of error, the proposed system can patrol through the hazardous site via a guiding track with the aim of early detection for fire reducing the burden of fire-fighters in fire fighting. Table 8 and Table 9 provide the list of the fire materials and the suitable fire extinguishers for them respectively.

Table 8-Classification of fire materials (Khoon et al., 2012).

| Classes | Materials |
|---|---|
| A | Solids (Paper, Wood, Plastic). |
| B | Liquids (Paraffin, Petrol, Oil). |
| C | Gases (Methane, Ethane, Propane, and Butane). |

| | |
|---|---|
| D | Metals (Sodium, Lithium, Manganese, Aluminium, Magnesium, Titanium from the cutting of metals). |
| E | Electrical Apparatus. |
| F | Cooking oil & fat. |

Table 9- Types of fire extinguishers used in oil industry(Khoon et al., 2012).

| Type of fire extinguisher | Characteristics |
|---|---|
| Water | Used for Class A fire.<br>Not suitable for Class B fire |
| Foam | Used for Class A and B fires.<br>Not suitable for electrical fire. |
| Dry Powder | Used for Class A, B, and C fires.<br>Best for Class B.<br>Effective for Class C Gas fire. |
| Carbon dioxide | Ideal for electrical fires. |
| Wet chemical | Used for Class F fire. |
| Metal | Used for Class D fire. |

## QUANTITATIVE RISK ANALYSIS

Collection and analysis of information about the past accidents can help in preventing future accidents on such method is Quantitative Risk Analysis (QRA). In QRA the available information is systematically used to identify the accidents and their probabilities to take place. It can also be used to predict the possible consequences to the working personnel, the asset and the environment. QRA and the investigation report of the accident may used for a systematic analysis of any hazard (Skogdalen and Vinnem, 2012).

## MANAGEMENT OF ENVIRONMENT

In 2003 Environmental Economics Research Committee (EERC) Working Paper Series: Industrial Pollution and Policy (IPP): 8, an Environmental Assessment of Oil and Gas Exploration (Madduri, V.B.N.S. and Reddy, E.M., 2003) was submitted to the Indira Gandhi Institute of Development Research, Mumbai, India. The report shows a detailed investigation on the impact of oil exploration activities along with case studies for onshore and offshore oilfields of India. From Andhra Pradesh 60 households and from Assam 40 households were picked up for the above case studies. The above studies were qualitative and not quantitative in nature. Based on their studies, they suggested the following activities to be taken up by the oil industry; (i)Construction of sump for drill site and drilling fluid waste collection;(ii) Development of resource and waste management; and (iii) Proper environment management system for drill site reclamation .

Regarding offshore oil exploration and production, the report says about the initiatives taken by the Government of India to protect the sea area. It mentions about the Coastal Ocean Monitoring and Prediction Systems (COMPAS) developed by the Department of Ocean Development (DOD) where pollution related 25 parameters are collected, analyzed and published.

**Oil Spillage**

Public awareness and concern about oil spills has been high over the last two decades. American Petroleum Institute (API 2009) has reported that 77 percent less oil is spilling now compared to the 1970s. Over the last 40 years, the total oil industry spillage has decreased consistently. Compared to the last decade it has been observed that the decreases in spillage range from 19 percent less spilled from refineries to 91 percent less oil spilled from tankers. The major oil spills of the world are listed in Table 10 below:

Table 10- Major oil spills.

| Position | Ship name/ Spill name | Year | Location | Spill size (tonnes)* |
|---|---|---|---|---|
| 1. | LAKEVIEW GUSHER | 1909 | United States, Kern County, California | 1,227,600 |
| 2. | GULF WAR OIL SPILL | 1991 | Persian Gulf, Kuwait | 1,091,405 |
| 3. | DEEPWATER HORIZON (Govt. High Estimate) | 2010 | Gulf of Mexico | 470,779 |
| 4. | ATLANTIC EMPRESS | 1979 | Off ,Tobago, West Indies | 287,000 |
| 5. | JAKOB MAERSK | 1975 | Oporto, Portugal | 88,000 |
| 6. | BRAER | 1993 | Shetland Islands, UK | 85,000 |

| | | | | |
|---|---|---|---|---|
| 7. | AEGEAN SEA | 1992 | La Coruna, Spain | 74,000 |
| 8. | SEA EMPRESS | 1996 | Milford Haven, UK | 72,000 |
| 9. | KHARK 5 | 1989 | 120 nautical miles off Atlantic coast of Morocco | 70,000 |
| 10. | NOVA | 1985 | Off Kharg Island, Gulf of Iran | 70,000 |
| 11. | KATINA P | 1992 | Off Maputo, Mozambique | 67,000 |
| 12. | PRESTIGE | 2002 | Off Galicia, Spain | 63,000 |
| 13. | EXXON VALDEZ | 1989 | Prince William Sound, Alaska, USA | 37,000 |
| 14. | HEBEI SPIRIT | 2007 | Taean, Republic of Korea | 11,000 |

*1 ton = 1000kg.

Sivadas, S. et al. (2008) have provided a detailed report on the oil spills on the western coast of India since 1970 and their long term impact on the Indian offshore area. The report calls for an immediate need for sustainable management to conservation of the aquatic resources in that region.

Emissions from oil and gas production facilities account for a major environmental problems in the fossil fuel exporting countries. It has been shown that $CO_2$ emission increase significantly as the production from the field declines (Gavenas et al., 2015). It has been shown that a field has about three times higher emission intensity than in the peak phase while it is producing 20% of peak level. The authors also indicated the influence of the oil and $CO_2$ price in the emission intensities of the gas.

Ronconi et al. (2015) have studied on the bird-platform interactions in offshore oil and gas production sites. It has been observed that attraction to lights and flares pose a great risk to some seabirds and migrating landbirds particularly during bad weather. Besides the above, exposure to hazardous oil and gas environment causes death of thousands of birds and disrupts the natural ecology of the ocean environment. An adaptive management strategy has been suggested to monitor and mitigate the above problem by the operating companies (McComb, 2015).

Methane emissions from any well head during drilling, or from shale gas development at hydraulically fractured oil wells, during completions, during ongoing production, and during liquids unloading, leaks from reciprocating and centrifugal compressors, and pneumatic devices are potential threat to the atmosphere. Usually, such emissions are expressed as methane or natural gas lost per unit of gross natural gas production. From the wellhead to the distribution meter, the range of such emission is from 0.8% to 11.7%. A recent study has explained the voluntary and regulatory policy mechanisms to control methane emissions into the atmosphere (Danish, 2014).

For managing occupational safety and health hazards, the following solution model can be based on the PDCA Cycle as described in Table 11 below:

Table. 11-PDCA Cycle.

| Activities | Details of the activities |
|---|---|
| Plan | Strategic Health, Safety, Security and Environment Roadmap<br>Work Flow Charts<br>Objectives and Targets<br>Key Priorities |
| Do | Risk and Injury Management<br>Illness and Health Management<br>Regular Assessment and Training<br>Regulatory Compliance |
| Check | Monitoring<br>Modeling<br>Trends<br>Performance Indicators<br>Auditing |
| Act | Review by the Management<br>Continuous Improvements Acts |

## CASE STUDIES

### 1. Deepwater Horizon, USA.

On April 20, 2010, an uncontrolled flow of water, oil mud, oil, gas, and other materials came out of the drilling vessel *Deepwater Horizon* owned by Transocean and for BP to drill the Macondo well in the northern Gulf of Mexico, USA. After the Deepwater Horizon disaster in 2010, a good number of research papers have been published based on the above incident. Skogdalen and Vinnem (2012) have carried out quantitative risk analysis of drilling for oil and gas using Deepwater Horizon as case study. The authors suggest the need of the risk reassessment associated with offshore drilling. The National Commission, USA recommends for a proactive, risk-based performance approach. This approach is specific to operations, individual facilities, and environments and is similar to Quantitative Risk Analysis approach in the North Sea.

**2. Atlantic Empress sinking in the Caribbean Sea near Venezuela.**

On July 19, 1979, the Atlantic Empress carrying 288,000 deadweight-ton (DWT) of crude oil and the Aegean Captain carrying 207,000 DWT of crude oil collided in the Caribbean Sea near Venezuela. A thunderstorm had thrown the Empress off course, unexpectedly creating a path directly in line with the Captain. Nearly 3.5 million barrels of crude oil were spilled, the largest spill from any oil tanker till date with a loss of 27 crew members. Without any oil contamination of the shore, the Atlantic Empress eventually sank after burning for 14 days. Although no indications of any environmental damage were observed, nearby islands with their tourist beaches and coral reefs were threatened. Horn and Neal (1981) have provided a chronicle of the events of the days following the collision in detail.

**3. Gas leak from Mumbai High North Platform, India.**

Oil and Natural Gas Corporation, India, at Bombay High at a distance of around 100 nautical miles off the coast of Mumbai was drilling a side track well from the rig Sagar Uday at Mumbai High North platform in the Mumbai High North field. On 19$^{th}$ July 2014, a high-pressure, highly inflammable gas leak occurred from the well being drilled. As a precautionary measure, 48 non-operational personnel were evacuated from the site, while around 40 operational staffers continued to be stationed there. A gas leak was not expected at a shallow depth of 3000 to 3300 ft. But during drilling operations, some gas leaked and all precautions had been taken for safety. The Coast Guard and Indian Navy have diverted ships to provide assistance in evacuation. The Coast Guard vessel 'Varuna' assisted in the evacuations. The helicopter company called Pawan Hans also assisted in the rescue effort. No causalities were reported due to timely action taken by the oil company and the contractor/other supporting companies.

## CONCLUSIONS

1. Special risks and challenges are inherent for the oil companies while operating in onshore and offshore oil mining areas and these are much different from traditional emergency responses.
2. For the operational safety, rigorous emergency response training is essential and must be regulated in the industry, and many companies may even go above and beyond those requirements for the safety of their employees and assets.
3. An industry equipped with essential facilities, advanced protective equipment and training devices can handle the operational safety in onshore and offshore oil mining operations most effectively.
4. Communication is one of the most important components which can affect safety the most. Once the proper communication established among the different stakeholders of any operational area, major accidents could be averted with minimum loss of personnel and property.
5. There are limitations in working in offshore locations for timely access during emergencies to personnel and assets. As a result, it reduces the initial level of support by outside responders and extends the challenges on workers to reach a safe place initially, and wait until appropriate resources can arrive on the spot.

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Dr. Karmakar had scientific visits to: Romania, France, Spain, the Netherlands, Belgium, Germany, United Arab Emirates, Singapore, United Kingdom and United States of America.

# SEEPAGE MODELING AND WATER RECOVERY IN MINING TAILINGS DAM

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# SEEPAGE MODELING AND WATER RECOVERY IN MINING TAILINGS DAM


## ABSTRACT

Water recovery from tailing for reuse is commonly employed in the mining industry to minimize water consumption in semi-arid and arid regions where water is a scarce commodity. In Botswana, where water supply for mining industry is becoming a serious challenge, water recovery from tailings dams is of a great interest in many mines. In this paper, the seepage modelling in connection with recovering water in Orapa Slurry Dam 2 is presented.The dam is constructed cyclonically and is one of the largest cyclone dams in the world with a footprint area of 2,297,428m$^2$. Orapa Mine located in Botswana where only half of the target amount of water is being recovered so far, is used as case study. Site investigations were carried out to determine the in-situ permeability of the different layers of the slurry and the foundation ground. Sieve analysis was also conducted to estimate the grain size distribution of slurry materials deposited in the dam. The GeoStudio software was employed to identify the phreatic surfaces and estimate the drain flows in order to determine areas within the dam where water recovery from tailings deposition could be maximized. The results indicated a good seepage flow. The stability analysis of the dam was performed as well. A factor of safety greater than 2 was obtained which is well over the required standard. It was concluded that there is possibility of recovering more water in Orapa mine slurry dam should appropriate deposition methods and slurry dam operation procedures be implemented.



## KEYWORDS

Tailing storage facility, slurry dam, water recovery, seepage modeling, drainage system.


## INTRODUCTION

Seepage and stabilty analysis are essential tasks in managing tailing storage facilities (TSFs) which are facing increasing challenges.While advances in technology allow finer grade ores to be processed, generating higher volumes of waste sediment with low pororsity, environmental regulations are placing more stringent requirements on the mining industry, particularly with regard to water recovery from TSF. Water recovery from tailings for reuse to minimize water consumption in most semi-arid and arid regions where water is a scarce commodity. It is well known that mineral processing including milling and floatation and subsequent tailings discharge together, represent the largest water use at metal mines. In Botswana, mining companies face the daily need of reducing water consumption associated with their mining and processing operations. Specially, at Orapa Mine, a diamond mining operation, water recovery in tailings dams is a great concern.

Several approches for modeling water recovery in TSFs exist, one of them being the consolidation-seepage model (Madariaga et al., 2004; Wels & Robertson, 2003). While the seepage analysis plays a key role in estimating the amount of water that could be recorved, seepage flow renders tailings dams vulnerable to failure since the arrangement of tailing particles and interaction between seepage flow and solid particles influence the TSF's stability (Yin et al., 2012; Zandarín et al., 2009). In order to assess the stabilty of a slurry dam, comprehensive geotechnical characterization is often required. The key paramters to be determined include onducted to determine the grain-size distribution, atterberg limits, specific gravity, maximum density, shear strength parameters, consolidation coefficient, pore water, hydraulic conductivity and desiccation behaviors of the tailings (Ahmed & Siddiqua, 2014; Shamsai et al., 2007). Over the past few years, intensive research has been accomplished in regard with seepage and stability of slurry dams owing to their importanc to TSF management. This allowed for a wide range of achievements including, for example: determining the hydraulic conductivity tailings (Aubertin et al., 1996), an investigation of the influence of waste rock inclusions on tailings consolidation (Bolduc & Aubertin, 2014), analysing the effect of seepage control on stability of a tailings dam during its staged construction with a stepwise-coupled hydro-mechanical model (Hu et al., 2015), tailing failure characteristics (Kossoff et al., 2014), sustainable tailing management (Adiansyah et al., 2015), an integrated apporach of tailing management (Grangeia et al., 2011) as well as a variety of numerical simulation of seepage and stability (Bolduc & Aubertin, 2014; Kacimov & Obnosov, 2012; Özer & Bromwell, 2012; Zhang et al., 2011). In the same way, the current study intends to investigate the seepage behaviour in the Slurry Dam 2 and its stability in Orapa Mine, Botswana. The sudy is justified by the need to maximize water recovery since on average only half of the target amount of water is being recovery.

## BRIEF DESCRIPTION OF THE PROJECT

### Geology

According to the published 1:200 000 Geological Series map, Distribution of the Karoo in Botswana, the site is underlain by basaltic lava of the Stormberg Lavas of the Karoo Supergroup. Kimberlite pipes are the ore bodies in which diamonds occur at the two open pit areas of the mine. The central portion of Botswana is known for its thick covering of aeolian deposits (windblown sands). These sands exhibit a pinhole voided soil structure, which isprone to collapse upon wetting and are also characteristic of free draining sands.No structural geological information was visible from the map. According to Weinert's climatic N-value, the site falls in an area where the N-value is greater than 5, indicating that the area is associated with arid regions where mechanical weathering is the predominant rock weathering mode.

### Orapa Slurry Dam Description

Debswana Diamond Company's Orapa mine is located in central Botswana about 400 km north of the capical city Gaborone. The mine has two slurry dams namely, Dam 1 and Dam 2. Dam 1 at Orapa mine has been dormant for several years. Restoration of the dam is currently in progress. Kimberlite waste produced by Plant No. 1 and Plant No. 2 of Orapa mine is currently only being deposited by means of cycloning onto Dam 2. Dam 2 was constructed with a compacted calcrete starter wall with up and down stream cut-off drains to a minimum depth of 1.5m. The dam walls are being raised in an alternating downstream and centre-line manner. Elevated drains are installed approximately every 6m. Supernatant water is decanted from the dam using a gravity penstock system. The penstock has two inlet structures that are operated separately depending on the pool location. Currently the eastern penstock is not in operation. Some production outputs for Orapa slurry dam 2 recorded from January 2004 to December 2015are summarized in Table 1.

## EXPERIMENTAL TESTINGS

In-situ permeability tests conducted on the foundation ground characterised mainly by Aeolian Sand gives an average permeability coefficient of 2.7 x $10^{-5}$ m/s making the material moderately porous.

The aeolian sand covering the site is low in potential expansiveness and generally tested as non-plastic (NP). This material has high sand contents of 77% to 85% and classifies as SM (silty sand) according to the Unified Soil Classification (USC). It has a low Grading Modulus (GM) varying between 1,03 and 1,07 and a Standard Proctor maximum dry density (MDD) of between 1850kg/m3 and 1973kg/m3at an optimum moisture content (OMC) of between 9,2% and 11,2%.The pebble marker classifies as either SM or SP (poorly-graded sand with silt) with 35%gravel, 55% sand, 4% silt and a clay content of 6%. It has a low potential expansiveness and classifies as non-plastic material. The pebble marker has a low GM of 1,74. It further has an MDD value of 2095kg/m3at an OMC of 7,2%.

Table 1 – Average monthly production outputs for Orapa slurry dam 2 from Jan 2004- Dec 2015

| Output | Target | Monthly Average |
|---|---|---|
| Actual Tonnes Deposited from No1.Plant | 180000 | 30281 |
| Actual Tonnes Deposited from No2.Plant | 500000 | 407635 |
| Total Tonnes Deposited | 680000 | 437916 |
| Actual Water from No.1 Plant to dams ($m^3$) | 181915 | 49241 |
| Actual Water from No.2 Plant to dams ($m^3$) | 505319 | 662872 |
| Total water to dams ($m^3$) | 687234 | 712113 |
| Return water from dam 2 ($m^3$) | 274894 | 321783 |
| Total Return Water ($m^3$) | 274894 | 321783 |
| Actual % Water Returned | 40 | 25% |
| % Grits (+ 300 µm material) from No1 Plant | 35 | 0 |
| % Grits (+ 300 µm material) from No2 Plant | 35 | 35 |
| % Grits (+ 300 µm material) at slurry dams | 35 | 28 |
| Actual % Mass Recovered to U/F | 40 | 32 |
| Actual Underflow RD ($t/m^3$) | 1,8 | 1,98 |
| Actual Overflow RD ($t/m^3$) | 1,3 | 1,21 |

The nodular calcrete is also low in potential expansiveness and has a plasticity index (PI) value of 11%, although one sample tested as non-plastic. This material comprises 38% to 60% gravel, 28%to 42% sand, 7% to 12% silt and a clay content of 5% to 8%. This material classifies as SM and GC (clayey gravel) and has a GM of between 1,67 and 2,19. The MDD values vary between 1850kg/m3 and 1894kg/m3at an OMC of between 11,2% and 15,2%. The LL of thismaterial varies between 0% and 31%. The residual basalt has a high MDD of 1908 kg/m3at OMC of 12,9% with a low potential expansiveness (PI of 11%). This material comprises 57% gravel, 33% sand, 4% silt and a clay content of 6%.The residual basalt has a GM of 2,16 and a LL of 27%. It is classified as GP/GM.

The cemented cobbles and boulder layer comprises 50% to 52% gravel, 37% to 38% sand, 6% to 7% silt and 3% to 7% clay. This material is non-plastic and corresponds with a GM of between 1,99 and 2,05. It exhibits a MDD of between 1862kg/m3 and 1875kg/m3 at an OMC of between 11,9% and 12,2%. This material also classifies as GP/GM and GM (silty gravel with sand).

The angle of internal angle of friction (φ) and cohesion (C) values obtained from results of the direct shear box tests on samples remoulded to 95% of the maximum Standard Proctor dry density are given in Table 2. The strength tests were done at a stress range (normal stress) of 50kPa / 100kPa / 200kPa.

Piezocone tests were conducted on the North and South wall of Dam 2. The results of the piezocone tests are presented in Figure 2 and Figure 3. Comparing the 2013 and 2015 LIDAR survey it can be seen that the dam had a slight increase in height along the side slopes due to cyclone runoff. 9m of slurry were deposited at the crest of the North wall in the two year period. The piezocone results show that the slurry is layered and has very low cone resistance values. The low strength of the material should be considered when raising the dam and the rate of rise kept as low as possible. Figure 4 and Figure 5 show the ambient pore water pressure versus depth for Dam 2 North wall and South wall, respectively. The line indicating hydrostatic increase of pore water pressure is also shown on the figures. It can be seen that the rate of pore water pressure increase is below hydrostatic.

Table 2 - Peak shear strength values of the foundation ground materials

| Material Description | Shear Strength Parameters | |
|---|---|---|
| | Internal Angle of Friction (°) | Cohesion (KPa) |
| Aeolian Sand | 33 | 0-6 |
| Nodular Calcrete | 39 | 0-10 |
| Residual Basalt | 39 | 0 |
| Cemented Cobbles and Boulders | 32-38 | 0-14 |
| Pebble Marker | 36 | 0 |

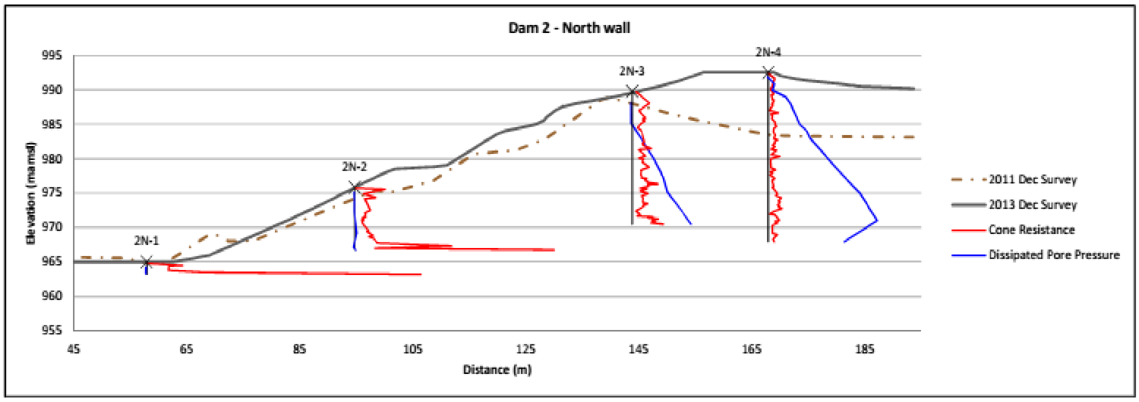


Figure 2 – North wall of Dam 2 piezocone test results

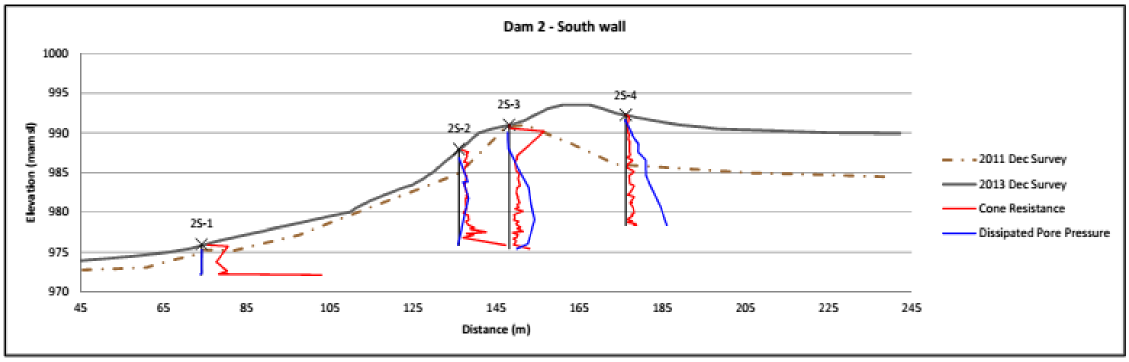


Figure 3 – South wall of Dam 2 piezocone test results

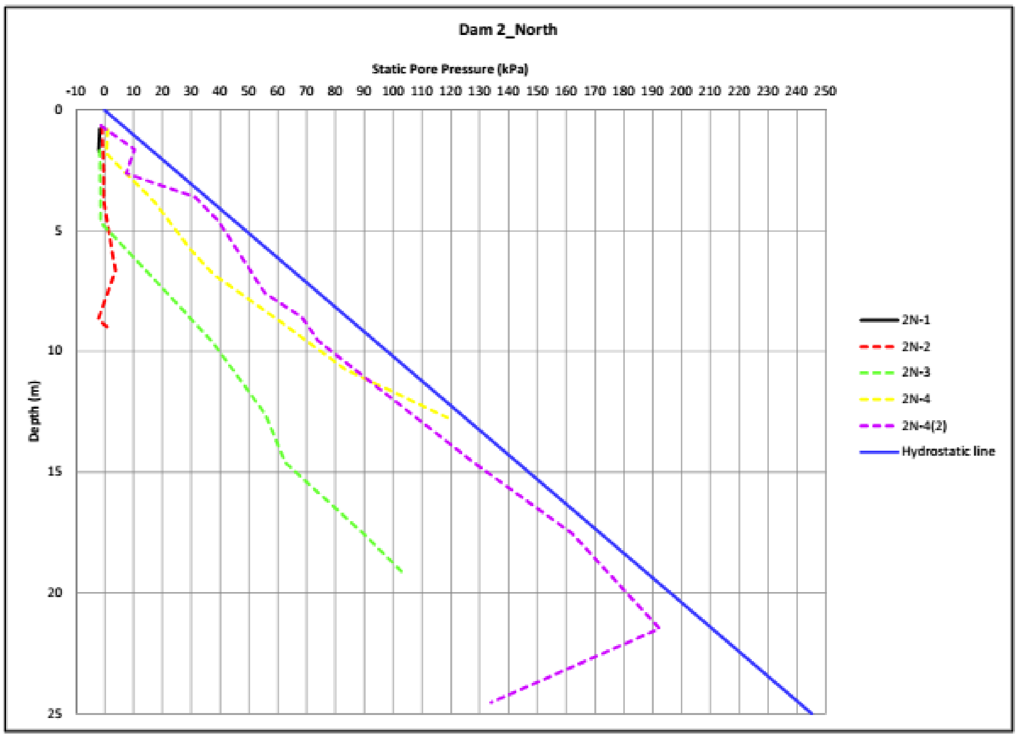


Figure 4 – North wall Static pore pressure of Dam 2

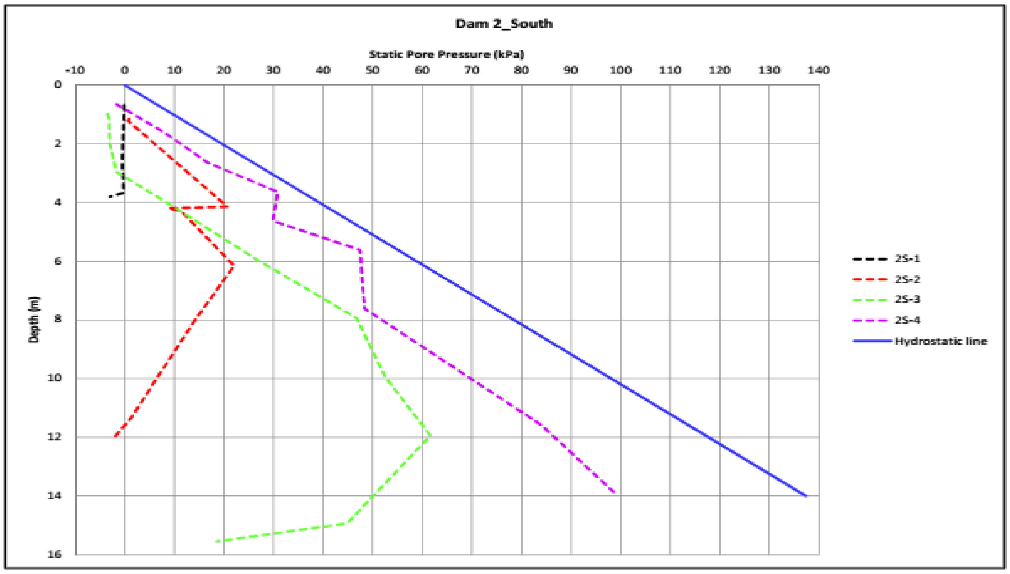


Figure 5 – South wall static pore pressure of Dam 2

## SEEPAGE & STABILITY MODELLING

### Model Description

The stability of each dam was assessed at the piezocone cross section locations as indicated on Figure 1 and Figure 2. The software package GeoStudio 2012 was used to model the current stability of the dams. The analyses were based on the 2015 piezocone results, 2015 LIDAR survey and 2015 laboratory test results. The SlopeW limit equilibrium module was used to perform the stability analysis. In SlopeW the Morgenstern-Price method of analysis was used. The method considers both shear and normal interslice forces. Both moment and force equilibrium were satisfied. The Mohr-Coulomb failure criterion was applied to all of the materials. Slip surface entry and exit point limits were specified. Using this method the most critical failure surface could be determined. A minimum slip thickness of 5m was used as a failure of this magnitude could induce subsequent failures and cause collapse of the slurry dam.

**Material Parameters**

The piezocone test results were used to identify three different material regions namely, the foundation material, slurry overflow and slurry underflow. The piezocone test results and laboratory test results were used to determine material parameters for these materials. Each of the material regions are denoted by a different colour with specific material parameters as presented in Table 3. The undrained shear strength of the overflow material used in the analyses is presented in Table 5. The cohesion was set as 0 kpa. The actual ambient pore pressures as measured by the piezocone were used in the stability analyses to model the pore pressure regime.

**Results**

Figure 6 and 7 show that installation of drains on the overflow wall strata lowers the phreatic surface hence reducing the possibility of seepage through the wall. For a pool of water at the wall boundary, creating potential seepage faces reduces seepage through the wall in the case where the central penstock could not cope with high water discharge into the dam. The same applies to when the pool is 10m away from the wall. The modelling indicates a seepage flow rate of 4.23x10-7 m3/sec per meter length at the lowest drain. In practical engineering terms, geosynthetic porous pipes are installed in trenches of 1.5m below the wall to collect excess seepage through the dam. Proper installation of drainage system would maximize water recovery.

The stability analysis of dam 2 indicates that the dam is stable with factor of safety >2 which is well over the required standard of 1.3/1.5. However, results shows that a higher factor factor of safety is achieved when the pool is away from the wall. This suggests that the penstock has to be optimumly used as well as proper installation of elevated drainage system and proper deposition control of the pool.

Table 3 – Material parameters used in seepage and stability analyses

| Material | Colour in the cross section | Unit weight ($kN/m^3$) | Coefficient of Permeability (m/s) | Effective internal angle of Friction (deg) |
|---|---|---|---|---|
| Foundation Material | Brown | 19.5 | $2.7 \times 10^{-5}$ | 37.0 |
| Overflow | Mint | 20.7 | $1.0 \times 10^{-6}$ | 30.3 |
| Underflow | Light Green | 16.3 | $3.9 \times 10^{-8}$ | 28.7 |

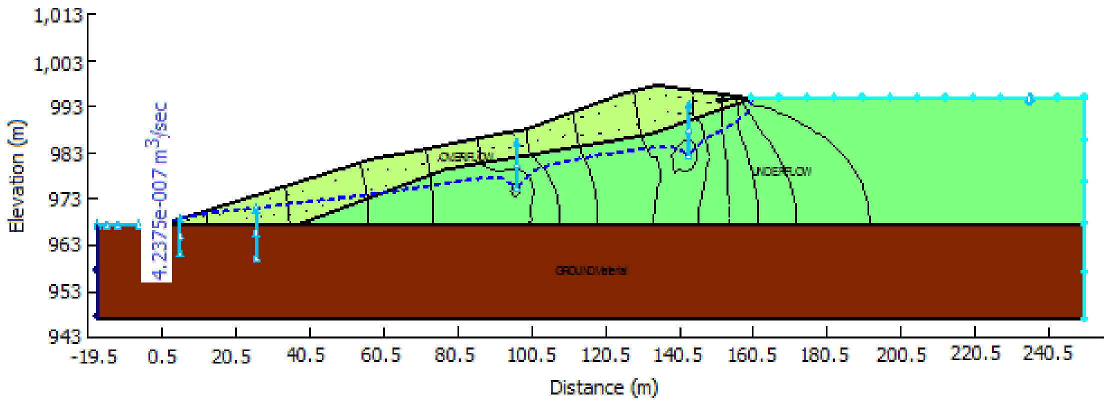


Figure 6 – Seepage results of Dam 2 when pool is at the wall

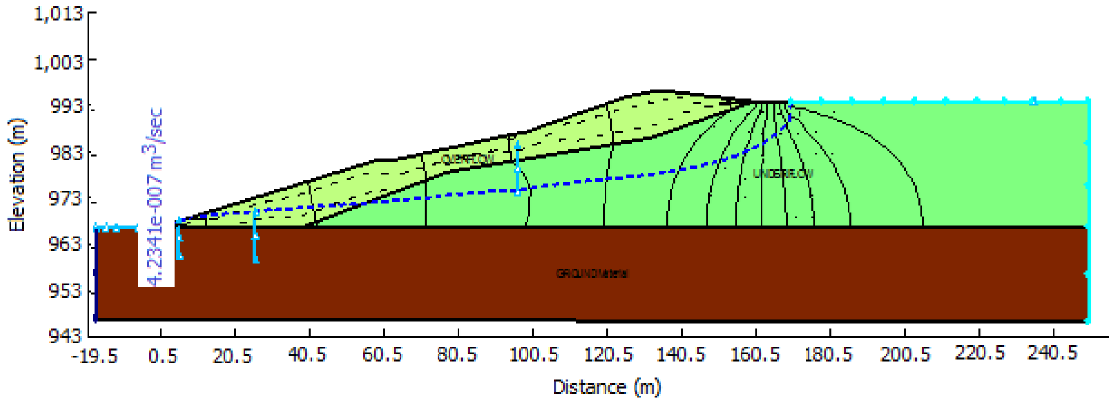


Figure 7 – Seepage result when pool is 10m away from the wall

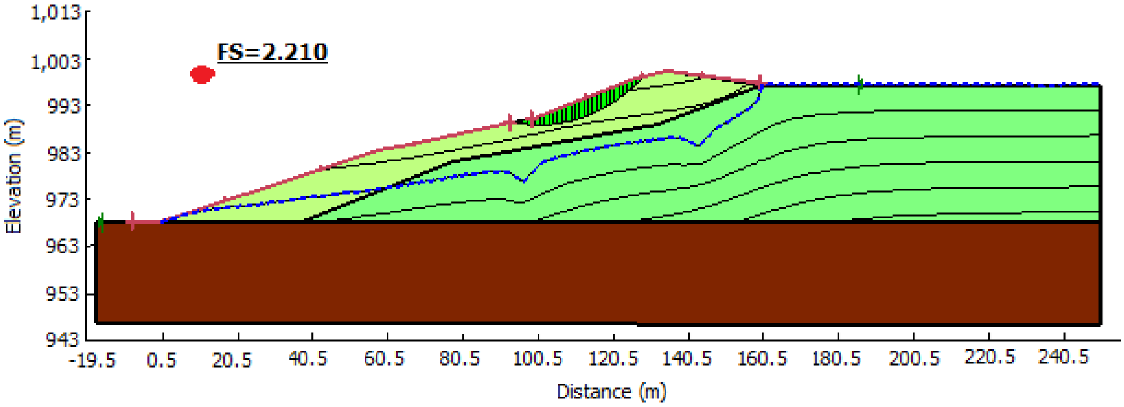


Figure 8 – Stability result when pool is at the wall

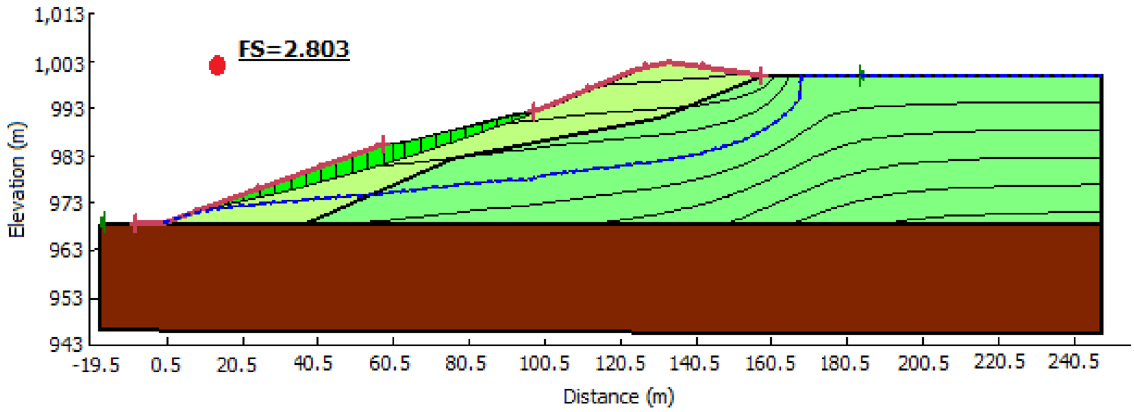


Figure 9 –Stability result when pool is 10m away from the wall

## CONCLUSIONS

Seepage and stability analyses of Orapa slurry dam 2 were carried out. The results suggested that installation of drains on the overflow wall strata lowered the phreatic surface hence reducing the possibility of seepage through the wall. A pool of water at the wall boundary reduced seepage through the wall in the case where the central penstock could not cope with high water discharge into the dam. When the pool is 10m away from the wall, the same results were achieved.

The stability analysis of Dam 2 indicated that the dam was stable with factor of safety >2 which is well over the required standard of 1.3/1.5. However, results showed that a higher factor factor of safety was achieved when the pool is away from the wall. This indicated that the penstock had to be employed properly. It should be noted that the current study considers a 2-D analysis. For more accurate results, it may be necessary implementing a 3-D analysis with the number of cone penetration tests increased to ensure a better repesentation of the geotechnical conditions that are actually taking place in the dam. This should be coupled with adequate monitoring of operations in daily basis. In practical engineering terms, carrying out the seepage and slope stability modelling is helpful in operating safely the dam.

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# SELECTION OF RATIONAL TECHNOLOGICAL SCHEMES OF OVERBURDEN OPERATIONS UNDER CONDITIONS OF EXCESSIVE WATERING

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# SELECTION OF RATIONAL TECHNOLOGICAL SCHEMES OF OVERBURDEN OPERATIONS UNDER CONDITIONS OF EXCESSIVE WATERING

## ABSTRACT

Pokrovskii open pit mine located at the Ordzhonikidze-Nikopol manganese ore basin (Ukraine) is considered as one of the biggest mining enterprises in its kind. According to geological estimations it has significant reserves of manganese ore with approximate term of their extraction up to 50 years. The main problem of these reserves development is excessive watering of overburden rock presented mostly by loams and, in turn, stabilization of massifs and mine dump slopes that are influenced by static and dynamic loads of working mine-transport equipment. As a result, stability of overburden mass at pit edges and mine dumps is disturbed under the influence of these factors. Watering of rocks considerably complicates technological operations of excavating-loading and transport equipment, hinders open-cast mining to achieve its estimated capacity and also leads to increasing of overburden costs. Thus, it is necessary to meet challenges, which would enable to estimate massif stability and determine its potential sliding surfaces and calculate safety factors for pit walls and overburden piles. The paper deals with selection and justification of rational overburden development under conditions of excessive watering of the rock massif at the Pokrovskii open pit mine (Ordzhonikidze, Ukraine). To calculate safety factors and evaluate overall slope stability for pit edges and mine dumps the method of algebraic summation of forces was applied. Possible slide curves and safety factors for stability of internal dumps are determined. The influence of piling technology on stability of slopes of heterogeneous rocks at Olexandrivskii and Pokrovskii open pits is studied. According to proposed conveying system of open-pit mining the formation of inclined draining trench at the face allows increase the safety factor of internal dumps by 14-32 % and its resulting inclination angle by 1-20 % in comparison with the project flow sheet. The technological schemes of overburden development under conditions of excessive watering are recommended.

## KEYWORDS

Slope stability, safety factor, method of algebraic summation of forces, open pit edge, mine dump.

## TOPICALITY

Joint stock company “Ordzhonikidze Mining and Processing Plant" (JSC “OMPP”) is the largest Ukrainian producer of manganese ore. It develops manganese deposits by open pit technology and produces 70% of manganese ore in Ukraine. The basic type of the mineral product is presented by manganese concentrate with pure manganese content varying from 26% to 43%. Nowadays JSC “OMPP” consists of seven open pits in operation, two dressing works and one dressing-agglomeration plant and other auxiliary shops.

Pokrovskii open pit of the JSC “OMPP” is the most perspective according to its reserves of manganese ore and approximate term of their extraction covers the period of 50 years. The main problem of these reserves development is excessive watering of overburden and, in turn, stabilization of massifs and mine dump slopes that are influenced by static and dynamic loads of working mining transport equipment and the technology of extracting and storing of overburden. As a result stability of overburden of pit edges and mine dumps is disturbed under the influence of these factors. Watering of rocks considerably complicates technological operations of excavating-loading and transport equipment, hinders open-pit mine to achieve its estimated capacity and also leads to increasing of overburden costs. That is why these specified issues are topical and require profound analysis and development of appropriate technological solutions.

One of the projects of overburden extraction at Pokrovskii open pit was developed by the limited liability company "Yuzhgiproruda" (Kharkiv, Ukraine). Firstly the overburden complexes of progressive operations appeared in that time. They were supposed to develop a basic bench with overburden spreader simultaneously. The development of upper bench was supposed by front shovel excavators with shipping of overburden rock to dump trucks and further transportation to waste piles. The project of "Yuzhgiproruda" was updated later by the Dnipropetrovsk mining institute (DMI) jointly with the Institute of geotechnical mechanics (IGTM) of the National academy of sciences of Ukraine (Sereda et. al., 1966). Overburden rocks were recommended to process according to combined field development system with two benches. In this way overburden rocks are extracted under transport-dump technology using two wheel bucket excavators and spreaders of certain types. Upper bench is developed by transport-dump complex that consists of bucket wheel excavator, belt conveyors and spreader. Lower bench rocks are stored in internal mine dump in two layers.

Also some improved flow sheets for the conditions of Pokrovskii open pit mine were offered by the Ordzhonikidze branch of the Research institute for Problems of the Kursk magnetic anomaly (NIIKMA) jointly with the Tula polytechnic institute: 1) combined field development system (the stripping technology on the lower bench and the transport-dump technology on the upper bench); 2) stripping technology (both on the lower and upper bench).

The determination of quarry slopes stability, their ground and estimation under conditions of complex geological conditions and also in massifs that have compound structure (Polyshchuk 2007, Panfilov 2006) allowed to determine that stripping method of the field development is the most effective technological decision for the conditions of excessive watering of rocks. A variety of types of draglines sets conditions for application of the range of flow sheets and therefore schemes for stripping method of the field development were designed for the conditions of Pokrovskii open pit (Yarovoi, 1980).

## PROBLEM STATEMENT

Different technological measures are used to provide stability of pit walls during an execution of stripping works and overburden operations under conditions of excessive watering of rocks at open pit mines of Nikopol ore-manganese basin (Southern part of Ukraine). The most widespread measure is the using underground and open systems of drainage. Thus advanced flanking drainage ditches were trenched for preliminary dewatering of the quarry field at Oleksandrivskii open pit. Although the experience of this quarry showed complete exsiccation of quarry field is not provided by such ditches even under block development of overburden rocks. It follows by the landslide phenomena during stripping operations of the week and excessively watered rocks that leads to the blockage of ore body and increasing the volumes of overburden re-excavating. So it is necessary to meet challenges, which would enable to estimate massif stability and determine its potential sliding surfaces and evaluate safety factor of this rock mass.

## RESULTS

Processed by walking excavators (draglines) flow sheet of development of overburden benches should be accepted according to a dump safety factor. Stability is estimated by the calculation of a line of possible slide of rocks. The calculation algorithm is based on the method of algebraic composition of forces in proportion to circular cylindrical surface of sliding. The rock mass is assumed homogeneous and it predetermines the output of slide line of in toe. For determining the location of slide line that has the least safety factor family of lines with the different outlet angles into massif toe is analyzed.

Stability coefficient or safety factor $\eta$ for the possible slide lines is determined from the expression:

$$\eta = F_y F_c^{-1},$$

where $F_y$, $F_c$ – confining and shearing forces, respectively.

The calculation algorithm includes the following actions: 1) sizing of limit height of the vertical rock outcrop ($H_{90}$) and coordinates of inclined piece of slide line; 2) determination of shearing area and coordinates of center of elementary massif block; 3) calculation of integrals of shearing and confining forces for each variant of slide line placing and bench height; 4) determination of safety factors; 5) changing benches geometry and slide lines.

The research was carried out on the analysis of flow sheets of formation of the internal dumps under different conditions of Pokrovskii open pit. The overburden at the open pit consists of loams, clays and sands. For calculations, the following initial data are accepted: $H_i$ – height of $i$-bench; $M$ – number of overburden benches; $\alpha_i$ – angle of slope of $i$-bench; $B_i$ – berm on $i$-bench; $\gamma$, $c$, $\rho$ – respectively volume weight, cohesion and angle of internal friction that characterize the physical-mechanical properties of rocks. Both geometric parameters of mine dump and indexes of physical-mechanical properties of rocks were varied in the process of calculation. The following variants were considered: 1) $M = 3$; for lower bench $H_1 = 20$ m, $\alpha_1 = 35°$, $B_1 = 40$ m; for middle bench – $H_2 = 13$ m, $\alpha_2 = 30°$, $B_2 = 10$ m; for upper bench – $H_3 = 7$ м, $\alpha_3 = 30°$; 2) $M = 3$, $H_1 = 16$ m, $\alpha_1 = 35°$, $B_1 = 40$ m, $H_2 = 17$ m, $\alpha_2 = 30°$, $B_2 = 10$ m, $H_3 = 7$ m, $\alpha_3 = 30°$; 3) $M = 3$, $H_1 = 16$ m, $\alpha_1 = 35°$, $B_1 = 40$ m, $H_2 = 17$ m, $\alpha_2 = 30°$, $B_2 = 10$ m, $H_3 = 12$ m, $\alpha_3 = 30°$. Given the percentage of volume of sand-clay rocks and loams in the dump weighted average cohesion can vary over the range 2 to 4.5 t/m$^2$ and its average value is 2.5 t/m$^2$. Volume weight of the rock mass is 1.8 t/m$^3$.

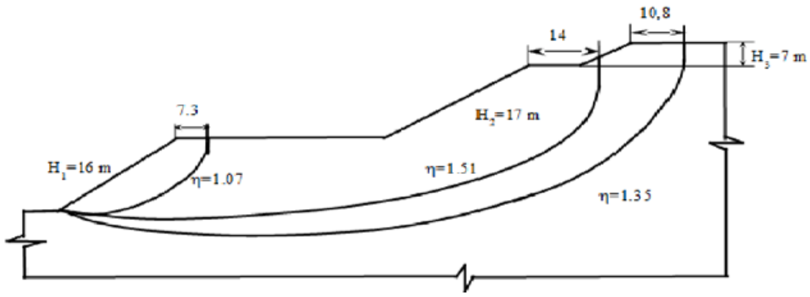


Figure 1 – Possible slide lines of dump benches built by homogeneous rocks

The study of the slide line location showed that for the base values of rock strength ($c = 2.5$ t/m$^2$, $\rho = 14°$) the least resource of stability has a lower bench. If $\rho = 8$–$12°$ the normative safety factor ($\eta = 1.2$) is not provided for all the range of changing cohesion values $c$. If indexes $\rho$ and $c$ have basic values a bench is in unstable position at all because of $\eta = 0.95$. The cohesion $c = 2.5$ t/m$^2$ provides normative stability of bench only if $\rho = 20°$.

Basic values of cohesion $c$ and angle of internal friction $\rho$ provide normative safety factor of lower and middle benches under their simultaneous formation (Fig. 1). Condition $\eta \leq 1.2$ is not fulfilled only if $\rho < 12°$. According to the above in the second variant the height of lower bench is diminished and the height of middle bench is enlarged.

In the third variant basic values of $c$ and □ provide the safety factor more than 1.0 ($\eta \approx 1.1$). Normative safety factor can be achieved only if $\rho > 11°$. So, if $\rho = 14°$ the value of $c$ must be no less than 3.2 t/m$^2$ and if $\rho = 20°$ the change of cohesion provides a value $\eta \geq 1.2$ over the all cohesion range (Fig. 2).

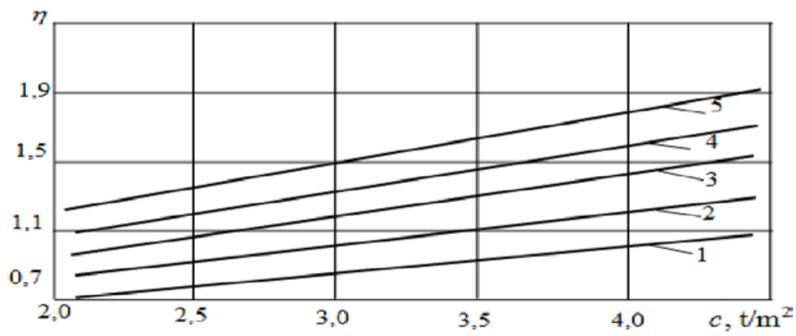


Figure 2 – Dependence of the dump massif safety factor in whole on cohesion of rocks:
1, 2, 3, 4, 5 – the values of $\rho = 8°, 11°, 14°, 17°, 20°$ respectfully

The chart analysis of the joint filling of lower and middle benches allows conclude that a redistribution of heights of overburden benches (accepted as 16 m + 17 m = 33 m instead of 20 m + 13 m = 33 m) gives positive effect. The similar result is obtained under stability forming of dump on the whole. In this case the safety factor is greater than its value in variant 1 is. If a value of $\rho$ = 14º and $c$ = 2.5 t/m$^2$ the safety factor η = 1.35. This implies that in the variant 2 obtained safety factors for all dumps even exceed the normative value. Therefore in the variant 3 possibility of increasing of the parameters of the third bench is considered. If $\rho$ = 14º and $c$ = 2.5 t/m$^2$ the safety factor of dump equals 1.25 and it is also an acceptable result. In this variant the dump passes to the instability state if $\rho$> 11º. Thus dump stability can be disturbed only because of lower bench creep in the considered flow sheets of dump forming. A lower bench is the weakest link of rock massif. For providing short-term bench stability (η ≈ 1.1) it is expedient to reduce the bench height on 4…5 m. The height of the second bench should be raised on the same value. This bench is a retaining prism to the overlying sand-clay rocks. In turn it allows increasing the height of upper overburden bench without the considerable reduction of dump stability on the whole.

Executed above calculations are based on weighted average characteristics of component rocks. Such assumption is possible when the matter is the calculation of stability of pit edge as a whole or dump under gross rock storing. However, this idealization disable obtaining wishful result under the selective piling of rocks since it does not take into account the structure of rock mass and physical-mechanical properties of varieties of rocks which compose it.

Subject to the indicated state algebraic addition of shearing and confining forces is carried out for each layered slope individually with an arbitrary number of them, regardless of capacity. The slide line with the least safety factor is determined by successive calculation of safety factor s of lower bench (dump stage) and jointly of lower and middle benches et cetera until a safety factor of all pit edge or internal dump is not determined. The influence of piling technology on stability of slopes of heterogeneous rocks is researched at Olexandrivskii and Pokrovskii open pits, where the clays, watered fine-grained sands with quick sands and loams are bedded layer-by-layer.

According to the described methodology calculations of 8 flow sheets of formation of mining flank of opencast and 16 flow sheets of internal dump (8 flow sheets stipulate selective piling, 8 schemes – gross piling) were fulfilled. The results of calculations of safety factor are given in the table 1.

Table 1 – Comparative estimation of stability of internal dump under an application of different flow sheets of overburden operations at Pokrovskii open pit

| Flow sheets | | Safety factor for internal dump | Safety factor for separate benches (the minimal value) |
|---|---|---|---|
| NIIKMA institute: | flow sheet 1 | 1.39/1.82 | 1.25/1.32 |
| “Yuzhgiproruda” institute: | flow sheet 2 | 1.65/1.63 | 1.30/1.23 |
| With making of “cut”: | flow sheet 3 | 1.70/1.85 | 1.44/1.42 |
| With cutting of working pit edge: | flow sheet 4 | 1.75/1.89 | 1.33/1.22 |
| With forming of draining trench pattern: | | | |
| | flow sheet 5 | 2.11/2.18 | 1.96/2.07 |
| | flow sheet 6 | 2.02/2.00 | 1.66/1.33 |
| | flow sheet 7 | 1.90/1.89 | 1.42/1.26 |
| With transportation of sands: | flow sheet 8 | 2.11/2.22 | 1.23/1.29 |

Note. Numerator – under gross piling of overburden rocks; denominator – under selective piling.

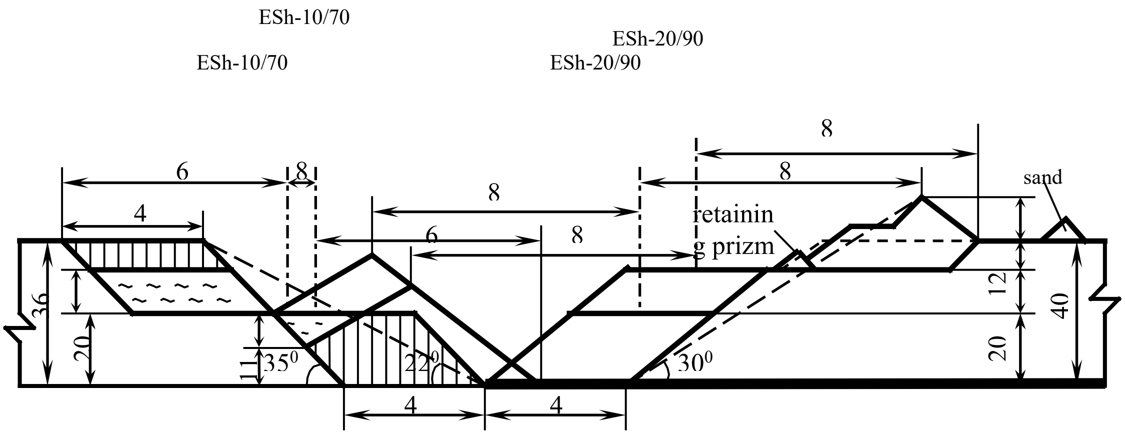


Figure 3 – Technological scheme of the development of Pokrovskii open pit with selective piling of fine-grained sands in overburden subbench (flow sheet 8)

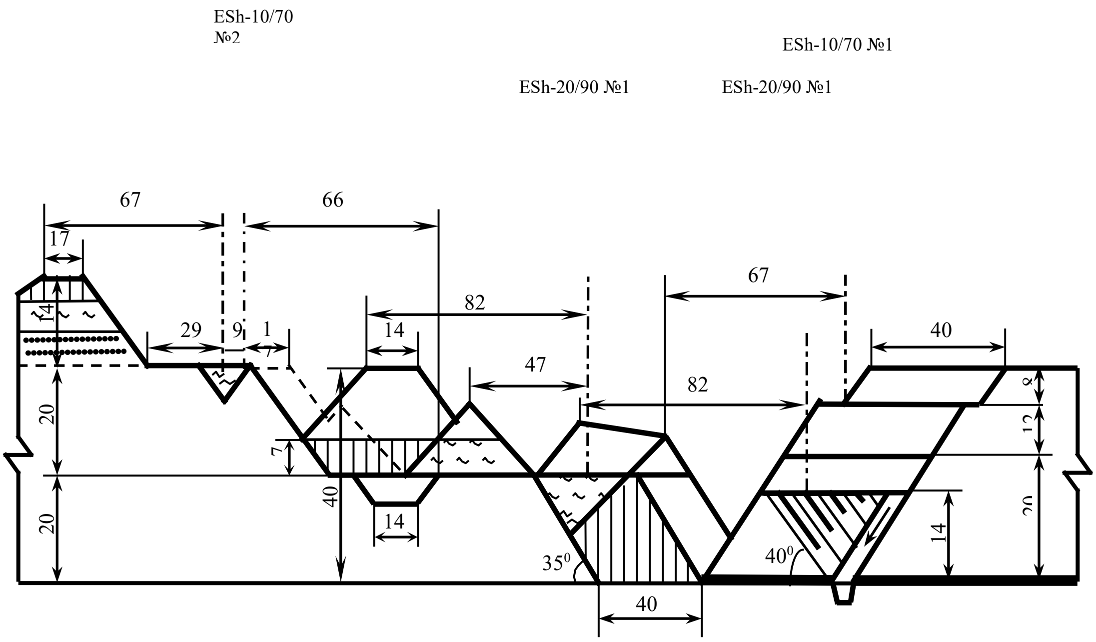


Figure 4 – Flow sheet of overburden rock development with forming of inclined draining trench (flow sheet 6)

If the normative safety factor is varies in the range 1.2…1.3 all flow sheets of forming of working pit edge provide its stability. The minimal safety factor ($\eta = 1.39$) is achieved in the flow sheets of "NIIKMA" institute, as it provides a straddle of working pit edge. The maximal safety factor ($\eta = 2.22$) is observed in the flow sheet where strongly watered sands are placed in early prepared by dragline ESh-20/90 site of working pit edge and then sands are took out of a working area by motor transport (Fig. 3). Working pit edge is cut at an angle of 55° and at a height of 18 m in the flow sheet 4 that has the least re-excavation factor ($K_r = 0.164$). In this flow sheet it is necessary to provide a retaining prism (volume – 135 m$^3$/m) formation in all length of work front. In such flow sheet safety factor increases by 17% compared to the flow sheet without a retaining prism.

The safety factor of an antisliding prism drained to natural humidity is 2.37. This antisliding barrier is similarly to barriers which were applied in the flow sheets with making of "cut" at Olexandrivskii open pit. Such antisliding barrier ensures the stability of rocks and will hinder the further rock creep to a working area under the condition of loading of re-excavated overburden rocks that remained in a cut.

For the majority of flow sheets a safety factor varies from 1.7 (flow sheet 5) to 2.18 (flow sheet 6, Fig. 4), a stability of separate stages of internal dump is provided completely in all flow sheets of the development of Pokrovskii open pit.

Calculation of slopes stability of pit edges η for the flow sheets to demonstrated of correlation dependence between the stability factor $\eta$ and rehandling factor $K_n$ (Fig. 5).

For the gross mine dump forming:

$$\eta = -1\ ,1\ 4K_n^2 8 + 1\ ,6\ 0K_n 5 - 0,0$$

Selective mine dump forming:

$$\eta = -8,6\ K_n^2 5 + 7,4\ K_n 3 + 0,4$$

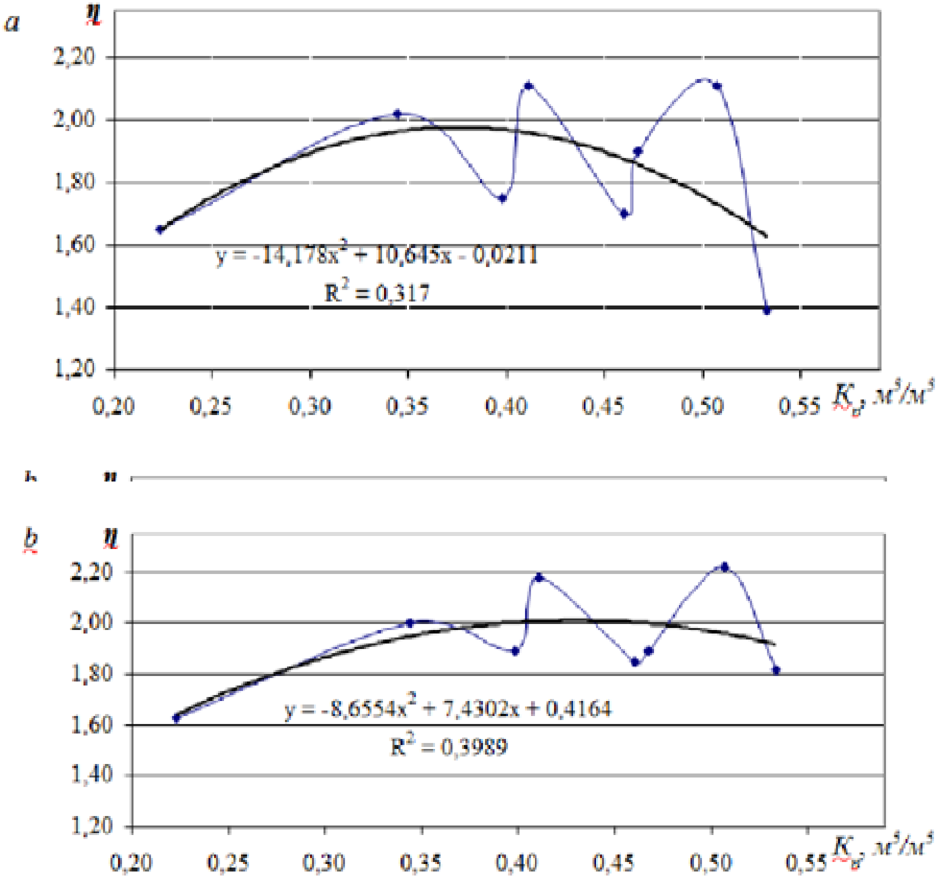


Figure 5 – Correlation dependence between rehandling factor and stability factor:
*a* – gross mine dump forming; *b* – selective mine dump forming.

The analysis of safety factor s of a working pit edge and an internal dump shows that in the aspects of stability of heterogeneous massif slopes the flow sheets 4, 6 and 7 are of the greatest interest. Mentioned flow sheets provide the use of draglines ESh-10/70 and ESh-20/90. It is necessary to apply the flow sheet 6 in the initial period of Pokrovskii open pit operation. The height of dragline exploited bench is about 27 m (mine dump forming is selective one). In the basic period of open pit working the flow sheet 6 (selective mine dump forming) and the flow sheet 7 (gross mine dump forming) are the most expedient under the height bench of 40 m. The said flow sheets as compared to the project one enable to increase by 14-32% safety factor of internal dump, piled according to stripping method.

## CONCLUSIONS

For the mining and geological conditions of Pokrovskii open pit the calculation of possible slide lines of watered massif is carried out. The influence of piling technology on stability of slopes of heterogeneous rocks at Olexandrivskii and Pokrovskii open pits is researched.

Subject to the method of piling of rocks (gross or selective piling), type of equipment, placing of equipment in a working area slopes safety factor s of rocks of homogeneous and heterogeneous massifs are determined for 8 flow sheets of formation of mining flank of opencast, and also for 16 flow sheets of internal dump formation. The stripping flow sheets providing inclined draining trench formation in a breast are analyzed. Suggested draining trenches allow enhancing of safety factor of internal dump by 14-32 % and its resulting angle enhancing be 1-2$^0$ in comparison with the project flow sheet.

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# SUSTAINABILITY ASSESSMENT OF THE MINING SECTOR IN BRAZIL

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# SUSTAINABILITY ASSESSMENT OF THE MINING SECTOR IN BRAZIL

## ABSTRACT

Trade balance of the mining sector in Brazil over the more recent years, has demonstrated how products from the mining sector have been playing an important role to the Brazilian economy. Nonetheless, the economic, social and environmental impacts of this sector have not yet been fully documented, debated and understood in reports presented by companies and public organizations in Brazil. Also, it is evident that the sustainability assessment is mainly pursued in large companies and poses a big challenge to small-medium-artisanal companies. The objective of this article is to propose a simplified approach for the sustainability assessment of Brazilian mining enterprises supported on a reduced set of indicators. To achieve this objective, a large number of sustainability indicators were identified from the scientific literature and international organizations. Recognizing however the complexity of collecting and analysing such a large number of indicators, an initial selection of these indicators was attempted according to three sustainability dimensions. The pre-selected indicators were proposed to experts on the mining sector in Brazil including members of the academy, public institutions and industry, aiming to validate this pre-selection. The findings resulted in framework combining a restricted number of indicators able to evaluate the sustainability in the mining sector in Brazil, including social, environmental and economic dimensions. The reduction of the complexity of the process is expected to contribute to engage small-medium-artisanal companies on sustainability practices and evaluation.

## KEYWORDS

Sustainability assessment, mining, indicators

## 1. INTRODUCTION

The last two decades have witnessed a dramatic growth in mining activity in many countries and a considerable body of research has emphasized reasons for revising resources extraction policies and improving governance of the mining industry (Speigel, 2012).

Aiming for sustainability, environmental assessment policies have become common-place in planning and evaluation at all scale of decision making, from private enterprises to town councils, governments and international forums. Environmental indicators as prime assessors of the pressures on the environmental systems and of the appropriateness of policy measures have come to play a vital role in sustainability reports (Niemeijer and de Groot, 2008). On regards to the social dimension, the importance of using social indicators to assess the impact of the specific policies is well evident allowing to reliably and impartially show well-being or the lack of it, either in general for the population of a region of interest, or for specific group. According to Gamu, Billon and Spiegel (2015), social aspects analysed through social indicators can easily influence the political dynamics of local communities, and companies can use them to analyse social impacts, engage particular groups and hear the voice of affected communities.

Sustainability assessment is an increasingly important issue for mining companies. In order to achieve a better understanding of sustainability and also of its usability authors such as Aubynn (2009), Hilson and McQuilken (2014), Hilson (2012), Seccatore et. al. (2014) supported that the sustainability must be analysed according to company's size, region and objectives. For this last aspect, Almeida and Torrens

(2002) suggested possible objectives such as, improvement of local infrastructure, improvement of safety conditions in the mine, mitigation of environmental impacts, ensuring the use of the right equipment for the conditions of each site, ensuring the rational comprehensive use of mineral resources and sharing community benefits.

For the particular case of Brazil, regardless of the high economic importance of the mining sector, sustainability assessment is still discussed only for a short number of large mining companies. A further challenge is then to analyse this sector considering different indicators among large and small mining companies. The objective of this work is then to propose an approach for the sustainability assessment of Brazilian mining enterprises supported on a reduced set of indicator. To achieve this objective, a large number of sustainability indicators were identified from the scientific literature and international organizations. Recognizing however the complexity of collecting and analysing such a large number of indicators, an initial selection of these indicators was attempted according to three sustainability dimension and following a set of pre-established criteria. . In order to better translate environmental, social and economic performance of mining companies in Brazil and to ensure a high acceptance of the proposed indicators, a group of experts was consulted for its validation.

The remainder of this paper, consists in 4 sections as follows. Section 2 begins with a brief introduction about the mining sector in Brazil. In section 3 the importance of sustainability indicators to mining sector is discussed. Section 4 describes the methodological approach followed in the research and presents the results of its implementation. In section 5, concluding remarks are presented pointing directions for further research directions

## 2. MINING SECTOR IN BRAZIL

The discussion about impacts originated from the mining sector in Brazil and other countries as well as contribution for sustainable development was a critical issue in Conference Rio+20. Building upon the achievements of earlier major events such as the Rio World Summit in 1992 and the World Earth Summit in Johannesburg in 2002 (Rio+10), this conference reiterated the vital role of the mining industry for sustainable development objectives.

Regarding the Brazilian case, according to the International Council on Mining and Metal the contributions of mining sector for the Brazilian macroeconomics are increasingly significant. Data provided by IBRAM-*Instituto Brasileiro de Mineração* (2012a), indicate that this sector increased from less than US$ 10 billions of product value in 2000 to around US$ 50 billion by 2011. Figure 1 illustrates the evolution of the trade balance of the mining sector in Brazil over the more recent years, demonstrating how exports of these products have been playing a central importance to the Brazilian economy although their value has been decreasing since the second semester of 2014.

As illustrated in Figure 1, international prices of minerals commodities show a generalized decrease since 2011. This is particularly evident for the first semester of 2015 when compared with 2014. The average price index (US$) of fertilisers, metals/minerals, basic metals and precious metals in 2015 decreased respectively 4.2%, 13.9% and 12.2% comparatively to the second semester of 2014 (DPNM, 2015). Evidences from World Bank Group show that the decrease of prices of metals and fertilizers are explained by the low global demand for metal (especially in China), oversupply and high stock and also influence of American dollar quotation.

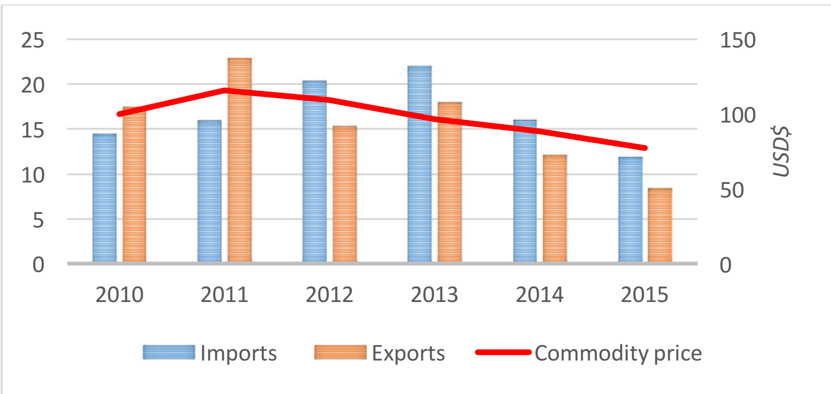


Figure 1: Trade balance of commerce for the mining industry (2010-2015). Source: DPNM, (2015) and World Bank (2015)

Due to the importance of mineral metals to Brazilian mining sector, the combination of lower global demand and reduction of minerals prices largely contributed for a reduction of the exportation value of the Brazilian mining sector. According to IBRAM (2015), the main factor responsible for this reduction is the price decrease of iron mineral in the international market. Also the World Bank (2015) highlighted the impact of the increase of iron mineral offer, with new market operators and increasing production capacity in both Brazil and Australia contributing to the decrease of iron mineral price which is one of the most important mineral commodities in Brazil.

According to the Mining Production Department in Brazil (DPNM) the Brazilian production mineral value achieved R$ 35.9 billion in the first semester of 2015. This value was estimated from the total nominal values of production commercialized reported by companies (R$ 29 billion in the first semester of 2015) and taking into account that these companies represented 80.8% of the total value of Brazilian mineral production in 2014 (DPMN, 2015).

Regarding to employment and according to data published in reports of the IBGE- Brazilian Institute of Geography Statistics (2012), the mining sector in Brazil has been contributing to the economic diversification with considerable employment effects. IBGE (2012) report shows that in Brazil this sector employs around 2.1 million workers directly, apart from the jobs generated during exploration, prospecting and planning stages, and people working in digging and mining.

Regardless of these important employment impacts, Silvestre and Neto (2014) recall that the majority of traditional production methods adopted for mining companies in Brazil involve multiple stages as minerals extraction and minerals processing. These methods are responsible to generate a large number of waste causing severe environmental and social damages in particular due to frequent accidents associated with these activities.

Mining sector in Brazil has been involved in some environmental disasters, with the most recent and mediatic one occurring in November 2015 in the state of Minas Gerais. According to Neves et al. (2016), this was the worst environmental disaster in the history of Brazilian mining sector. Sixty million $m^3$ of sludge overwhelmed houses and the historical, cultural and natural heritage of a village in a municipality of Mariana in this state. The sequence includes nearly a million of people without tap water for days, fishing suspended in traditional fisher's village, universities and schools closed in two Brazilian states. Additionally, Meira et al. (2016) underlined that there are hundreds of damns with mining waste and more than 40 of them are unstable and at full capacity only in this state.

Neves et. al. ( 2016) argue that in Brazil some of the most mining affected ecosystem services are those related to freshwater, such as water provisioning to agriculture, households and support to livelihoods, water filtration, control of erosion and flood and cultural services. Also Enriquez and Drummond (2007), highlighted that the interest of indigenous communities and the needs of communities around to development of mining projects have not been properly considered.

Due to importance of the mining sector to Brazil and its high environmental and social risk but also due to its high economic importance at national and regional levels, achieving sustainability in all related activities represent one of the most important goals for the sector. However, information on sustainable practices and related reports from Brazilian mining companies are still scarce in the country. It is recognized that mining companies must invest heavily in the development of knowledge, methods and techniques needed to restore landscape and degraded rivers adjacent to mining areas, but other social and economic issues should not be overlooked. The assessment of sustainability with the final goal of contributing to engage communities and companies in the search more sustainable practices is then a fundamental issue to be considered by researchers, companies and policy makers.

## 3. SUSTAINABILITY ASSESSMENT THROUGH SUSTAINABILITY INDICATORS

To guide mining companies to achieve sustainability many strategies have been suggested in the literature. Seppala et al. (2002), supported the use of life cycle impact assessment to assist the evaluation of environmental impacts caused by the complex array of interventions associated with the sector including emissions, land use and resources extraction.

Lindner et. al. (2010), suggested also a sustainability impact assessment tool aiming to evaluate social, environmental and economic impacts. Roca and Searcy (2012), analysed indicators disclosed in corporate sustainability reports using the case of a set of companies from Canada. Also Worral et al., (2009) suggested sustainability criteria and indicators framework to suit the particular needs of legacy mine land. Hilson and Nayee (2002) proposed an environmental management system particularly well suited to mines.

On regards to sustainability assessment methodologies, those are based on the identification and evaluation of criteria which exposes potential impacts on the three dimension of sustainable development: social economic and environmental (OECD, 2010). The purpose of sustainability assessment is to provide decision-makers with an evaluation of global to local integrated nature-society systems in short-and-long-term in order to assist them to determine which actions should or should not be taken in attempt to make society sustainable (Singh et.al. 2009). Aiming for sustainability, chapter 40 of Agenda 21 calls on countries and the international community to develop indicators of sustainable development. Such indicators are needed to increase the focus on development and to assist decision-makers at all levels in adopting sound national sustainable development policies (Shields, 2005).

Among the benefits of the indicators, the possibility of providing measurable and valid information for the managers to make use of them on decision making is of high importance. Sustainability indicators also have become important to environmental impact assessment and "state of environment" reporting. This has increased the influence of indicators on environmental management and policy making at all scales of decision making (Niemeijer and de Groot, 2008). Combining these aspects, it is clear that sustainability indicators should be considered as useful towards sustainability assessment for many companies, presenting a picture of their development stage.

The use of the indicators is strongly recommended due to two main reasons: firstly, the indicator monitors progress and provide picture trend and changes over time, secondly indicators clearly show not only how individual organizations are performing but can also assess national and regional benchmarking performance in the sector (EPCEM, 2013).

Sustainability decision-making in mining or any other sector needs to be based on indicators that identify the interactions of organizations with the environment (Fonseca et al., 2012). According to Puig et al., (2014), the development and selection of sustainability indicators has become a relatively complex process because of their multifunctional nature. The authors underline that the selection of sustainability indicators should be accompanied by rigorous validation process and the categorization should be based on the dimension of sustainability. As such, although indicators are used to reflect sustainability criteria, decision-makers also need a framework that can enable the selection and operationalization of the most relevant indicators for this purpose. According to Ziout (2013), effective sustainability assessment models should have particular characteristics such as: usage of available data, ability to address case-specific issues, provide reliable consistent information, and effectiveness of the model depends on quality of indicators used. Alonso (2015) have established some criteria for indicator selection for comparison of passage transport sustainability, adapted now for the case of mining companies as shown in Table 2.

Table 2: Criteria for selection of indicators. Source: Adapted from Alonso et. al., (2015)

| Criteria | Definition | Criteria | Definition |
|---|---|---|---|
| **Target relevance** | Direct towards one aspect of sustainability. | **Unambiguous** | Do not depend on interpretation |
| **Standardization** | Able to be standardized by company size. | **Data availability** | Able to access required data. |
| **Validity** | Able to measure the issue it is supposed to measure | **Sensitivity** | Able to reveal changes on sustainable practices in companies. |
| **Transparency** | Easy to be understood and to be interpreted by community and lay people | **Measurable** | Simply and easily measured by quantitative or qualitative means within a given time frame for data collection and evaluation |

While indicators are useful tools to reduce a complex set of diverse data, it should be kept in mind that every process of selection or aggregation is not considered as an easy one. Therefore, indicators development processes are best conducted if the characteristics of the scenario where they will be applied are considered. For this reason, Falck and Spangenberg (2014) also support that indicators sets must balance the needs for reducing complexity, being easily understandable, resonating with a clearly target audience and being limited in number.

As sustainability awareness has been increasing in the mining sector throughout related stakeholders, effective sustainable strategies became an important aspect to be taken into account among companies, governments and society, due to impacts originated for mining activities and affecting different stakeholders. The development of methods to support sustainability assessment in the mining sector is deemed to be a relevant contribution for the sector with important spillovers for the entire community. The revised papers demonstrate the pertinence of the issue and the need to further elaborate on the selection of indicators aiming to provide the community with a framework well suited for the mining sector, reliable but straightforward.

## 4. PROPOSED METHODOLOGY

The methodology proposed aims to result on the construction of a sustainability assessment framework comprising a set of indicators. According to Horsley et. al., (2015), traditionally, the literature on sustainability indicators falls into two broad methodological paradigms: expert-led and top- down; and community-based and bottom-up. Expert-led approaches predominantly use quantitative indicators drawn from a range of social and other sciences. Proponents acknowledge the need for indicators to quantify the complexities of dynamic systems, but approaches do not necessarily emphasise the complex variety of resource-user perspectives. The second paradigm is based on a more localised, contextual and participatory philosophy. Research in the literature on sustainability indicators traditionally emphasises the importance of understanding local conditions, values and needs to set goals and establish priorities and assumes sustainability monitoring as an on-going learning process for both communities and researchers (Horsley et. al., 2015).

In this research both paradigms were considered. Bottom-up approach was applied considering that relevant literature related with sustainability assessment was consulted and an understanding about indicators to be used in Brazilian mining companies under local conditions was attempted. Top-down was used through the collection of expert's opinion with large experience in the Brazilian mining sector, in order to provide a final agreement about the set of indicator proposed in this research.

For the design of the indicators framework the following steps were considered:

- Survey and selection of first set of indicators

The first step to develop the framework consisted in a survey of indicators, which was carried out from an extensive literature review where reports, papers and scientific projects related with mining sector were consulted. In particular, reports from different organizations including GRI (Global Reports Initiative), ICMM (International Council on Mining and Metals), OECD (Organization for Economic Co-operation and Development) and IBRAM (Brazilian Mining Association) were used in order to analyse which sustainability indicators have been suggested by these organizations. In addition to this, the specificity of the Brazilian mining sector was considered. This step allowed identifying a comprehensive list of 68 meaningful indicators that were considered as important for this research.

- Selection of a restricted set of indicators

This stage focused on the reduction of the number of these indicators. For this GRI (2010) report and Index of Mining Sustainability (ISM) from Viana (2012) were consulted and criteria to selecting sustainability indicators defined in the currently literature were considered. As such, indicators from GRI and ISM were assumed to be particularly relevant as those targeted already the mining sector and the Brazilian case. These indicators were analysed and filtered individually according to the eight main criteria established described in Table 2. This step allowed to reduce from the initial 68 indicators to 19 resulting in an initial framework to be validated by experts from mining sector in Brazil. The shorter list of indicators was grouped based on the three sustainability dimensions.

- Experts' selection and consultation

For the validation of the selected indicators a participative process was designed based on the consultation of a group of experts from mining sector in Brazil. The identification of relevant experts was a pre-requisite to development of an appropriate and meaningful sustainability framework to Brazilian mining sector proposed in this research. These included professionals who have large work experience in the mining sector and from important mining associations/organizations in Brazil including public mining agencies, academic and research institutions and syndicates. The group comprise then the most important stakeholders to Brazilian mining sector. A total of 25 experts were contacted and from those 11 agreed to participate on the study and provide their judgment on the relative importance of the proposed indicators. For the sake of simplicity, the eight criteria suggested by Alonso (2015) for indicator analysis, were reduced to three, namely 1) Measurable by process, 2) Transparency and 3) Relevance. Experts were then instructed to respond to a face-to-face questionnaire and to analyse the indicators according to these criteria.

To avoid bias and different interpretations each one of these indicators was described to the experts. In short, experts were asked firstly to sign Yes or No on the compliance of each on indicator to each one of the criteria having in mind the final goal of reaching a sustainability assessment framework for mining companies in Brazil. Secondly, experts were asked about the agreement on the indicators position in each dimension. Thirdly, experts were asked if they would like to add other indicators that they felt could bring additional information to the sustainability assessment process.

-Final framework

Based on the results from the previous steps, a final framework with a reduced and validated set of sustainability indicators could then be proposed for sustainability assessment in Brazilian mining companies taking into account the three pillars of sustainability.

Tables 1, 2 and 3 describe the results of the first attempt to reduce the large set of indicators to 19 (some of them composed), categorized according to sustainability dimension, describing the proposed measurement procedure and the scale to be considered. Ordinal indicators are classified according to a five-point Likert scale of rating, where 1 represents the lowest sustainability level or requirement and 5 represents the highest ones.

Table 1: Economic indicators selected to sustainability assessment in Brazil

| ECONOMIC INDICATORS | | HOW TO MEASURE | | | | | REFERENCES |
|---|---|---|---|---|---|---|---|
| E1 | **Profitability** | Companies operation margin (EBTIDA margin – Earnings before interest, taxes, depreciation and amortization) | | | | | (Azapagic, 2003), (GRI, 2016) |
| E2 | **Research and development (%)** | Percentage turnover (PT) of companies invested in research and development (R&D), including geological and social-environmental one. (Yearly - last five years) | | | | | (Azapagic. 2003) (GRI, 2016) |
| E3 | **Average salary (%)** | Ratio between workers' average salary (AS) and minimum national salary (MNS). (AS/MNS) | | | | | (GRI, 2016), (Boratto, 2012) |
| E4 | **Economic impact of environmental liability (%)** | Ratio between amount paid in environmental liability and the annual profit of company | | | | | (Boratto, 2012 |
| E5 | **Economic risks of environmental liability (Ordinal)** | Existence of technical standard, court order, or international agreement that imposes additional costs to mineral product. | | | | | (Boratto, 2012) |
| | Technical Standard | Local government | Legislative order | International agreement | Order court | | |
| | 1 | 2 | 3 | 4 | 5 | | |

Table 2: Social indicators selected to sustainability assessment in Brazil

| | SOCIAL INDICATORS | HOW TO MEASURE | | REFERENCES | |
|---|---|---|---|---|---|
| S1 | **Social Responsibility (%)** | Percentage turnover (PT) of companies invested in socio-responsibility actions, including both compulsory and voluntarily actions (S1.1 + S1.2) | | (GRI, 2016), (Boratto, 2012) (Azapagic, 2012) | |
| | | S 1.1 -Percentage turnover (PT) of companies invested compulsory (Yearly - last five years) | | | |
| | | S1.2- Percentage turnover (PT) of companies invested on voluntarily actions (Yearly - last five years) | | | |
| S2 | **Environmental Social-performance (Ordinal)** | Implementation of actions for evaluation the socio-environmental performance | | (Boratto, 2012) | |
| | Never implemented | Being implemented (few or no results available yet) | Implemented at internal level | Implemented to both internal and external stakeholders | ISO 26000 or SA8000 certification |
| | 1 | 2 | 3 | 4 | 5 |
| S3 | **Safety and health (Ordinal)** | Existence of management and safety and health systems | | (GRI, 2016), (Boratto, 2012) (Azapagic, 2012) | |
| | Never implemented | Being implemented (few or no results available yet) | Implemented in internal level | Implemented to both: internally and external stakeholders | OHSAS 18001certification |
| | 1 | 2 | 3 | 4 | 5 |
| S4 | **Occupational accidents (%)** | Frequency of accidents (RF) in the company during the last five years. | | (GRI, 2016), (Boratto, 2012) | |
| S5 | **Professional qualification (%)** | Percentage turnover of company (PT) invested in professional qualification (PQ). (Yearly - last five years) | | (GRI, 2016), (WBCSD, 2008), (World Bank, 2008), (Boratto, 2012), (Azapagic, 2012), (WBCSD, 2008) | |
| S6 | **Local workers participation** | Ratio between number of workers from local community and total number of workers of company | | (Boratto, 2012) | |
| S7 | **Employment (%)** | S7.1 - Number of direct jobs | | (GRI, 2016), (Boratto, 2012), (WBCSD, 2008), (World Bank, 2008) | |
| | | S7.2 - Number of temporary jobs | | | |
| | | S7.3 - Ratio between created jobs (CJ) by company and total city population | | | |

Table 3: Environmental indicators selected to sustainability assessment in Brazil

| ENVIRONMENTAL INDICATORS | | HOW TO MEASURE | | | | REFERENCES |
|---|---|---|---|---|---|---|
| EN1 | **Environmental management (Ordinal)** | Existence of environmental management system | | | | (GRI, 2016), (Boratto, 2012) |
| | Never implemented | Being implemented (few or no results available yet) | Implemented in internal level | | Implemented and informed to external stakeholders | ISO 14001 certification |
| | 1 | 2 | 3 | | 4 | 5 |
| EN2 | **Environmental Actions (%)** | Percentage turnover of companies investing in environmental actions (Yearly - last five years) | | | | GRI, 2016), (WBCSD, 2008), (World Bank, 2008) |
| EN3 | **Environmental fines** | Total of amount paid in environmental fines (Yearly - last five years) | | | | (GRI, 2016), (Boratto, 2012) |
| EN4 | **Waste quantity (%)** | Ratio between waste and tons of product (Yearly - last five years) | | | | (GRI, 2016), (Boratto, 2012) |
| EN5 | **Energy intensity (%)** | Energy consumption by tons of product ( kWh/t) | | | | (GRI, 2016), (Boratto, 2012), (Azapagic, 2003) |
| EN6 | **Management of liquids effluents Ordinal)** | Companies' action implemented by companies to management liquids effluents | | | | (GRI, 2016), (Boratto, 2012), (Azapagic, 2003) |
| | Never implemented | Being implemented (few or no results available yet) | Septic tank system and recipient to separate oil and grease | | Effluents control in place | System to effluents control and reduction |
| | 1 | 2 | 3 | | 4 | 5 |
| EN7 | **Emissions particle management (Ordinal)** | Companies' actions to emissions particle control (Trucks to roads humidification, humidification systems, crushing installation.) | | | | (GRI, 2016), (Boratto, 2012), (Azapagic, 2003) |
| | Never implemented | Being implemented (few or no results available yet) | Internal humidification in place | | Permanent humidification internal and around the company in place | System and equipment for measuring and do emission particle management |
| | 1 | 2 | 3 | | 4 | 5 |

Experts judgment during "experts' selection and consultation" phase provided information about the importance of the proposed indicators:

(1) Economic dimension: economic impact of environmental liability (E4) and economic risks of environmental liability (E5) were excluded of the framework proposed. According to the experts, the way to measure these indicators was not completely clear and it could be difficult to be computed for some mining companies. This was particularly evident for E5 as it was considered that the indicator depends on external aspects such as governmental roles and as such not being relevant to sustainability assessment and comparison of mining companies.

(2) Environmental dimension: emission and fluids liquids management (EN6) and emission particle management (EN7), were also excluded from the proposed framework. The majority of the experts agreed that these indicators have relevance for mining and mineral industry. Nonetheless, considering the characteristics of mining companies in Brazil, these indicators may not be applied,

due to the need to invest of specific equipment to measure emissions which reduces the possibility of acquisition for small companies. For this reason, they were not considered on the final framework.

(3) Social dimensions: all proposed indicators were included in the final framework.

(4) Additional indicators: no additional indicators were proposed by the experts.

Based on this, a final framework was proposed as summarized in Figure 2.

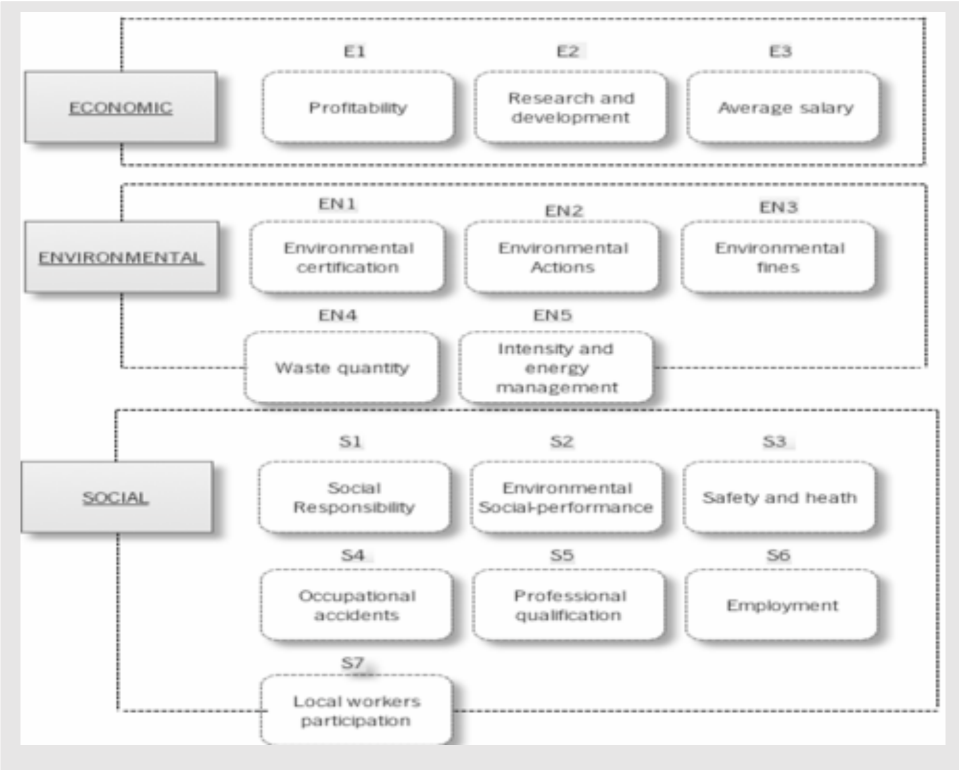


Figure 2: Final framework validated by experts.

The contributions of experts allowed to reduce the number of sustainability indicators previously selected in this research to a set of significant indicators that are considered to be relevant, understandable and easy to measure which should contribute significantly to its acceptance and recognition among mining companies, policy makers and other stakeholders.

## 5. CONCLUDING REMARKS AND FURTHER RESEARCH

In this research we empirically investigated sustainability assessment approaches in the mining sector in Brazil. Findings from experts' consultation and literature consulted demonstrated that in Brazil the information is scarce and sustainability reports are available only for large mining companies.

This research aims to contribute to turn the concept of sustainability easier to be recognized and valued by most mining companies, providing a framework for the simplified but effective assessment of their performance. In order to support these companies, a framework was then created based on a set of indicators validated by Brazilian experts and covering the three "pillars" of sustainability. This should encourage mining enterprises to increase the sustainability assessment reporting and as such to engage them on the search for more sustainable practices.

The final result of this work was a framework aggregating fifteen indicators considered to be measurable, transparent and relevant and as such able to be applied by mining companies. The framework could be followed by useful outcomes if applicable for mining companies, originating significant results to sustainability assessment and as such bringing new evidence to industrial decision-makers and to policy makers and contributing to a better understanding to mining sector in Brazil.

This research is part of a larger on-going research project aiming to tackle the challenge of sustainability assessment of small and medium mining companies in Brazil. As such, this a first step that must now be complemented with field work and testing phases. The research is proceeding with the implementation of the proposed framework on different companies aiming to assess its acceptance and usefulness.

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# SUSTAINABLE MODEL OF RESTORATION AND REHABILITATION IN KAOLIN MINED AREAS AT CABO DE SANTO AGOSTINHO – PERNAMBUCO

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# SUSTAINABLE MODEL OF RESTORATION AND REHABILITATION IN KAOLIN MINED AREAS AT CABO DE SANTO AGOSTINHO – PERNAMBUCO


## ABSTRACT

Mining is fundamental to a country's economy and contributes to creating a high quality of life for present and future generations. Developing a balanced (equal) society is crucial, but in order to achieve this, it has to be operated in a socially and environmentally responsible way, following the precepts of Sustainable Development. Many authors believe that incorporating the mining industry into these precepts (Sustainable Development) is an antagonistic challenge. As a viable solution, this article offers a case study of a consortium between mining and farming activities, contemplating the "Caulim Itapoama Mineração LTDA", located in the city of Ipojuca - Pernambuco by the KM 12,80 of the PE-60 road. Here they carry out the extraction of aluminosilicate clay, used in the ceramic industry, along with sugar cane plantation, which is considered the Secular Economic Activity of the region. It is in this context that Operational Sustainability can be defined. The two most important industries of the primary sector of economy coexist in harmony, offering present and future generations the comfort of industrialized products and the continuity of farming in the region. The implementation of well-planned mining techniques will ensure rehabilitation of the land right after the mining itself, rendering in this case the used area to retain healthy and ready-to use soil.



## KEYWORDS

Operational sustainability, Mining restoration, Kaolinite, Terrace mining, Mining and agriculture


## INTRODUCTION

The mineral industry is one of the pillars of modern economy serving as basis for virtually all other industrial activities. According to *Dubinski (2013),* the mining industry is one of the oldest documented kinds of human activity. Brazilian economy, for example, always lied on a mining basis. First there was the gold rush in the 17$^{th}$ century that populated states like Minas Gerais and Mato Grosso making the contingents moves from the shore to the countryside. After that first rush we also had diamonds, silver, aluminum, copper and etcetera.

The whole construction industry is fomented by mining since it delivers the iron for siderurgy, limestone for cement production and crushed stone and sand for concrete production. It also provides all metals for production of electronics, photovoltaic cells and etcetera.

Even though the context has changed and we have a solid transformation industry, banks and also technology development enterprises, Brazilians favorable trade balance is still strongly dependent on the results of the iron industry for example.

That dependence on the mining industry goes worldwide. The cement consumption *per capita,* for example, is an international reference for social development. As the famous physicist Max Planck said once, *Mining is not everything but without mining everything is nothing.*

Mining is also a long-term enterprise that may live, between conception and extinction, many decades of even centuries. (Hartman, 2002) Divided a mining enterprise in five phases: prospection, exploration, development, exploitation and recuperation. Each of these phases are different hence their social and environmental impacts differs. It is important to know each of these phases in order to understand the impacts that can be caused due to mining activity. The first and second are previous to mining activity itself and they focus on finding a mineral deposit and define its characteristics like volume, structural and geomorphological condition and etcetera.

Prospection: uses direct and indirect methods of evaluation to define whether there is a possible deposit and if it is worth studying it furthermore. Some of these methods are air-photographs, geophysics/chemistry. Exploration: that's when the tonnage, richness and other information of the deposit are calculated. Through that phase invasive methods like drilling are used. The information acquired with those 2 phases are used to define whether is there economical/technical viability to proceed with the project into the 3rd phase and 4th.In Brazil economical/technical viability is summarized by the 23rd article of the Mining Code.

Development: in this phase the infrastructure needed by the project is implemented. The access roads are created, the soil, vegetation and overburden are striped and buildings are lifted so the area is ready to receive the mine operation. Also the bureaucracy needed is done. In Brazil that includes acquisition of mining rights, negotiate the terrain with the owner and get all other licenses for legal operation.

Exploitation: that when the company starts the production of minerals and all operations are done at the same time. In a general case drilling and blasting is done while pairs of truck/loader loads and transports the mined material to its destiny. The mining method is defined in order to achieve the best economical-environmental efficiency.

It's in development and exploitation phases that the damages to environment are done. The vegetal coverage is removed with the soil, great amounts of earth are moved changing topography and contributing to air pollution. After the exhaustion of the mine (or as in some other cases along with the mining operation) the activities for recuperation of the area are implemented. Recuperation can be considered the conclusion of mining operations in a sustainable way guaranteeing the posterior use of the used area.

## MINING AND ITS ENVIRONMENTAL IMPACTS

The mining industry is treated as an environmental villain for many media vehicles and lately that bad image has only been aggravated by events like the SAMARCO dam burst in Minas Gerais, Brazil, that contaminated a whole river with thousands of tons of mud killing people, fauna and flora.

The impacts that can be caused by the extraction of minerals are topographical deformation, various changes of water relations, impoverishment of soil, contamination of soil and water, gas and dust emissions, vibrations, noise, deforestation and others.

Some of them are inherent to the activity like the deforestation and topographical deformation and some of them may never happen if there is a proper planning and execution of the activities like the contamination of soil and water.

It is also important to acknowledge that mining differs from other industries in a very important concept: Time. As minerals are a finite resource, all mining projects are conceived with the idea that it will finish its activities once those resources are no longer an asset thus the closing of an operation can be due to stagnation of the reserve or the impossibility of extracting it in an economic viable way. That fact is relevant to understand that mining damages are not like other industries. At some point the activity will necessarily stop and measures for the recuperation of the area shall take place.

One of the greatest problems on open-pit mines in Brazil, especially amongst small business, is the lack of planning or, in many cases, the bad planning. That reflects on a poor choice of mining equipment and is directly related to low productivity, hi costs and wastes of resources.

Being the mining sector so important to the country, the Brazilian Environment Ministry, amongst other departments such as National Department of Mining Production and the Pernambuco's Agency of Environment, adopted a series of management tools as mandatory for starting and operating in this sector of the economy. The effort aims to guarantee that all national operations are in conformity to legislation on production and environmental areas.

Those management tools are known by their initials as: PRAD, SLA, PCA and a few others that changes from state to state. Each one of them is related to different phase of the process.

The PRAD (planning for recovery of used areas) assures that by the beginning of the operation there already is a plan for recovering the used areas. That leaves no room for excuses like there "is no money for it". Enterprises have no way of starting a business on mining without planning its future.

The SLA (Environmental Licensing System) is the tool the state uses for controlling the environmental impacts the project can generate prior to its occurrence. It is divided in three layers (Prior, installation and operation licenses) and are only given to projects considered environmentally viable. Though there is no straight definition of viability, it is common sense that if the negative impact of the project is small, no risk to fauna/flora in danger of extinction, the damage caused can be reversed and the community will benefit from it, the project is environmentally viable.

Brazilians laws for environmental control of mining activities are really effective but there is still a need of professionals and structure to assure that law enforcement agencies are able to properly supervise establishments and enforce the laws.

## CARACTERIZATION OF THE STUDIED AREA: KAOLIN MINING OF CABO DE SANTO AGOSTINHO – PE.

The area studied is located in the Cabo de Santo Agostinho city. It is 41 Km away from the capital of Pernambuco, Recife and it is known for being the host, along with Ipojuca, of the Suape Port and Industrial Complex. Its economy relies on industry and service sectors being those alone responsible for approximately 90% of its GDP according to IBGE (Brazilian Institute of Geography and Statistics).

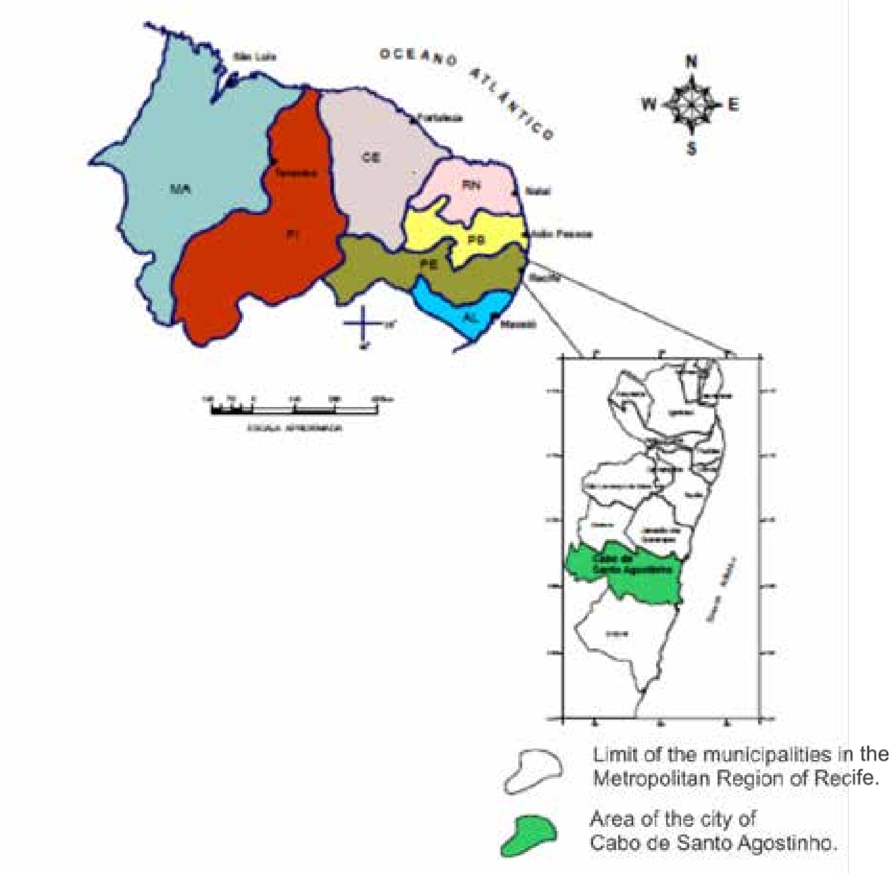


Figure 1 - Mine location

The region is composed by a volcanic-sedimentary sequence, Cabo Formation, where the kaolinite deposit was discovered. The proper geological knowledge of the deposit was a key point for the election of the mining method.

The kaolinite deposit in study is situated in a near-horizontal (cross-bedding) sedimentary structure composed of 3 layers. The first one is an yellow clay 50 cm thick. The second has another 50 cm of a gray clay and the third goes for 3 more meters of gray clay with siliceous sand, as can be seen in Figure 2.


Figure 2 - Stratigraphic profile of the region

The Itapoama Mineração extracts economically both the aluminosilicate clay (the gray one) at a rate of 36.000 tons/year and 12.000 tons/year of siliceous sand. The clay is mainly selling for the ceramic industry due to its white burning property while the sand produced is destined to the *Caulim do Nordeste S.A.* that uses it on the construction industry, glass production and etcetera.

## THE MINING OPERATION

The choice of the mining method in small enterprises in the northeast of Brazil is usually the *Crater Mining*. That comes from a historical use of that method in the region by quarry, granite, gypsum and others mines. Only with a proper basis on mining engineering and a careful analysis of geological data that choosing the best mining method is possible.

The Itapoama case is a singularity. The fact that the deposit of kaolinite has a cross-bedding structure and it is located in a sugar-cane plantation region obligated the company to carefully choose its mining method so the viability wouldn't be compromised by high rent fares due to the cease of the agricultural activity while the productivity of that method achieves the company needs.

They wouldn't be able to use the *Crater Mining* method since its use passes necessarily for a long term occupation of the area so and instead they chose the Striping-Mining method.

Strip mining method is a technique where mining and landscape recuperation are done ensemble. First the area is divided in benches following the structure of the ore. The soil is removed and stored for future restoration of the area. Then the overburden is removed and placed in an adjacent area that was already mined. After that the ore (in this case the kaolin) is extracted, and one cycle is finished. The operation moves to the next bench and the process is repeated.

That method is largely applied for coal mines and the machinery used are generally able to mine and transport the material at the same time like Draglines and Bucket Well Excavators (BWE). Both are designed for incessant operation so they can be used to its maximum capacity. This method achieves very high productivity with low unitary cost. The Figure 3 displays a scheme of the method.

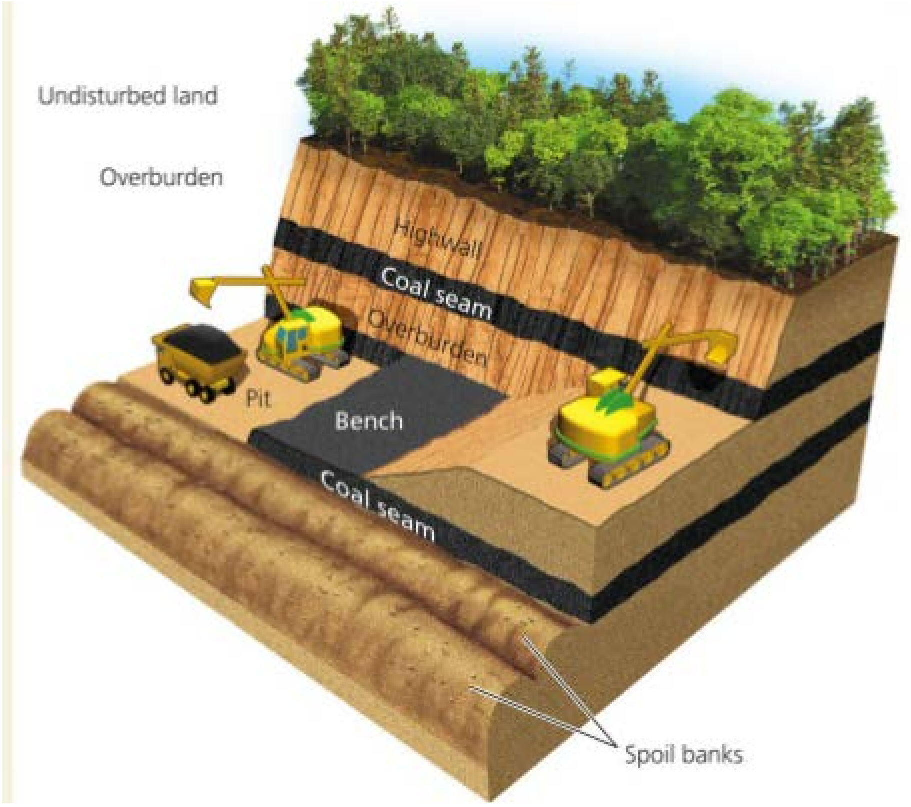


Figure 3 - Strip mining scheme for coal mining

There are a few particularities to this case in study that makes the traditional arrangement of strip mining not viable:

- The amount of ore extracted is relatively small (no more than 50.000 tons a year in total) making it impossible to pay for heavy machinery like BWE;
- The operations cease at least once a year due to rainy season;
- Ore thickness is too small and so is overburden;

With that accounted, the Itapoama arranged their operation as follows:

- The top soil is removed with a bulldozer and stored for later recomposition;
- The overburden is removed with a pair loader/truck and directly deposited on the last mined site;
- The ore is removed the same way the overburden was but transported to a storage site to be processed and sell.

The operation format can be seen on the photo that follows.

Figure 4 - Mineração Itapoama

Another particularity of this case is the orebody that is almost 3 times thicker than sterile so in order to recompose the topography it is necessary to bring material from outside of the mine. The company brings a ferriferous clay from a close farm so that the recomposition is possible.

**MINING INDUSTRY ON THE PRECEITS OF SUSTAINABLE DEVELPMENT**

The term "sustainability" has been widely used by all sectors of economy with many different meanings depending on perspective. In order to be accurate, this paper is guided by the definitions proposed by A. Han Onn and Alan Woodley from the Queensland University in Australia. Their research divided the mining sustainability agenda within 3 tiers.

- Tier 1: Perpetual Sustainability, which focuses on benefits to shareholders and the continuation of mining;
- Tier 2: Transferable Sustainability, which extends benefits to the broader community and environment;
- Tier 3: Transitional Sustainability, which focuses on providing intergenerational benefits to the broader community and environment, including after the completion of mining.

Their study showed that the first is an old concept where enterprises consider as results only the amount of capital that is produced ignoring completely the environment and the community (perpetual sustainability). That old and greedy administration method is evolving towards a more social/environmental friendly one where enterprises are profitable and interact in a positive way with the community.

Mining can insert itself on the 3rd tier if they work on the reduction of its negative impacts on society and environment, keeping an open channel of communication with the community and also making sure that once the deposit is exhausted their heritage won't be minesite left as a liability. There are many different possible ways to achieve that but any of those has to start with a proper planning of the activities.

The Itapoama Mineração show that in the location it is inserted it is possible to be sustainable in a particular way. Its striping operations are done so the vegetal and the top soil are removed separately for later recomposition of the mined area. They have proper installations for maintenance of equipment so no oil or other contaminants are spilled on the soil. The mined areas are recomposed right after extraction of the kaolinite so the posterior usage of those areas isn't delayed.

## FINAL CONSIDERATIONS AND CONCLUSIONS

What makes that operation a unique case is the fact that it occurs concomitant with the agroindustry. They share the area in a mutualistic relationship where the mining industry operates when the sugarcane plantation is stopped due to soil rest. The mining method chosen does the recuperation of the mined area along with the extraction of the kaolinite and allows agriculture to take place right after the operations. It is also important to take into consideration that the exchange of an aluminosilicatic clay for a ferriferous achieves an increase in saccharose concentration. According (Vasconcelos & Garcia, 2005) that happens because the $Al^{3+}$, that is abundant on the kaolinite, reduces the development of sugar-cane roots. On the other hand the recomposition clay used is rich in $Fe^{3+}$ that aids on formation of chlorophyll.

The main concept of operational sustainability is the constant reduce of resources use along with increase of productivity. In this case it was achieved by the correct election of the mining method. The use of the terrace mining method allows the process to be more efficient reducing the carbon footprint (by reducing transport distance and fuel use), the area needed for operations (since there is no need for a wastedump) and restoring the used land right after the mining activity giving it an immediate after use and reducing the landscape impact.

As a consequence of operational sustainability, in this case, that operation is also inserted on the 3rd tier (Transitional Sustainability) granting jobs for local community while the agroindustry is stopped and ensuring the continued use of mined areas providing a better condition for sugar-cane plantation with higher productivity making local agroindustry stronger with higher possibility to survive in the Brazilian competitive market. The Itapoama Mineração ensures an efficient production and delivers a series of benefits for the next generations of people that will depend on the mined are and local economy.

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# SUSTAINABLE TERRITORIES: INTEGRATED GOVERNANCE AND LOCAL STAKEHOLDER ENGAGEMENT IN THE AMAZON

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# SUSTAINABLE TERRITORIES: INTEGRATED GOVERNANCE AND LOCAL STAKEHOLDER ENGAGEMENT IN THE AMAZON

## ABSTRACT

In Brazil the National Mining Plan 2030, published by the Federal Government in 2011, places the mineral sector in a position to leverage sustainable development in the country for the next 20 years. This plan recognizes the Amazonian region as a key region where mining will expand considerably in the next few years. The Amazon is the current boarder of mineral expansion in Brazil, a fact that apart from raising optimism, in the long term it also raises concerns, given the area´s large territorial extension which represents 60% of Brazilian national territory, and its conflicts in relation to the use and occupation of the territory. Because of the geological, environmental, territorial (challenging logistics) and historical conditions, the Amazon region requires a different approach. The facts mentioned above impose an additional challenge to the mining policy in the region, as it needs to take in consideration not only market competition of the mineral sector as a whole, but also the regional socioeconomic context. The National Mining Plan recognizes that mining activity alone does not guarantee local or regional sustainable development when not integrated with adequate policies and shared responsibilities among the public and private sectors as well as the civil society. Within the context of the partnerships among these different sectors, we highlight a number of essential components that may contribute to mining becoming an efficient tool to provide local and regional sustainable development, including: 1) the strengthening of local municipal governance; 2) the strengthening of civil society organizations; 3) the diversification of alternate economic activities; 4) the improvement of environmental management. The implementation and integration of these four components within a 15-year-timeframe are the pillars of the Sustainable Territories Program, which were created in association with the Mineracao Rio do Norte (MRN) and the civil society organizations Instituto do Homem e Meio Ambiente da Amazonia (Imazon), Agenda Publica and Equipe de Conservacao da Amazonia (Ecam) plus the Amazon municipalities of Oriximina, Faro and Terra Santa, involving over eighty local civil society organizations and municipal councils, 35 traditional communities and 88 thousand, comprising an area of over 12 million hectares of natural protected areas and traditional community lands. In this paper we introduce the conception of the program mentioned above and the main outcomes of its first phase of implementation.

## KEYWORDS

Sustainable mining, stakeholder engagement, sustainable development, integrated land development .

## INTRODUCTION

In the past decades, the rapid increase of industrialization and the growth of world population, along with an economic development speedup, especially in the emerging developing economies, has brought a significant growth in demand for metals, such as hydrocarbon. This scenario has forced a great number of countries and companies to promote the development of modern mining techniques and other natural resources exploitation projects, extending to isolated and remote territories, and considerably increasing the boarders of development based on extractive industries.

In Brazil, the National Mining Plan 2030 published by the Federal Government in 2011 placed the mineral sector in a position to leverage the country´s sustainable development for the next 20 years. This plan recognizes the Amazon as the key region where mining will expand considerably in the next few years. The Amazon region is regarded as the current frontier of mineral expansion in Brazil. While this fact raises optimism, in the long term it also raises a few concerns, given Amazon´s large territorial extension which represents 60% of Brazilian national territory, and its conflicts in relation to the land use and occupation. "Because of its geological, environmental, territorial (challenging logistics) and historical condition, the Amazon requires a different approach. These facts impose an additional challenge to the mining policy in the region, as it needs to take into account not only market competition of the mineral sector as a whole, but also the regional socioeconomic context." (Brasil, 2013)

The mining plan highlights challenges to mining activities within the Amazon, one of which is the urge to consider mining as a tool to align regional development harmonically with the formal commitments made by each of the local states. These commitments must emphasize and assure that the benefits resulting from mineral extraction are to be reverted to the region´s social and economic development. The Amazon has a great mining potential but it is still seen as economically and socially vulnerable. Currently there is a considerable amount of projects related to the regulation of mining exploitation in indigenous territories in the National Congress, as required by Brazil´s Federal Constitution of 1988.

Given its complex background, through PNM 2030, the government acknowledges the fact that the Amazon area issue must be approached by different policies aiming at having its needs met by the Executive, the National Congress, Ministries, and Amazon Federal Units. That means, a correlated effort of initiatives that may provide feasible actions which include mining and sustainable development in the area, once mining activities bring the opportunity to solidify development, changing social vulnerability tendencies.

However, it is worth mentioning that mining activity alone does not assure the local sustainable development when not aligned with proper policies and shared responsibilities among public and private sectors, and the civil society. Thus natural resources extraction can be beneficial to national and local development where such activities happen, taking into account that the agents involved are committed to managing and investing the generated revenue into alternative income, that is, using human capital and infrastructure in a transparent and responsible way.

Although the public sector has primary responsibility of guaranteeing that the extraction sectors contribute to the inclusive growth and human development, the private sector also plays an essential role in the process. Many agents in the extraction industry acknowledge this role and there are several efforts leaded by the industrial sector that aim at increasing the industrial activities positive impacts within local development. There is also an emerging emphasis regarding the urge for more cooperation between the public and the private sectors towards land managing improvement.

In the sight of a possible and required partnership among all sectors – public, private and civil society – it is important to point out some essential features to insure that the land may be considered and may benefit from mining undertakings as a sustainable development tool: the institutional strengthening and its public management; the public sector and civil society capacities improvement; the strengthening of capital stock through local associations, city councils and other participative approaches; the qualification of public policies and the services provided to the local communities; an inclusive and environmentally responsible economic development.

In the case of the Amazon area, a few specific needs add up to those previously mentioned: promoting respect, preserving and/or rescuing traditional cultures; inclusion of local and traditional communities in land development solutions, respecting the local cultural and economic peculiarities; inclusion in the democratic debate and share of institutional spaces with all local communities.

Facing such a complex background, the Programa Territorios Sustentaveis (PTS), or Sustainable Territories Program, was structured in 2015 to be implemented in the coming 15 years, aiming at contributing to a strategic framing of sustainable land development in Oriximina, Faro and Terra Santa municipalities, located in the west side of Pará state, where Rio Norte mining company, Brazil´s bauxite largest producer, operates.

The program is issued by the following public interests civil society organizations: Agenda Publica, Equipe de Conservacao da Amazonia (Ecam) and Instituto do Homem e Meio Ambiente da Amazonia (Imazon), and financed by MRN.

MRN is a closed capital corporation, established in 1979 by an association made of Brazilian and international companies. MRN extracts dried and wet bauxite. The mining company can produce 18 million tons of ore every year. In the year of 2013, 17,3 million tons of bauxite were produced. The company´s headquarters are located in Oriximina, alongside Trombetas river bank, a branch of Amazon river. MRN’s mission is to produce bauxite and to provide the ore with full compliance to the quality specifications, assuring client satisfaction and revenue to its shareholders, respecting the relation between man and nature. In order to do that the company has around 1.300 employees, 86% being locals, 2% from other states in the northern region and 12% from other states in Brazil. This scenario reflects the company´s commitment in valuing and developing local labor.

**Area Profile**

The three municipalities diverge in demography and land area, but all of them have environmental protected areas within their limits. These areas suffer direct influence from mining exploitation. Two of the municipalities – Orixima and Faro – also have part of their areas occupied by indigenous and quilombola lands (slave descendants’ communities that have land rights acknowledged by the Federal Constitution).

Figure 1 – Areas’s outline

The municipalities of Terra Santa, Oriximina and Faro combined have an area of over 12 million hectares (the size of a country like Portugal), with more than 88 thousand inhabitants. Besides the urban population, there are farmers, indigenous communities, quilombola communities and other traditional communities living alongside rivers and roads as well as in woodland reserves. The main economic activities developed within the area are: subsistence farming; fishing; Brazilian nuts extraction; logging; cattle breeding. Currently, mining is the most important economic activity in Oriximina, which is the largest and the most developed municipality in the area. However, mining contribution in the income of Terra Santa and Faro communities has been gradually increasing. Even with all of the mentioned economic activities, the local communities face a great deal of challenges, such as lack of social organization, low income, unsettled land rights and mainly, low access to basic services as health, education and basic sanitation.

The Human Development Index of the three municipalities is between 0,56 (Faro) and 0,62 (Oriximina). The Human Development Index (HDI) is a summary measure of average achievement in key dimensions of human development: longevity, education and a decent standard of living. The HDI is the geometric mean of normalized rates for each of the three dimensions. The Brazilian HDI – IDHM - follows the same dimensions of the global HDI but it also focus on adjusting it to the country´s reality and other national indexes which are more suitable to evaluate the country municipalities´ development.

Evaluating the IDHM from 1991 to 2010 allows us to better understand the context of economic stagnation and the urge to tackle social improvements in all three municipalities. Hereby, we introduce only the evolution of the local index in Oriximina, taking into account that Faro and Terra Santa are located within Oriximina´s area; they show the same socioeconomic background and therefore they also face similar challenges such as overcoming the area´s social vulnerabilities.

In 1991 Oriximina´s IDHM was 0,39 and it has raised to 0,62 in 2010 mostly due to education, responding to a national increase resulting from the increase of federal investments in social programs and public policies in the past twenty years.

When splitting health, education and longevity indexes we find a local income recess for the past 20 years, although the country´s largest bauxite mining company is located in the area. So, the index shows us that, although Oriximina´s income is higher than the state´s average, the economic development is not significantly responding to the fact that there is such a large mining corporation within the same area. This fact is even more concerning when we take into consideration the fast advance of MRN´s operations towards other municipalities, which would decrease Oriximina´s revenue even more.

Besides the income stagnation, there was also an increase on income distribution inequality. The Gini Index – used to measure the rate of income concentration – ranged from 0,59 in 1991 to 0,61 in 2000 and to 0,64 in 2010, showing a progressive income concentration. It also points out the difference between the poorer and the richer in a specific community. It varies from 0 to 1, being 0 a full equality, (everyone has the same income concentration) and 1 complete inequality (one person retains all income concentration).

## ENGINEERING DESIGN

Considering the above mentioned background, the proposal intends to build a democratic and integrated local management model taking into account the Amazon background; encouraging inclusive and sustainable public interest land development, through public institutions strengthening, economic alternatives structures and the increase of local participation, considering the preservation of traditional cultures and environmental conservation.

PTS was structured in four pillars: 1) Public Management; 2) Social Capital; 3) Economic Development; 4) Environmental Management. Each pillar has its own goals and expected outcomes. In order to guarantee the alignment throughout the planned actions in each axis we have stablished a long term goal: implementation of an efficient and integrated management model, that supports a diversified economy, balanced with sustainable socio-environmental values.

In this work we understand that the combination of the political and institutional bias with the sustainable development traditional milestones (economic, social and environmental) is an essential element to the desirable land management model.

PTS´ public recipient are the local communities of the three encompassed municipalities (Oriximina, Faro e Santa Teresa), which includes a total of 88.089 people (Censo 2010). The program recipient groups are: municipal managers; municipal advisory boards; local communities represented by associations and popular organizations; quilombola communities (approximately 550 families), indigenous population; economy representatives such as local small, medium and large company entrepreneurs within the area.

Given the time lapse expected, the program was structured in different implementing macro stages, seen in Figure 2:

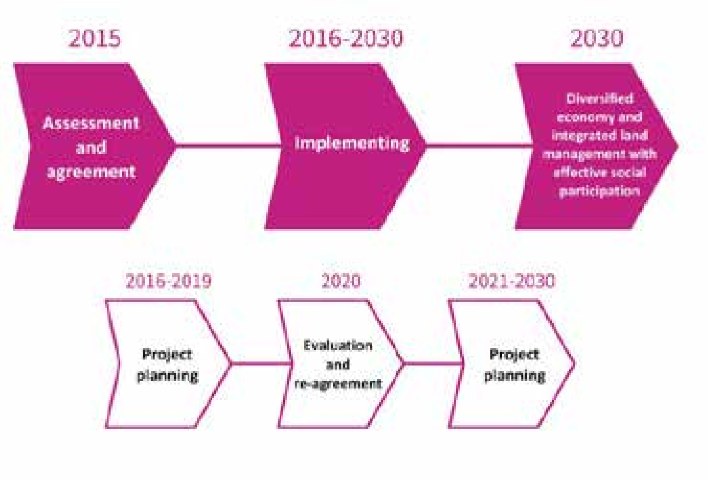


Figure 2 – Program’s macro schedule

**Assessment and Municipal Agreement**

The first stage of the program is made of agreements and alliances among agents that already live in the area seeking for local partnerships, collaborative work, and also the proposal´s regularization.

Simultaneously, a land assessment was made with basic environmental and socioeconomic indicators, primary and secondary data, creating the project´s target area. Through this assessment, public management institutional abilities and primordial target areas were also evaluated. The target areas are: the municipality social capital, the environmental background and the local environmental offices management. With this work we were able to design action plans that anticipate goals for the next five years of PTS operations in the area.

**Target Axes**

Axis 1: Public Management

A planning and public management relies on the fund-raising institutional capacity, executing projects and assisting sectional public policies buildup. Also, the area´s integrated development relies on the effort to seek solutions for all three municipalities’ common challenges.

This axis considers 9 goals and 62 tasks related to the support of Faro, Terra Santa and Oriximina city councils and local offices, their public policies and services planning, civil servant instruction, fund raising and management benefiting the local communities´ health, education, and infrastructure areas.

The main goals here are: 1) Making agreements, assessments and mapping all key stakeholders; 2) Controlling financial and taxes municipalities status improvement and legalization; 3)

Public policies instruction to local leaders and associations; 4) Strategic and sectional planning with a follow-up system; 5) Improving fund-raising technical and managerial skills, and project and contract supervision; 6 ) Design clear laws and implementing accessible information; 7 ) Government and citizenship institutionalization promoting civil servants and local leaders professional development; 8) Basic social areas identification and management plan revision; 9 ) Management of the knowledge acquired.

To sum it up, the first axis main outcome is: providing a clear and effective public management implementation within the municipalities of Oriximina, Faro and Terra Santa.

Axis 2: Social Capital

The municipal advisory boards are the main channels to promote civil society participation in public management, they allow the community to help designing local public policies as well as to take part in the decision making process. Promoting the boards institutional strengthening brings political and technical conditions for the public sector and its boards to work in a more appropriated manner. However, having these advisory board representatives on board requires participative environments and the local civil society organizations strengthening. Hence, we focus on social capital strengthening, also supporting an environment of cooperation between the government and civil society.

This axis encompasses 4 main goals and 30 tasks aiming at empowering social articulation, offering support to local communities and leaders to participate in decision making processes as municipals board advisors. The second axis main goals are the following: 1) Oriximina, Faro and Terra Santa associations mapping and assessment; 2) Regularization of these associations; 3) Strengthening local participation; 4) Seeking for civil society self-sustainability.

The main outcome of this axis is to provide an environment with solid social capital and participation.

Axis 3: Economic Development

Development is a phenomenon that combines various economic and extra economic factors, such as: income, wealth, knowledge and power. We think as “land development” the process of turning dynamic the comparative and competitive advantages of a certain territory, simultaneously leveraging economic development, social capital, government terms and natural resources sustainable use. For us, it is crucial that economic development is inclusive, integrating traditional communities, rural and urban areas.

The third axis brings 2 main goals and 9 tasks related to economy development and improvement using the municipalities´ current potential and productive chains (such as: Brazil nuts, copaiba extraction, fishing, logging, farming, cattle farming, tourism), considering the conservation of protected areas and traditional cultures. The goals here are the following: 1) Designing new land development perspectives; 2) Implementing a boosting program for Oriximina, Faro and Terra Santa´s productive chains.

The main outcome of this axis is to provide economic diversification based on the area´s socio-environmental values.

Axis 4: Environmental Managment

In regards to the environmental issue, the goal is to implement a sustainable model of socio-economic development, linking conservation and the use of forest reminiscent through the improvement of an integrated and clear public-private participative management plan that includes the local stakeholders and seek to promote better quality of life for the area´ inhabitants.

The protected areas in the region overtake the land geographically and play a key role in determining a path for the region´s own development. Brazilian protected areas, conservation units, are divided in different categories. Most of them allow activities such as tourism or research in their area.

Some of them can also have traditional communities recognized lands. Each area and local community plays an important role in the implementation of a strategic and integrated land management.

Unfortunately, protected areas can be seen as development standstills, especially to a model based in farming and cattle breeding. But at the same time, all three municipalities receive tax revenue, due to the existence of the same protected areas, as compensation for the land use legal restrictions. Besides, these protected areas are home to many traditional communities that rely on natural resources to survive.

Currently, other trial projects that pay for environmental services are being worldwide implemented and developed. Here, the proponent institutions bring along their expertise and institutional network of successful experiences in the designing and creation of projects that support the local economy, traditional communities and municipalities.

The environmental axis encompasses 5 main goals divided into 17 tasks aiming at providing direct support to the municipalities´ environmental offices with conservation management and legal permits issues, mapping the rural areas land regularization (known as Cadastro Ambiental Rural – rural environmental registration number).

The outcomes to be tackled here are the following: 1) Building up land development vision and new perspectives; 2) Implementing a program to boost up the productive chains of Oriximina, Faro and Terra Santa.

The main outcome if this forth and last axis is to provide an integrated and effective environmental management plan to Oriximina, Faro and Terra Santa.

We would like to highlight here that each one of the four axes has specific goals and managers, and it is only by combining all expected outcomes that we will be able to pursue PTS´ long term vision: to implement an integrated land management within a 15 year time lapse that supports a diverse economy combined with sustainable social and economic values.

In 2015, after the conclusion of the initial assessments and after designing action plans, the program was discussed with local leaders and decision making stakeholders, seeking not only legitimacy but also, and most importantly, carrying out essential partnerships to a long term integrated land management plan.

By accomplishing the program main goals, we expect to build up a democratic and integrated local management plan that can be applied throughout the Amazonian context; promoting sustainable, inclusive land development, through public institutions strengthening, economic alternatives, and social participation increase; considering traditional cultures preservation and environmental conservation.

**Projects**

Within the main projects included in the four axes action plans, we highlight the following:

Project Office (Gabinete de Projetos)

The aim here is to instruct municipal administration consultants who may elaborate, execute, evaluate and conduct management plans within the city councils, especially those focusing in stablishing agreements with other public administration spheres, such as the federal government. Through this, we expect an increase in the fund-raising ability for other programs and policies in the area.

Sectorial Plans (Planos Setoriais)

Based on the primary assessment and analyzing the area´s background, we can design municipal sectorial plans regarding health, education, social work, and others areas. The “Planos Setoriais” are designed by different offices and secretaries and approved by the local advisory boards.

Through them, the public administration can work on specific action plans to each local office and approve them with the civil society, making governmental action more focused and effective.

Management on the sight (Gestão a Vista)

The "Gestão à vista" project aims at making public administration data easily and efficiently accessible. Through the use of infographics we can provide sectorial action plans synthesized information and public administration key areas specific indicators accessible to all civil servants´ boards. The aim here is to connect the city council´s daily activities with the outcomes of all completed actions (also directly generating the servant´s engagement to their own work). Also, we aim at making public administration commitments open and visible to all, speeding up changes in the servant´s routines improving the quality of services with clear managing agreements.

Citizenship and Government School (Escola de Governo e Cidadania)

Through "Escola de Governo and Cidadania" we want to build an institutional area for civil servants**,** board advisors, and local leaders professional and personal development; aiming at promoting social participation as well as improving public service qualification in public policies designing, upgrading civil servants and local communities quality of life.

The main differential of this proposal is a pedagogic frame based on public service real lives´ situations. The school will work as a managing committee in which participants will be able to get trainings in topics of local public administration interest, such as public management, human resources, economic development, public finances management and health care.

Faro and Terra Santa Public Management System (Sistema de Gestao Publica Ambiental em Faro e Terra Santa)

Since 2011, a complementing state law defines the municipal competencies towards main environmental control activities stablishing tools to a cooperative work and shared responsibilities among municipalities, states and the Union. Some of these tools are: implementation of the environmental municipal fund; designing the environmental municipal council; certificating professionals that can issue environmental permits and administrative sanctions; designing an urban development and environmental management plan.

Faro has an environmental office with six employees. In 2010 the environmental municipal board was stablished, but they have never met or discussed any of the local environmental issues. In the same year the environmental municipal fund was created, but it has no funds. The municipality does not have its own environmental policies or laws and its specific urban development and environmental management plan is outdated. Terra Santa environmental office called SEMMA has four employees. The municipality does not have an advisory board or environmental fund. However its urban development and environmental management plan was made in 2006.

The environmental local offices of Faro and Terra Santa will receive technical assistance in order to obtain a certification with the State Environmental Office. With this certificate the environmental offices will be able to monitor related activities and issue permits reducing environmental irregularities within their areas.

## INDICATORS MONITORING

The outcomes of each predicted goal are being monitored by specific management indicators that gather a specific board panel especially created to meet PTS´ needs.

Additionally, the advances in land sustainable integrated development expected in a 15-year time lapse will be monitored by the Social Progress Index of Amazonia and Sustainable Development Goals.

The Social Progress Index (SPI) measures 54 social and environmental indicators to get a global perspective of the nations´ environmental and social performance. It analyses more than the economic development. The index was created in 2013 by Social Progress Imperative, in an process that relied on the help of several researchers and world experts in public policies, taking into account that all development measures based only in economic indicators are insufficient, since economic growth without social growth leads to social exclusion, conflicts, dissatisfaction and environmental degradation.

SPI was originally proposed on a global scale, however, since its creation in 2013, different national and subnational initiatives are arising, mainly in Latin-American countries as Brazil, Paraguay, Costa Rica, Chile, Colombia, Peru, Trinidad and Tobago and El Salvador. The index evaluates three development dimensions. The first dimension is “basic human needs” which evaluates if a country and/or region has conditions to meet its community essential needs. This dimension measures if the population has enough food, basic health care, drinkable water access, and if housing and basic sanitation are assured.

The second dimension “well-being principals” measures if the community is allowed to have good health, well-being and good quality of life. This dimension also evaluates if the society can environmental sustainably live and if it is assuring natural resources protection for future generations.

Lastly, the third dimension “opportunities”, measures if the community has any restrictions to its own legal rights and if a person is able to make decisions alone, also it measures prejudice and hostilities that might prevent a person of achieving full potential. This dimension includes high education degree in the Amazon area, as advanced knowledge and abilities may bring better job opportunities.

The sustainable development goals are part of the United Nation Organization (UNO) development 2030 agenda and they include 17 main goals divided in 169 tasks based on the UNO Millennium Development Goals (MDG), focusing on targeting what was not accomplished. The goals seek to solidify human rights for all and to reach gender equality by empowering women and girls around the world. They are integrated and indivisible, and balance the three dimensions of sustainable development: economic, social and environmental. Although globally applicable, the goals are linked to regional policies and action plans proposing governors, local managers and entrepreneurs as key players.

Monitoring the advance and impacts of these goals will enable us to make necessary adjustments and may have an impact on our decision making processes.

## PRIMARY RESULTS

In PTS´first year (2015), the main goal was to better understand the local context and to make agreements enabling solid action plans design in long term operations where all local stakeholders understand their shared responsibilities in the land sustainable development. Therefore, the program relied on the work of many Brazilian professionals who have dedicated 15 thousand hours in fieldwork, working on assessment and action plans in all of the four mentioned axes. We highlight here the main outcomes of this work.

**Public management axis**

- Engagement of 30 local leaders (public sector) and civil society representatives;
- Organization of workshops reading indicators and public management, setting up 67 public management indicators in each of the three municipalities;
- Definition of a support team to design Oriximina´s directive plan and include all data regarding indigenous and quilombolas communities.
- Local treasury and financial offices support in financial contract management.

**Social Capital Axis**

- Qualification plans that included 82 local associations and municipal advisory board, reaching out to a total of 24.500 associates within the three municipalities, representing 70% of the area´s civil society institutions;
- Eight meetings with the traditional communities association representatives;
- Assistance provided to 100% of Oriximina quilombola associations (9 in total) tackling the contract regularization and mitigating taxes debts;
- Definition of 15 result indicators and 4 impact indicators;
- 250 hours of interviews with local leaders and civil society representatives and 350 hours of local leaders training, which included 150 people;
- Partnership with Google company in the "traditional people and new technology" program providing trainings at Trombetas area in 2016 and 2017.
- Structuring women workers association in Oriximina with an action plan extending its activities to Terra Santa and Faro, this program was held in partnership with Indigenous Women of Oriximina Municipality Area Association.

**Economic Development Axis**

- Application of 223 surveys aiming at mapping the main productive chains of all three municipalities (logging, Brazil nut extraction, copaiba extraction, tourism, farming, fishing and cattle breeding);
- Assessment and action plans designing for all mentioned productive chains, involving 18 organizations;
- Designing a public use plan for Faro.

**Environmental Management Axis**

- Local environmental management assessment pinpointing the potential to raise the municipal revenue in approximately 20 million reais/year in all three municipalities combined (around 5 million American dollars)
- Institutional mapping and guidelines designing for the municipal environmental advisory board of Terra Santa.
- Support of the inclusion of Terra Santa in the "Para Government Green Municipalities Program", in which computers and vehicles will be available to help prevent deforestation actions.
- Municipal public finances, taxing public policies and social participation trainings held in Oriximina, Terra Santa and Faro.
- Local offices environmental management plan assessment.
- Designing of a training course for the environmental advisory board members of Oriximina, Terra Santa and Faro.

## DISCUSSION

Development is an outcome made through clear choices that broaden the possibilities of reaching the expected future goals. Therefore, it requires participative planning and shared management of all projects that focus in the sustainability of each specific area.

The state is a key player in promoting sustainable development; hence its isolated action is not enough. State, market and community interests need to converge in order to allow sustainable development in any area, especially when we consider a region with such complex socio-economics interactions as the Amazon.

The local municipalities are directed linked with their environmental and natural resources which must be respected and preserved. At the same time, the region´s social and economic development relies on private investments. In this scenario, the implementation of an integrated management plan demands the encouragement and strengthening of all stakeholders (public sector, civil society, traditional and urban communities).

When this stakeholders´ interaction is fragile or not efficient, measures to upgrade public management and social participation need to be applied. In this case, it is important to empower public managers so that the local public policies can be based on a land wider vision that benefits all the involved communities, including the private sector. Besides, improved municipal, state and federal policies integration is necessary in order to promote land development.

Another important aspect that can provide an efficient land development strategy is amplifying competent social participation by strengthening municipal advisory boards, local associations and other decision making spaces. In this way, governments and civil society can develop more democratic and efficient public policies, promoting an accurate land sustainable development which respects both the local cultures and the environmental.

## CONCLUSIONS AND ACKNOWLEDGEMENTS

PTS focuses on a long term strategic land development based on the facts previously described. The outcomes reached up to now reassure us that we are in the right path, even if the program is very new. The methodology also is based on the executives' organization expertise and their successful case studies. We are aware that there is a lot to be done, but we highlighted here some of our most successful features observed throughout this first year of project implementation.

A great amount of local development projects in Brazil are carried out within political offices and promote a very limited social participation of the affected communities. The same happens in corporates social responsibilities' projects. In PTS we aimed at strengthening and promoting stakeholders interconnections including Oriximina, Faro and Terra Santa social agents and institutions.

The macro-stage concluded in 2015 (Assessment and Agreements) brought an important support to the program execution, setting priorities and commitments. At the same time, civil society organizations strengthening and increase of participation will bring power balance and, in a long term, it will broaden the area´s social capital, combining the action plans to the local demand and reality.

While sustainability traditional view is based on three main pillars, economy, society and environmental, we believe that land development must also include an institutional-politic pillar within predicted goals and outcomes. We understand that high standard operating public institutions are crucial to sustainable development and that only a long term integrated action plan can bring solutions to the complex challenges of the Amazon region.

Most importantly, the private sector role in social and environmental responsible actions is still very limited, even when funds are available. Because of that, we chose an innovative initiative that combines the expertise of three non-governmental institutions and a large private corporation´s economic strength in order to design an integrated development strategy for Trombetas area. We are aware that there are great challenges in the coming 14 years, but as great is our potential to effectively contribute to a successful future to the area as well as designing an integrated regional development methodology that can be monitored and repeated in other areas around the Amazon region.

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# THE CHALLENGE FOR ACHIEVING SUSTAINABLE DEVELOPMENT THROUGH RESPONSIBLE SMALL-SCALE MINING IN INDIGENOUS AREAS IN BRAZIL

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# THE CHALLENGE FOR ACHIEVING SUSTAINABLE DEVELOPMENT THROUGH RESPONSIBLE SMALL-SCALE MINING IN INDIGENOUS AREAS IN BRAZIL


## ABSTRACT

This paper discusses the issue of responsible small-scale mining within indigenous territories in Brazil, based on the preliminary findings of an on-going research carried out in the northwestern part of the Amazon region, in Brazil. The region concentrates the largest indigenous population of the country and includes three major linguistic branches (Aruak, Tukano and Maku) with over 23 ethnic groups, centered in the town of São Gabriel da Cachoeira. Subsistence issues affect these communities as it appears that the assistance provided by the current social and environmental programs is not sufficient to reach all communities, in particular, those located in more remote areas. In terms of the current legislation, the Brazilian Constitution of 1988 establishes that the authorization for any mining initiative within indigenous areas must have specific approval by the National Congress. In order to address this issue, the local indigenous communities have organized themselves as an indigenous cooperative called CIERNM to seek common grounds and legal mechanisms to advance towards sustainable development of the communities. The proposal of CIERNM is to achieve social development through properly managed actions focused on social, environmental, cultural and economic responsibility. Hence, responsible small-scale mining has been identified as one of the main vectors for achieving sustainable development in the communities due to the known mineral occurrences in the region, which include gems, base metals and precious metals. The article reports the preliminary findings of the research, including contacts performed by CIERNM with local, regional and federal authorities, agencies and universities to build a persuasive project to carry out responsible small-scale mining in the area. The results also include the proposed approach with the recommended steps to obtain the necessary approval by the National Congress and other authorities as established by the current legislation.



## KEYWORDS

Amazonas, Responsible Mining, Small-Scale Mining, Indigenous Lands, Sustainable Development


## INTRODUCTION

The county of São Gabriel da Cachoeira is located in Brazil extreme northwest, state of Amazonas. To the north is limited to Colombia and Venezuela, to the south and east is the county of Santa Isabel do Rio Negro, and to the south is the county of Japurá. The region is known as "Dog's Head" due to the geographic format and has the highest concentration of indigenous population in the Brazilian territory, estimated in 43,094 inhabitants in 2015 by the Brazilian Institute of Geography and Statistics (IBGE). Approximately 20 thousand of them live in São Gabriel da Cachoeira and 25 thousand live in villages along the main riverbanks, according to information provided by Major Pontes from the 2$^{nd}$ Jungle Infantary Brigade of the Brazilian Army. The main linguistic branches are aruak, tukano and maku, summing up to 23 ethnicities, each of them with its own language spoken by the majority of the population (being 75% indigenous).

The history in the region has records since the missionaries' entry, especially the Salesians. The initial tripod of their goals was education, catechism and health. Education because there was the concern the natives were not deceived by *batelões* (name given to the traders from that time that used barges), catechism because that was the main reason of missions, and health as there was the need to aid both natives and missionaries against tropical deceases.

After the Federal Constitution was promulgated in 1988, Indigenous Lands were demarcated in the Dog's Head region as a result from continuous claims by the indigenous movement supported by non-governmental organizations. With that started the search for political and economic sustainability in the region, mining has been a more constant subject to be debated among natives through representative political organizations such as the Federation of the Negro River Indigenous Organization (FOIRN), as well as official bodies like the State of Amazonas Legislature, and Secretary for Indigenous Affairs (SEIND). Nevertheless, prior negative experiences, e.g. the Traíra Ridge in the Tiquié River, and the Porcos Ridge in the high Içana River, are often highlighted and cause distrust among the interested parts.

In many cases, discussions about the subject were pointed out by the indigenous living in the city, arising mistrust by the natives living in the Indigenous Lands. It is in the middle of this argumentation that the Indigenous Cooperative for Natural Resources and Minerals Extraction (CIERNM) was created to bring together natives from the Indigenous Lands that want – among other lines of action – to develop the exploration of mineral resources focusing on responsible small-scale mining. It is expected this approach to be a possible vector for social and economic development, and being done under the legal requirements it will guarantee better basic life quality to the peoples in the region, also being a lever to achieve further sustainability policies.

Searching for support on the feasibility of the cooperative's goal has been a challenge towards official bodies, political agents and local universities. Mining subjects are always faced as harmful to the environment enforced by the fact the initiative comes from native indigenous peoples organized in a cooperative that reside in Indigenous Lands, which causes weirdness to the existing organizations in governmental and non-governmental spheres.

## METHODOLOGY

This paper is based on information collected by the Indigenous Cooperative for Natural Resources and Minerals Extraction (CIERNM), located in São Gabriel da Cachoeira, in partnership with USP Center for Responsible Mining (NAP.Mineracao). The methodology being presented is based on the information collected by legal instruments that regulate mining in indigenous territories in Brazil, and the research is based in the responsible mining concept with a consistent strategic planning.

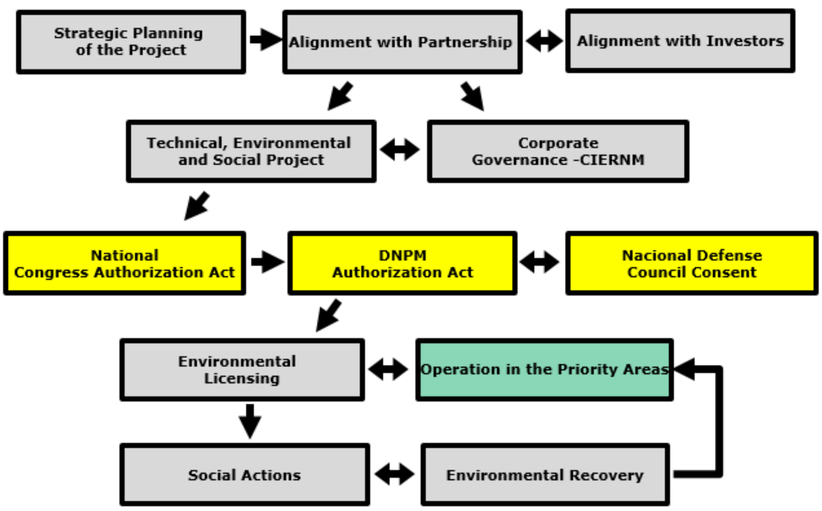


Figure 1 – Proposed methodology for implementation of responsible mining in indigenous lands

In the historical context, Brazil has adopted a new Federal Constitution in 1988 and recognized the cultural plurality of indigenous peoples. The new constitutions have also granted them the right to permanent lands (Paixao, Hespanha, Ghawana, Carneiro, Zevenbergen & Frederico, 2015).

The Constitution of the Federative Republic of Brazil (Brazil, 1988), defines in the Article 231:

Paragraph 1. Lands traditionally occupied by Indians are those on which they live on a permanent basis, those used for their productive activities, those indispensable to the preservation of the environmental resources necessary for their well-being and for their physical and cultural reproduction, according to their uses, customs and traditions.

Paragraph 2. The lands traditionally occupied by Indians are intended for their permanent possession and they shall have the exclusive usufruct of the riches of the soil, the rivers and the lakes existing therein.

Paragraph 3. Hydric resources, including energetic potentials, may only be exploited, and mineral riches in Indian land may only be prospected and mined with the authorization of the National Congress, after hearing the communities involved, and the participation in the results of such mining shall be ensured to them, as set forth by law.

As the Statute of Indians (indigenous people, as referred in the Constitution) was stablished (Law n. 6,001, from December 19th, 1973), it defines that federal lands can be delimitated in any part of the territory, being their possession and occupation by indigenous groups recognized. Afterwards, it was created the National Indian Foundation (FUNAI) that is active until today and holds the responsibility to promote and protect the indigenous peoples and guarantee the protection of indigenous lands (Paixao et al. 2015). FUNAI also develops national strategies related to the lifestyle, development and integration of the groups to the society Paixao et al., 2015).

Paixao et al. (2015) quotes the division of areas reserved to indigenous tribes as it is described in the Law n. 6001/73, as follows:

a) Indigenous Reserve – An area to be used as the habitat of indigenous groups, having the sufficient means of subsistence.

b) Indigenous Park – Area under indigenous possession, in which their degree of integration allows Federal assistance in economic, educational and health means, while preserving flora, fauna, and the natural landscape of the region.

c) Indigenous Agricultural Colony – Area used for the development of agricultural exploration (farming and livestock), administered by the indigenous affairs organization (presently, FUNAI). These colonies have a mixed settlement of indigenous groups and non-indigenous individuals.

d) Indigenous Federal Territory – It is an administrative unit directly under Federal Administration of the Brazilian Union. It is required that, within this unit, at least a third of the population is indigenous.

Even though the indigenous peoples have guaranteed the possession and use of rivers, lakes and soil, it is forbidden for them to explore hydric and mineral resources; only the National Congress can authorize mining initiatives in indigenous lands, securing their rights to participate in the profits (Fernandes, Alamino & Araujo, 2014; Brazil, 1988).

With the growing international recognition of indigenous rights, changes in corporation policies being done mainly by international indigenous organizations, and a greater coverage of the indigenous peoples political capability, the juridical and political context is being renewed for mineral extractive industries (Nygaard, 2016). In a positive perspective, countries as Canada, Australia, Colombia, Nicaragua and Philippines are ahead in the recognition process of indigenous legal rights (O'Faircheallaigh, 2013). However, the extraction of mineral goods in indigenous lands creates doubts and controversies. The indigenous peoples deal with the social, cultural and environmental consequences, but have no financial compensation or return (Nygaard, 2016).

Amazon is the greatest rain forest in the world, with a rich biome with multiple characteristics. A great part of the forest is in border areas. Starting in the 70's, under the military regime, the economic expansion boosted the northern region of Brazil and directly affected the Amazon with deforestation and invasion to indigenous areas (Paixao et al., 2015).

According to statistical data from IBGE, approximately 896,917 people declare themselves as indigenous peoples, divided in 305 ethnical groups and 274 different languages. From the total indigenous population officially recognized by the government, almost 517 thousand (57.7%) live in indigenous lands, among them 94.9% live in rural areas; around 379 thousand (42.3%) live outside the indigenous lands, and 78.7% of them live in the urban area (Paixao et al., 2015; IBGE, 2010).

**National Congress Authorization**

According to Villas Bôas (2013), the extraction of mineral goods in indigenous lands is legally possible after authorized by the National Congress, highlighting the participation of indigenous in the mining results, as disposed in the law.

Due to the lack of regulation concerning the participation of indigenous communities in the mining results, it cannot be granted mining titles in indigenous lands, because it lacks the presupposed authorization of its validity (Villas Bôas, 2013).

**National Department of Mineral Production (DNPM) Authorization**

An important fact to be highlighted is that when the Federal Constitution assigned the authorization for mining in indigenous lands to the National Congress, it was taken from DNPM the decision power concerning the subject. Therefore, the institution with powers to decide whether research or mining works can be done in indigenous lands or not is the National Congress alone (Curi, 2007).

**National Defense Council Consent**

The Law n. 6,634, from 1979, regulates the extraction of mineral goods in border areas of the country. For it to be approved it is necessary a prior consent by the National Defense Council. The constituent predicted special treatment to the mineral activity in border areas, due to its importance to national defense (Villas Bôas, 2013).

**Responsible Mining in Indigenous Lands**

As any other industrial activity, mining activities work with the goal to supply social demand. However, mining finds its raw materials directly from nature, what characterizes it as an essentially extractive industry. Accordingly, besides being concerned about political-economic factors inherent to any production process, mining also has to develop its activities with greater care, as it directly deals with nature and ecosystems.

According to Vale (2002), the concept of mining and sustainable development is related to a development model that meets the need of the current generation without compromising the conditions of future generations to use mineral resources.

The responsible small-scale mining project in indigenous lands is not associated to expectations for radical and instantaneous changes in the local community life. What is expected is a continuous process for better conditions in education, infrastructure, transportation, health and social development, committed to practical results.

Responsible Mining in Indigenous Lands represents an initiative that is needed and indispensable to consolidate methods, procedures and processes that allow local operations to be developed as responsible small-scale mines. It should involve all the community, focusing in the associates of CIERNM in the decision making process in a way to discuss and clarify all the challenges, demands, needs and limitations involved.

The preservation of environmental resources in indigenous lands is fundamental to guarantee the survival of their future generations, as well as to maintain the possession and control of the activities and projects developed on the hands of the indigenous communities (Paixao et al., 2015; ISA, 2000). Indigenous groups must promote economic and environmental sustainability, not being depended in any third parties to do it (Paixao et al., 2015).

According to Paixao et al. (2015), the regularization of indigenous lands is a slow and bureaucratic process. Beyond an economic perspective, mineral extraction in indigenous lands needs a perspective that reflects the ethnic aspects related to the environment, society and groups that will be affected by the mining activity (Ribeiro, 2015).

## DISCUSSION

CIERNM was founded on February 28th, 2015 constituted by exclusively indigenous associates. As illustrated in Figure 2 the office is located in the county of São Gabriel da Cachoeira, due to the convergent flux of rivers to that geographic location. The intention behind its creation was to add incentives to the existing organized movements to the socioeconomic sustainable development of indigenous peoples cooperated through the extraction and commerce of natural and mineral resources where they live.

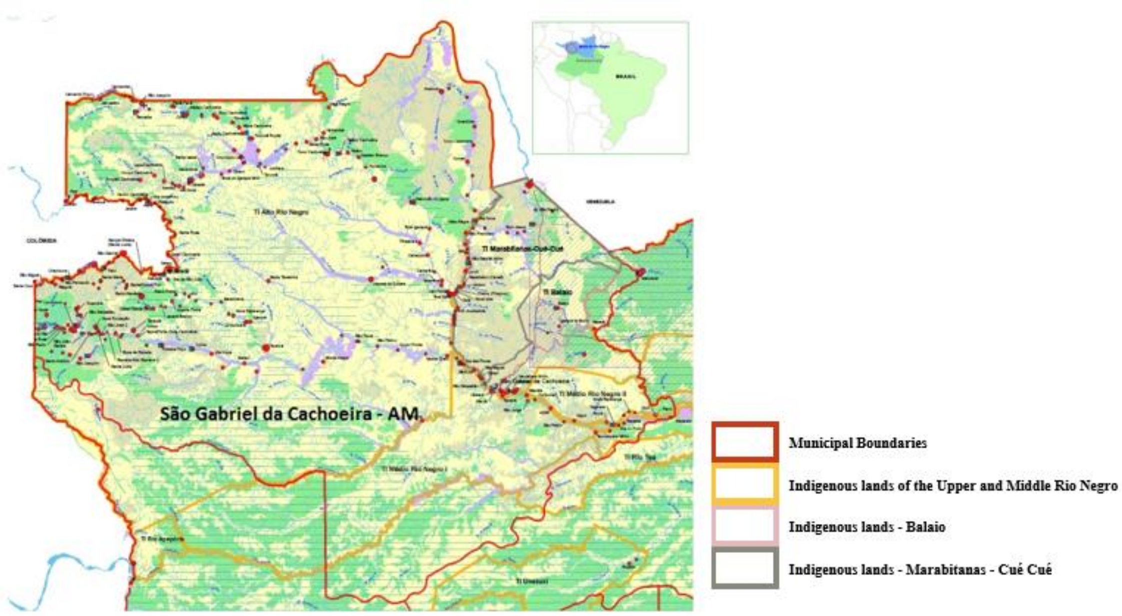


Figure 2 – Map of the city of São Gabriel da Cachoeira – AM    ISA (2006)

It is understandable that those activities will ensure the permanence of indigenous families in their communities as labor activities will be provided. Furthermore, they will aid in the maintenance of borders and will cooperate in the national sovereignty. The initiative has received a prior assent from the National Defense Council in an act dated to June 26th, 2015 and published on the Official Gazette, n. 121 from June 29th, 2015.

### National Congress

The National Congress performs the national legislature, and is composed by the Deputies Chamber and the Senate. The Deputies Chamber is divided in several fronts, each formed by deputies who defend common interests, forming the so-called benches. Leaders who have an important role in the decisions taken by the Congress lead the benches; they gather to set the voting agenda of the Plenary and guide members in the most controversial votes and of great interest (Alves, 2012).

Alves (2012) states that is possible to notice that what there is more are leaders in the Congress. Being so, these parliamentary benches of different branches act following the interests of the sponsors of their campaigns. The deputies seek their leader’s cooperation so they can do and defend their work and interests.

**Bill 1,610/96 – Exploration of Resources in Indigenous Lands**

The subject of mining in indigenous lands was discussed in debates during the elaboration of the Federal Constitution of 1988 and there was a mobilization of parliamentary benches to defend their interests. The approved text exposes the conditions required for the regularization of research works and future mining rights in indigenous areas. Those conditions are set in the Articles 176 and 231.

The Deputies Chamber resumed discussions concerning the subject taking into account the Bill 1,610/96. It aims to regulate a paragraph in Articles 176 and 231, and is still in course in the house.

The main concern is not whether the mining activity should or should not be regulated, but the interests of the congressional representatives that are in front of the discussion. In addition, it is important to avoid the untying of the matter from other subjects in debate, such as the Mining Code and the Indigenous Peoples Statute that are directly linked with the issue of mining in indigenous lands. Finally, subjects that are directly related and that should not be treated separately and in different times (Raisa, 2010).

According to publications by Greenpeace (2015), Bill 1,610/96 is a farmer's bench demand over the rights of indigenous peoples, as well as the Constitutional Amendment Bill (PEC) 215 that wants to change the power to determine indigenous, *quilombola*, conservation unit lands from the Executive (government) to the Legislature. Going against this interest, the Senate has already positioned itself against the approval of PEC 215.

**Mining Interests in Indigenous Lands**

According to DNPM, an area of mining interest within indigenous lands is defined when its polygon is entirely inserted in an indigenous area. Even though such areas may still be in stage of exploration, DNPM does not address any type of evaluation on the process. Therefore, the mining interests are merely speculative, working only as an expectation for the individual right (Curi, 2007). These interests started in the 80's by companies with a perspective of a future constitutional authorization to remove the principle of nullity of Paragraph 3 of Article 231.

The mining interests, when filed at DNPM, are put under a standstill condition. In practice, this means the process will be archived without a technical evaluation.


Figure 3 – Filed requests at DNPM in indigenus lands DNPM (2016)

As illustrated in Figure 3 the mineral rights polygons in yellow and the indigenous land in the Dog's Head region in red. These mining interests grant no individual right to the interested part, but only an expectation of right.

**Community Consultation**

A constitutional requirement form the mining authorization in indigenous lands is the consultation of the indigenous communities affected by the possibility of mineral exploration in their lands. Despite references made in the Federal Constitution and the Bill concerning prior consultations, how it should be done is not specified or regulated, granting the Congress the duty to evaluate it when done. While the consultation is made, it is important to listen all the affected community; this is established in the Article 231 from the Constitution and aims to secure the participation of indigenous communities in the decision making process of economic projects to be developed in their lands, and to categorically investigate the impacts undertaken by the community (Curi, 2007).

It must be emphasized that the consultation should not be performed to the bodies representing the indigenous peoples interests, e.g. FUNAI, but exclusively to the indigenous natives in the affected areas.

In addition to the prior consultation, it is also foreseen in the Article 231 the participation of indigenous peoples in the economic results from the mineral exploration in theirs lands. On PEC 215, it is planned a minimal participation of communities over the economic results.

It is important to highlight the need of technical and legal elements that assure broad security to the rights of indigenous peoples, their participation in the decision making process, and a fair and clean participation in the mining results, as expected in the Federal Constitution. From the imposition in the Constitution, there is no doubt that only the National Congress has the power to provide authorization for mining, and the indigenous communities affected must be consulted and their right to participate in the economic results secured and assured. Therefore, the discussion of this subject demands several debates with the indigenous peoples that must have active vote in the decision taken in the regulation process.

## FINAL CONSIDERATIONS

CIERNM ordinary meetings are always based on the context of the county of São Gabriel da Cachoeira that covers a great part of the indigenous lands, which is not adequate to the surviving of indigenous peoples because it lacks a proper economic identity. The municipality survives solemnly by resources from official governmental programs.

The proposal of the small-scale sustainable mining sets as possible vector towards economic and social development in the area. With the legal requirements taken into account, the proposal can acts as a support to enforce further sustainability policies. Special attention towards the governmental control entities should be taken since the proposal is pointed to be the basis for future policies in the field. Only through its proper execution, monitoring, and observation through own governances will demonstrate the driving importance of the act for sustainability in indigenous lands and effecting the constitutional dictum.

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# THE DEVELOPMENT OF A HANDBOOK ON BEST PRACTICES FOR LIMESTONE MINING IN KARST AREAS

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# The Development of a Handbook on Best Practices for Limestone Mining in Karst Areas

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**Abstract**

The Guide on Best Practices for Mining Limestone in Karst Areas ("Guide") is one of the products developed under a partnership agreement among Votorantim Cimentos (VC), a global cement company, and two environmental conservation organizations, namely, the Sociedade Brasileira de Espeleologia (SBE) and the Instituto Amigos da Reserva da Biosfera da Mata Atlântica (RBMA). The objectives of the Guide are as follows: (1) provide summarized information on karst environments, their formation processes, their ecological and evolutionary importance and their role as a provider of resources and services to society, and (2) contribute to raising awareness among mining professionals concerning the importance and vulnerability of karst environments. This paper describes the process of developing the Guide and summarizes its content and form of presentation. The process of developing the Guide involved the participation of experts working in a variety of fields, including those with professional and academic experience. The overall goal was to prepare a set of recommendations that could help mining companies to mitigate the impacts of their activities on the natural resources of karst areas and the communities living in them. The development process consisted of nine stages of work activities: definition of the topics to be addressed in the Guide; technical visit to a limestone mine; three workshops involving the SBE-VC-RBMA Technical Cooperation coordination team and the invited experts; presentations of the Guide contents at two national congresses on speleology and mining respectively; a round of consultations with Votorantim Cimentos' technical professionals; and a round of public consultations that were open to all interested parties. The resulting product was a document consisting of an introduction and three main sections. Section 1, "Karst area, a special kind of environment," summarizes the main characteristics of these environments, their formation, and their role as a provider of resources and services for society, in order to understand their vulnerability and their importance when planning anthropogenic [human] activities. Section 2, "The study of karst areas, as the basis for planning," addresses topics such as karst geo-systems, caves, biodiversity in karst areas, underground biology, paleontology, archeology and sustainable community development, aiming to provide a theoretical basis for the best practices to be presented in the following section. Finally, Section 3 presents recommendations on best practices that are designed to prevent and mitigate the adverse environmental and social impacts arising from limestone mining in karst areas. They are presented in the order of the stages of a mine's life-cycle, as follows: feasibility studies, implementation, operations, decommissioning and post-closure. The practices are presented in summary tables according to each stage of a mine's life-cycle and each of the seven thematic areas covered by this Guide. The tables are structured around three key questions: *What to do? Why do it? How to do it? (examples).* This resulted in a total number or 114 best practices, of which 47 were related to feasibility studies, 29 to implementation, 27 to operations, 8 to decommissioning and 3 to post-closure.

**Keywords**

Best Practices, Mining, Karst Areas

## Introduction

Meeting regulatory requirements and society's expectations regarding the protection of caves and karst landscapes are key challenges for companies which use limestone as their main raw material. This paper presents a best practices Guide for companies in these situations. It was developed under a partnership among a cement company and two environmental conservation organizations.

Aiming at contributing to the dissemination of best practices, the Guide of Best Practices in Limestone Mining in Karst Areas was developed under a partnership between Votorantim Cimentos, a global cement company with its head-office in Brazil, and the Sociedade Brasileira de Espeleologia (SBE) and the Instituto Amigos da Reserva da Biosfera da Mata Atlântica (RBMA).

Votorantim Cimentos, a subsidiary of a large industrial conglomerate, is a building materials company, producing cement, concrete, aggregates and mortar. It was founded in 1933, and today is one of the largest companies in its sector in the world. In 2014, it had a cement production capacity of 54.5 million metric tons/year and revenues of R$ 12.9 billion, and has a presence in the following 14 countries: Argentina, Bolivia, Brazil, Canada, Chile, China, India, Morocco, Peru, Spain, Tunisia, Turkey, the United States and Uruguay.

The Sociedade Brasileira de Espeleologia (SBE), which was founded in 1969, is an organization which represents individuals and groups interested in caving, in the whole of Brazil, and has a strong focus on the conservation of caves and their environments. The Instituto Amigos da Reserva da Biosfera da Mata Atlântica (RBMA) is a civil society organization founded in 1999.

Despite often having conflicting interests, it was possible for the three organizations, through a process of dialogue, to find ways to address the challenges of mining in limestone areas, where the vast majority of caves are located, in order to optimize the greatest benefit for each organization and minimize the negative impacts of mining activities. The partnership is developing, implementing and disseminating best practices and social and environmental projects related to mining in limestone areas, and the areas surrounding protected areas, as well as in other areas in the Atlantic Forest, in order to contribute to conserving biodiversity and protecting speleological heritage sites.

Within the general scope of this mandate, the three partners agreed to develop a document summarizing the best practices for limestone mining in karst areas. SBE invited practitioners and researchers who were experts in karst environments to share their experiences and provide practical recommendations and the scientific foundations for a precautionary approach to mining in karst areas.

The objectives of the Guide are as follows: (1) provide condensed information on karst environments, their formation, their ecological and evolutionary importance and their role as a provider of resources and services to society, and (2) contribute to raising awareness among mining professionals concerning the importance and vulnerability of karst environments.

The adoption of the Guide's recommendations by mining companies is expected to increase the degree of adherence of each of their operations in relation to best industry practices. Thus, it is expected that such adoption will contribute to:

- The company's degree of legitimacy in obtaining and maintaining its social license to operate
- The incorporation of karst protection objectives in the company's policies, procedures and management controls
- The implementation of best practices in mining management in karst areas
- An improvement in the quality of environmental studies in karst areas

- A reduction in the company's risks in relation to (i) causing irreparable environmental damage due to lack of knowledge or insufficient precautions, (ii) having its reputation adversely affected (image risk)
- Enabling future generations to have access to, and benefit from, the resources and services provided by karst environments.

The mining sector is increasingly aware that compliance with legal requirements, generation of jobs and payment of taxes represent only a fraction of the actions that are necessary for companies to be well received by the communities where they operate. The social license to operate is becoming a vital factor in ensuring the viability and permanence of mining in areas endowed with mineral resources. Moreover, business risks increase when social acceptability decreases.

The Guide provides guidance for the planning and implementing of effective practices to mitigate environmental impacts in karst areas. It also contributes to increasing the understanding of the nature and importance of karst environments, and the main impacts of mining activities on these areas themselves and on the human populations who live in them.

**Guide preparation process**

The Guide preparation process consisted of the sequential stages summarized in Table 1. The core team was composed of seven experts, one technical coordinator and an executive coordinator. The themes addressed by the invited experts were as follows: karst systems, caves and physical speleology, underground fauna, biodiversity, paleontology, archeology and local communities and development.

Other guides with similar scope, either on limestone mining or on karst areas, were used as initial reference sources to help with the definition of the main themes to be addressed . The most important references were the following: Biodiversity management in the cement and aggregates sector - Integrated Biodiversity Management System (IBMS) (IUCN, 2014), Guide on best practices for the environmental rehabilitation of quarries and limestone mines (Neri and Sánchez, 2012), Guide on mine closure planning (Sánchez et al, 2013), Guidelines for cave and karst area protection (WCPA and IUCN, 1997), Karst management handbook for British Columbia (British Columbia, Ministry of Forests, 2003), Biodiversity Management System (IUCN, 2010), Life and water on karst. Monitoring of trans-boundary water resources in Northern Istria (Haina et al. 2015). It should be noted that most publications on best practices deal with the issues related either to extractive activities (e.g. biodiversity, land rehabilitation, closure planning) or to the karst system (e.g. management of the karst system) without correlating the two types of issues. This indicates that the newly developedGuide not only provides recommendations that can help mining companies to mitigate the impacts of their activities on the resources and communities living in karst areas, but also fills a gap in the knowledge contained in the existing guides.

Based on this finding, SBE-VC-RBMA Technical Cooperation coordinators, with the support of the technical coordinator, defined the themes to be addressed in the Guide. This then guided the choice of the experts to be invited to join the work team. From the beginning, it was understood that it would not be sufficient merely to provide a description of the best practices. The intention was to address the themes in a systemic way and to ensure they would provide a robust theoretical basis for the recommendations on best practices. This was a fundamental premise in preparing the Guide, since, in order for it to achieve its desired objectives, it was essential to present a review of knowledege for each best practice, so that the reader would be able to understand them and adapt the recommendations them to his/her actual problems, considering that each mine has its own characteristics and that the Guide was not intended to be prescriptive in nature, but to provide reasoned guidance.

The 1st workshop brought together the experts in each subject and SBE-VC-RBMA Technical Cooperation team and took place at Votorantim Cimento's head-office. The aims were to agree on the objectives of the work to be carried out, the form of presentation of the content, the terms to be used, in particular in relation to aspects of mining activity, such as the stages of the mine's life-cycle. Since there was not always a consensus on the use of these terms, it was essential to make clear our understanding of the terms used in the Guide, right from the beginning. As a result of the 1st workshop, the main themes and questions to be addressed were defined, considering the principles underlying the purpose of the Guide and the experience and expertise of each author. In addition, the experts were made aware that the recommendations should be grounded on the state-of-knowledge about karst systems, their ecosystems and human communities, and that they had the challenging mission of conveying complex information to non-specialist readers.

| Stages | Objectives |
|---|---|
| Definition of the themes to be addressed in the Guide | Definition of the themes and approaches in the Guide, carried out by the SBE-VC-RBMA Technical Cooperation coordinators. Subsequently, this was adjusted in conjunction with the project's technical coordinator |
| 1st workshop with experts for each theme and representatives from Votorantim Cimentos | Alignment of the work program and clarification of the contributions expected from each participant |
| Technical visit to an operating limestone mine | Understanding the operation of one of the sponsoring company's mines |
| 2nd workshop with experts for each theme and representatives from Votorantim Cimentos | Integrate the various themes covered in the Guide and facilitate the participation of the company's mining technicians in order to identify specific problems and questions on its preliminary content. |
| Presentations of a draft of the Guide at the 33rd Brazilian Speleology Congress (15th to 19th of July, 2015) and the 16th Brazilian Mining Congress (14th to 7th of September, 2015) | Present the project respectively to the speleological community and to mining professionals and obtain feedback |
| 3rd workshop with experts for each theme and representatives from Votorantim Cimentos | Adjust technical aspects in order to finalize the Guide |
| Round of consultations with Votorantim Cimentos' technical staff (1st of December 2015 to 18th January 2016) | Obtain feedback from the intended primary users of the Guide, identify gaps and check the appropriateness of the recommendations under the perspective of mining professionals |
| Round of consultations open to all interested parties (1st of December 2015 to 18th January 2016) | Obtain feedback from stakeholders and potential users of the Guide, identify gaps and check the appropriateness of the recommendations under multiple perspectives |

Table 1 - Stages in the process of developing the Guide

In order to align the understanding of limestone mining activities by the experts, some of them not being familiar with mining, a technical visit to Rio Branco do Sul site of Votorantim Cimentos, located in Paraná State was conducted. The visit involved the operating unit's technical professionals, the SBE-VC-RBMA Technical Cooperation team and the experts on each theme.

Once the theoretical basis and the objectives of the Guide were established, work began on the preparation of the content of each them chapter and corresponding recommendations. This involved a series of discussions and exchanges of information among the experts throughout the process of its development.

The 2º workshop with the experts and the SBE-VC-RBMA Technical Cooperation coordination team had the objective of integrating the various themes covered in the Guide and facilitating the participation of the company's technical staff in order to identify specific problems and questions on its preliminary content. This activity also enabled the group to identify the suggestions made by the Votorantim Cimentos' technical professionals so that the Guide would be really effective in the sense of providing pragmatic and relevant information for mining companies.

On May 15, 2015, a round of consultations was held with Votorantim Cimentos' technical professionals order to understand the project sponsor's needs, eliminate doubts and identify information gaps.

During the Brazilian Speleological Congress, held from the 15th to the 19th of July 2015, a presentation on the Guide was made, including its objectives, assumptions and proposed structure. The presentation team also took advantage of the occasion by asking the participants to contribute, by completing an opinion survey and providing suggestions. Following this Congress, a preliminary version of the Guide was prepared, enriched with the contributions obtained during the event. The Guide was then also presented at the 16th Brazilian Mining Congress, held from the 14th to the 17th of September, 2015, with the aim of presenting the project to the mining sector and requesting the participation of the attendees in a round of consultations open to all interested parties.

Between the 1st of December, 2015 and the 18th of January 2016, a public consultation was carried out. The public consultation was announced to members of the Brazilian Society of Speleology, Votorantim Cimentos's employees, consulting firms, universities and other groups. A final draft of the Guide was made available to interested parties, alongside a form for providing comments. As a result, 53 comments were received from 9 people. All the comments were considered by the authors and individual responses were sent to the respective participants.

**Structure and contents**

The Guide is composed of an Introduction and three main sections (Table 2). The Introduction presents the Guide's objectives, intended users and expected results. It also comments on the importance of karst areas and the growing global demand for limestone, setting the need and intended contribution of the Guide.Furthermore, the Guide stresses the importance of taking an ethical approach to facing the challenges of mining in karst areas.

The first section, "The karst, a special kind of environment," gives a brief summary of the main features of a karst environment in terms of its formation, ecological and evolutionary importance, as well as its role as a provider of resources and services for society. Based on these characteristics, it can be demonstrated why the karst area is vulnerable and why human activities in this environment must be carefully planned and their implementation and operation closely monitored.

| | | |
|---|---|---|
| **INTRODUCTION** | The objectives of the Guide and the expected results from the implementation of its recommendations | *Objective*: Contribute to the dissemination of knowledge on best practices in limestone mining in karst areas and on the ecological and social importance of karst environments.<br><br>*Expected results* from its utilization: 1. Increased protection of karst environments; 2. Improvement in the quality of environmental studies; 3. Reduction of risks for mining companies |
| **SECTION 1** | **The karst, a special kind of environment** | A summary of the main features of a karst environment in terms of its formation, ecological and evolutionary importance, as well as its role as a provider of resources and services for society. Based on these characteristics, it can be demonstrated why |

| | | |
|---|---|---|
| | | the karst area is vulnerable and why human activities in this environment must be carefully planned |
| **SECTION 2** | **The study of karst areas, the basis for planning** | Organized in seven thematic areas: Karst Geo-systems; Caves; Biodiversity and Landscape Ecology; Underground Biology; Paleontology; Archeology; Sustainable Community Development. |
| **SECTION 3** | **Best practices for limestone mining in karst areas;** | Recommendations on best practices that are designed to prevent and mitigate adverse environmental and social impacts arising from limestone mining activities in karst areas. They are presented in the order of the main stages of a mine's life-cycle: feasibility studies, implementation, operations, decommissioning and post-closure. |

Table 2 – Structure and Contents of the Guide

The main characteristics of karst environments, summarized in Section 1, are presented in more detail in Section 2 "The study of karst, the basis for planning", in which the following topics are highlighted: karst geo-systems; caves; biodiversity in karst areas; underground biology; paleontology; archeology; and sustainable community development and mining in karst areas. The study of the specific features of the karst elements and processes demonstrates the fragility of this environment, and, based on this, the necessity and importance of adopting best practices in mining activities taking place in this type of environment.

This section also provides recommendations on best practices that are designed to prevent and mitigate adverse environmental and social impacts arising from limestone mining activities in karst areas. They are presented in the order of the main stages of a mine's life cycle: feasibility studies, implementation, operation, decommissioning and post-closure. This resulted in a total number or 114 best practices, of which 47 were related to feasibility studies, 29 to implementation, 27 to operations 8 to decommissioning and 3 to post-closure. Table 3 shows examples of descriptions of the best practices regarding karst geo-systems, archeology and paleontology, relevant to the feasibility study stage of a mining project.

| Stage | Theme | ID | Best Practices |
|---|---|---|---|
| Feasibility Study | Karst Geo-systems | MF1 | Survey the area |
| | | MF2. | Utilize data and information obtained in exploration |
| | | MF3. | Structure a geo-referenced data base |
| | | MF4 | Conduct a hydrogeological study |
| | | MF5 | Evaluate the speleological potential |
| | | MF6 | Prepare a theoretical model of the karst area |
| | | MF7 | Define the "thematic study areas" from a systemic perspective |
| | | MF8 | Conduct a speleological survey focused on registering exogenous and endogenous karst features using collection control methods and adequate sampling levels |
| | | MF9 | Carry out a speleological-topographical survey with an adequate degree of precision and detail |
| | | MF10 | Update the theoretical model of the karst area |

| Stage | Theme | ID | Best Practices |
|---|---|---|---|
| | Paleontology and archeology | PA1 | Definition of the area of study |
| | | PA2 | Collection of secondary data |
| | | PA3 | Input of data collected into a Geographic Information System |
| | | PA4 | Data analysis |
| | | PA5 | Identification of pending issues or needs for more detailed information |
| | | PA6 | Fieldwork activities for primary data collection and checking of secondary data |
| | | PA7 | Integration of secondary and primary data |
| | | PA8 | Construction of a map of the paleontological and archaeological potential of the area being studied |
| | | PA9 | Preparation of a paleontological and archaeological analysis |
| | | PA10 | Preparation of a paleontological monitoring and recovery program |
| | | PA11 | Preparation of an archaeological survey program |

Table 3 - Best practices for karst geo-systems, paleontology and archeology.

Following this, each stage of the mine's life-cycle is put into the context of its respective objectives, and the recommendations on best practices are presented in the form of summary tables for each stage of a mine's life-cycle, and for each of the seven thematic areas covered by the Guide. The tables are structured around three key questions:

1. *What to do?* This is a summary description of the proposed best practice.

2. *Why do it?* This explains the main reasons for the adoption of the proposed best practice

3. *How to do it (examples)?* This provides examples of techniques, tools and approaches to implement the proposed best practice.

Table 4 shows an example of the presentation of best practices related to karst geo-systems in the feasibility study stage

The thematic chapters in the Section 2 of this Guide give the main reasons for using the best practices and how to implement them. In line with other guides on best practices, the content is presented in the form of general recommendations. The application of these best practices to real life situations requires a professional evaluation of the situation - usually carried out by a multidisciplinary team - and adaptations to fit the specific conditions of each mine or study area.

It is important to understand the function of the surveys recommended in this section of the Guide: the data and information collected should be used in the decision-making process on the project. For example, the decision on the location of waste rock piles should ensure that there is no interruption of the water flows in the karst area and the position of the pit should avoid the elimination of important caves. Such decisions require the availability of adequate and timely information.

To achieve this, the question of the time required to carry out the various surveys is of utmost importance. This is particularly true for studies of the biotic environment which can take relatively long periods in order to obtain a satisfactory diagnosis. Thus, the planning of studies sufficiently in advance requires special attention.

In this situation, the managers of a mining company have a number of responsibilities, especially that of ensuring the quality and integrity of the environmental studies carried out to support its internal decision-making processes.

| Feasibility Study | | | |
|---|---|---|---|
| | **What to do?** | **Why do it?** | **How to do it (examples)?** |
| 9 | **MF9. Carry out a speleological-topographical survey with an adequate degree of accuracy and detail** | 1. To provide support for carrying out the following types of studies: morphological and morphometric; hydrological and hydro-geological; sedimentary; palaeontological; archaeological; and speleogical-biological<br>2. To map out the geometric arrangement of underground routes and the endogenous karst morphology;<br>3. To provide the basis for hypotheses about the genesis, evolutionary dynamics and functioning of the karst system in which the cave (s) is (are) inserted;<br>4. To contribute to the definition of micro-habitats that are favorable for the sighting and collection/capture of underground fauna. | • Develop speleological-topographical maps that accurately describe macro and meso features, which include occurrences of speleothems, espeleogens, water courses and bodies, surface deposits of fossils, and any evidence of archaeological remains.<br>• Use classification methods with a degree of accuracy similar to topography, such as those proposed by the British Cave Research Association or the Union Internationale de Spéléologie |

Table 4 - An example of best practices related to karst geo-systems in the feasibility study stage

It should be noted that the adoption of the best practices proposed in the Guide has two important implications for project planning and management:

- the results of the studies on the karst areas play a key role in project decision-making, affecting key parameters such as estimated ore reserves, final configuration of the pit, location of of waste rock and stocks piles, of crushing and sizing plants and ancillary facilities;

- at more complex sites, carrying out the studies recommended in the Guide could take significantly longer than the time normally associated with environmental impact studies required for obtaining government approvals, and may involve significant costs, which should be estimated in advance and with the greatest possible accuracy.

The best practices for each stage of a mine's life-cycle are presented below. In total 114 best practices were recommended, of which 47 were related to feasibility studies, 29 to implementation, 27 to operations, 8 to decommissioning and 3 to post-closure.

**Conclusions**

The collaborative process of preparing the Guide resulted in a series of recommendations that emphasize the acquisition of information and knowledge about karst systems, their resources, ecosystems and human communities. Current practice in environmental assessment and mine planning at most if not all sites may depart from the recommendations presented in the Guide. Additionally, as with any guidance document, actual application will require adaptation to the situation found in each site. Hence, a review of practices at one operating mine will be conducted by Votorantim Cimentos in order to test the Guide and to measure the gap between current and recommended practices As a result, an action plan can be prepared for each site.

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# THE HARMONIZATION OF MINERAL INDUSTRY IN ENVIRONMENTALLY SENSITIVE REGIONS - THE CASE OF THE SPELEOLOGICAL COMPLEX OF PERUAÇU RIVER - BRAZIL

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# THE HARMONIZATION OF MINERAL INDUSTRY IN ENVIRONMENTALLY SENSITIVE REGIONS - THE CASE OF THE SPELEOLOGICAL COMPLEX OF PERUAÇU RIVER - BRAZIL


## SUMMARY

Concepts of compatibilization between mining industry and environment are presented to contribute for the establishment of a theoretical and applied framework for conservation and preservation practices in areas with environmental restrictions. Due to the social and environmental pressures that are increasingly affecting most mining projects, those procedures, which now may be considered as special, will be routine in the future, thus justifying the definition of their implications for the survival of the extractive industry. As a case study, a description is provided on the actions proposed to mitigate the most important environmental impacts which affect the geographical, biological and historical characteristics in the Environmental Protection Area (EPA) of Peruaçu River, northern State of Minas Gerais, Brazil. The region constitutes a territory where conditions for developing activities of sustainable development are present, allowing the authorities to monitor the consequences of social endeavors in harmony with qualified environmental management.

Circumstances recently emerged creating protected areas in overlapping areas with those given over to mining, or on the contrary, environmental protection areas in which there are located interests of mining are the basic conditions that make the river valley Peruaçu, environmentally very sensitive location, for the same lies in the typical vegetation zone of the Brazilian savannah, inhabited since prehistoric times, where lush record archaeological sites. The identification and characterization of impacts on the environment shows that the most important changes are due to the physiographic changes and the loss of quality original landscape. This in turn is understood today as a natural feature of the cultural heritage of humanity due to their relative scarcity, which needs to be conserved and managed rationally. The criteria for reinstatement or landscape restoration of a degraded area, in mineral exploration, are conditioned by geological factors, geotechnical, topographical, social, economic and cultural rights which should assist the establishment of clean solutions for land use and the vegetation cover in the final destination of the affected land.



## KEYWORDS

Mining industry, ecosystems, management, sustainability, reclamation, environmental diagnosis.


## INTRODUCTION

Among the various types of disturbances that man produces in nature, those related to the extraction of mineral resources, are of particular interest, through the magnitude of its interference in the environment. Holdings in the open air are those that produce or can cause major environmental impacts, due to the movement of materials that conduct the disappearance of the previous productive use of land and soil, the increase of erosion by the devastation of vegetation cover, air pollution and the surface and/or groundwater waters, the consequent alteration of the original landscape and to still living beings including humans. The understanding of spatial planning during and after mining activities, combined with a view of the transience of these exploratory actions, transform environmental planning, for companies in the sector a major factor impracticability of projects. It is within the context of sustainability for the ecological development of an exploration of the object region of its mineral resources, that is established in this article, where if profiling descriptive analysis about prospects for action planning, compatible with the maintenance of environmental integrity simultaneously with the use of these resources in an environmentally sensitive area, namely the Valley Peruaçu river in the northwest of Minas Gerais, Brazil (figure 1).

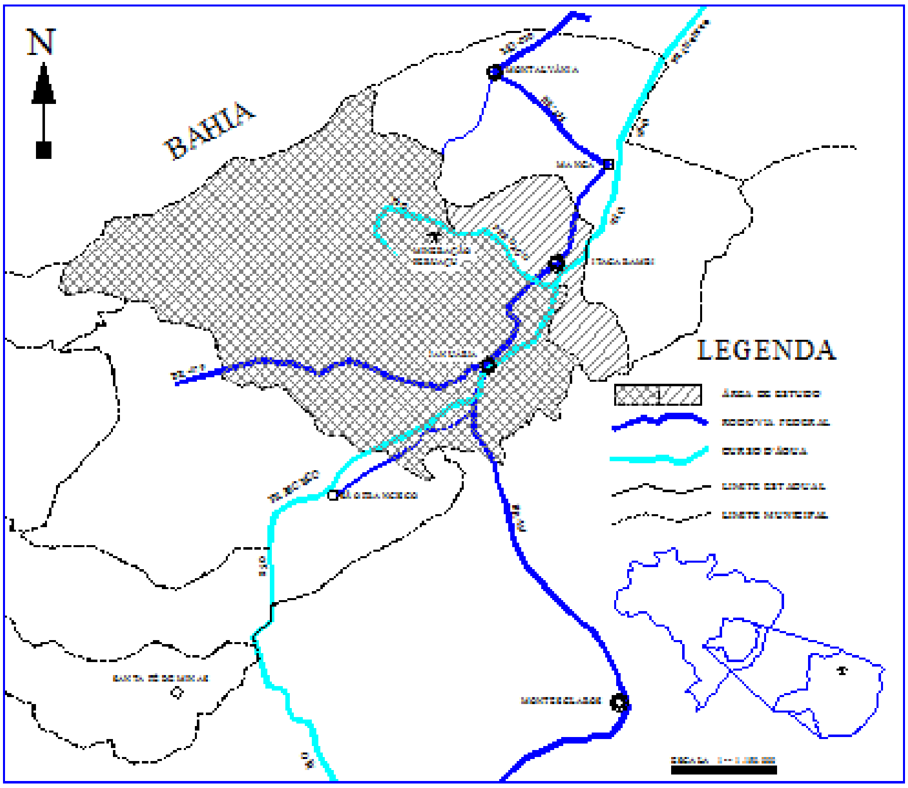


Figure 1 - Layout Geographic Location

With the conceptual considerations inserted in this work is expected contribute to the establishment of a scientific overview, theoretical and experimental for environmental practices carried out in various fora, what did not know a whole effective systematization, as in the case of mining in the valley of the river Peruaçu. The dissertation topic is therefore the analysis of the compatibility of extractive activities with the environmental protection requirements of protected areas, constituting a preview of the care to be taken in the future, as will increasingly be restricted land use in all countries.

## SUSTAINABILITY BETWEEN INDUSTRY AND ENVIRONMENT

The environmental costs of mining can be classified in the actions of assessment, prevention, mitigation, monitoring and rehabilitation of impacts on the physical, biotic and anthropic means, caused by developments in the mining sector, in the stages of planning, development, operation and closure. That is, as mentioned Taveira & Cavalcanti (1998), any mining step may cause environmental costs and these can be characterized as variable costs as their orders of magnitude are generally associated with the quantitative or qualitative production variations. Thus the environmental cost components are:

1- Cost of Degradation: the cost incurred in actions and projects to remedy or mitigate the effects of environmental impacts already caused by the project, when there is no control, or residual environmental impacts for the case of control;
2- Cost of Control: the cost incurred to prevent the occurrence of all or part of the environmental impacts of a project;
3- Mitigation Cost: the cost is due to actions to reduce the consequences of the environmental impacts of a project;
4- Compensation cost: the cost inherent to the actions that outweigh the environmental impacts of a project, in situations where recovery is impossible;
5- Monitoring Cost: is the cost involved in the follow-up actions and assessment of impacts and environmental programs;
6- Institutional cost: the cost corresponding to the payment of fines and insurance, in compliance with environmental legislation.

Such costs generate the categories of environmental costs:

1- Direct Costs: easily associated with a product, process or unit; made up of the cost of capital (plant and equipment, for example) and the operating costs (labor materials, deposition of sterile, etc);
2- Indirect Costs: not directly allocated to a process, product or specific units; It consists of spending on monitoring, management of water quality and by-products;
3- Costs of Non-compliance: associated with deviations resulting from inadequate environmental management, consist of expenses with fines of control bodies, legal action; labor claims arising from inadequate health and safety company, remediation of environmental liabilities;
4- Costs and Intangible Benefits: those that can't be directly associated with a product or process having as a characteristic the fact of being identified by the combination of a result to a preventive measure adopted and shall consist of the expenses with the deterioration of the company's image market, with a reduction in employee productivity, increased time and costs for licensing by the environmental agency.

The field of environmental principles and economic management practices is the fundamental condition to determine the scale of the risks that the regulations will cause the longevity of a mineral project. The factors related to the environment are changing the value of assets and the way he carries out production, the materials that are used for this production and the "modus operandi" of directors, planners, geologists and mining engineers, among others. These factors produce positive and negative effects on the life of a mine. Minerals and ores that had been widely used for a long time and whose economic benefits were shaken by new environmental positioning, have nowadays, difficulties of financial viability, which bind to the processing industries of these raw materials with respect to pollution and energy consumption.

## BRIEF HISTORY OF MINING IN RIVER VALLEY PERUAÇU

Geological investigations in the Valley Peruaçu River region, began in the late 1960, when Georesources Research Company of the Government of Minas Gerais, at the time called Minas Gerais Metals SA (METAMIG SA) and the federal State Mineral Resources Research Company (CPRM) signed an agreement to lead prospecting, copper and zinc in the north and northwest of the state. Forward looking campaigns were forward in the region until the early 1970, when the analysis of data collected discouraged the continuation of field studies.

The mining activity in the region began in the mid-1970s with the limestone exploration for construction and fluorite for steel. But almost no prospecting and exploration of fluorite deposits, prevented the continuation of exploration activities, because it mistakenly thought to be possible to obtain the fluorite as a byproduct of limestone mining. The economic conditions of the time, such as the cost of transportation of the processed material, costs for drilling equipment, the limitations of investigative order as the absence of aerial photographs, topographic maps of details imposed discontinuance of the mining operations.

So by the end of the 1970s, gives is handcrafted and randomly exploitation of fluorite in the region, but the project was lost in the aforementioned, empiricism of his executioners. Interestingly, even in the face of such exploratory forays in the region, information on outcropping deposits of manganese, at no time he was held officially. Only in the early 1980s, the news about the manganese deposit will awaken reason to require areas for your search. Then, first, the context for the implementation of a systematic research it is confirmed that location. The first research requirements for manganese substance for implementing exploration and future mining of the deposit were carried out in 1983 and 1984 and was quantified a deposit of manganese ore to steel grade. In 1988, Peruaçu Mining Ltd., receives the Decree of Mining in an area of 970 ha, allowing you to exploit the estimated manganese ore and from that moment begins the mining, processing and marketing of the product mineral (figure 2 and 3). The company came to have 15,700 ha required for manganese ore research and its regional operations nearly three decades confirms that the mining venture a long-term investment.

For the region Valley Peruaçu river, the introduction of mining activity, carried out the break the isolation suffered by the local population, especially as regards access between the municipal centers, districts and villages. The first action taken by the manganese mining company, with local repercussions, was the opening and road maintenance that connects the area of direct influence to the city of Itacarambi. This facilitated the traffic of vehicles and consequent transport of persons and goods. The regional historiography has, since the 1980s, strong bond with the mineral economy and its different market trends.

Figure 2 - Overview of major armhole showing Mn ore to the fund. Note the layout of the sterile armhole borders to facilitate the environmental recovery work.

Figure 3 - Treatment Station and Processing of Manganese

**COMPLEX SPELEOLOGICAL AND ENVIRONMENTAL CONSERVATION UNITS IN THE BASIN RIVER PERUAÇU**

Also in the mid-1970s, cavers from Speleological Society Tripper (SEE) of Ouro Preto School of Mines confirmed the discovery of a complex of caves in the lower course of the river Peruaçu, that arouses curiosity of the scientific society on the archaeological potential allies to karst occurrences.

The basin area of Peruaçu River, the main tributary of the left bank of the middle reaches of the river San Francisco is located between the municipalities of Januária and Itacarambi. The basin of the river Peruaçu good part of its network of temporary type of drainage, as well as most of its tributaries. Another feature of this river, that highlights of the other rivers in the state of Minas Gerais, is the fact that it has part of its underground course, in endocarst environment, a large area (approximately 8 km), which highlights the cave of Janelão, with 3020 m of development along the main drainage axis. This river runs also about 115 km from a region that has characteristics distinct forms of relief units.

The location of archaeological sites has been carried out over the past four decades in the lower course of the river Peruaçu region, where there is a karst corridor of 17 Km, in which outcrop dolomites and limestones. This fluviocarste features a wide variety of way "canyons", walls, towers, sinkholes, caves and shelters. These two types of occurrence were used by prehistoric men as local housing and rituals. The first traces of human occupation of limpets date to about 12,000 years and are characterized by a lithic industry chipped flint and some sandstone artifacts. Several food fires contained remains of coconuts, freshwater mollusks and hunting as deer and armadillo. Red colored pigments and orange indicate the ink preparation. Although one can’t say that some paintings are dated of this period, the pigments demonstrate the use of mineral paints (figure 4). Nearly all sites (55) sheltered area containing petroglyphs. The set of paintings found in shelters and the lower course of the river caves Peruaçu is undoubtedly one of the world's largest existing sites with more than 1,500 figures density.

Figure 4 - View of Horse Cave Entrance (Cave Paintings)

Around 8000-7000 years ago, terrestrial gastropods (snails giants) become part of the diet of these populations. Posts are firmly planted on the floors of shelters with unknown purposes (housing structures?). In the same period, are the first burials in pits. In more recent levels decrease mollusks, while there is a greater use of small mammals, fish and even birds. The fires, some surrounded by stones are found, and licuri coconuts and guariroba, jatobá seeds, pitomba, cansanção, pequi and other fruits collected. The introduction of ceramic occurs between 2000-1200 years ago and appears to be associated with horticulture. The lytic chipped instrument does not undergo changes in this transition. Possibly the polishing technique also appears in this period or even before, but the disturbance of sediment to open holes for vegetable deposits, It occurred more than 1200 years enabled not clarify this issue. These "silos" were constructed in order to preserve mainly corn seeds for a new planting. The mixture of plant debris and sediment involving the tangs formed a compact mass rodent-proof. Thanks to this construction technique men left voluntarily signs that also planted vegetables like beans, cassava, pepper, annatto, tobacco and cotton, and continued to use collected dozens of other vegetables.

In the region, it is known the presence of at least two ceramists cultures. The oldest is possibly connected to the introducer group of horticulture in the area. The Aratu-Sapucai culture, had a fairly widespread area encompassing territories now occupied by the states of Minas Gerais, part of Goiás, Bahia and some states in northeastern Brazil. It consists primarily of a utilitarian ceramic smooth, not decorated, globular in shape and large vessels used as funerary urns. There is no own vessel for the preparation of cassava bread (a type of polenta) or cassava flour, which suggests not using these foods by these groups. It seems that little use the chipped stone artifacts, but on the other hand knew and manufactured axes polished, so necessary in a society horticulturist. Are known, so far, three sites in the open, along the river Peruaçu belonging to that culture. The other major group known in the region are the Tupi Guarani. Best culturally understood, they consisted of warring people whose presence is marked even beyond the borders of present Brazil. Canoeists people, they used the rivers as routes of entry. The pottery produced by them is surprisingly equal in Brazil. Its remarkable feature a ceramic decorated with polychrome painting, with geometric motifs or plastic decoration, whose main reasons are produced by parallel print nail or scratcheds rhythmical. Horticulturists people had cassava their main breadwinner. The war was determined by the production of flour, the only food warrior. Large open dishes were used for toasting flour and produce beiju. Up until in the moment knew 4 locations in the Valley of Peruaçu River, with traces of Tupi-Guarani presence, 2 in closed shelters and 2 in the open. The potters groups inhabited the area until the advent of the white man, in the late seventeenth century and early eighteenth century. The Tupi Guarani were described by chroniclers and missionaries in the white occupation century. Thanks to these narratives were recorded important aspects of these peoples, now missing.

As for the rock art were identified at least 4 traditions, which in turn indicate the presence of different cultural groups in the region. The oldest, a San Francisco tradition, is characterized by large geometric figures monochrome and bichrome. It is succeeded by another tradition, Peruaçu / Vulture, whose population has practiced horticulture. Stand representations of plants, among them a cornfield and animal figures, nonexistent in the earlier tradition. It is followed by Tradition Drawings, characterized by recording in low relief on the rock. In search of better support, they came to clear in some places, the earlier paintings. They used based on a red coloring ink layer printed on them and recording birds and mammals. The last and most recent, the Norwest Tradition, had occurred mainly in the south of the State of Piauí. It appears in the valley of the river Peruaçu modestly, always peripheral to the panels (figure 5). Anthropomorphic figures predominate, with large abdomens, fine trait, produced often dry with the use of coal. Form scenes whose theme are familiar triads (2 adults and 1 child), copulation and meetings around a "tree".

Figure 5 - Rock Paintings of the Speleological Complex of Rio Peruaçu

In 1989 it is created by the Brazilian Federal Government in the form of Decree Law Nº 98.182, the Environmental Protection Area (APA) of Rio Peruaçu Caves, in an area of 175,000 ha, delimitation of the river watersh. The Environmental Protection Areas (APAs) are the portions of the national territory configuration and size variables, subject to planning various forms and may comprise wide range of natural landscapes and semi-natural, with remarkable features and endowed with biotic attributes, aesthetic or cultural that require protection to ensure the well being of human populations, conserve or improve the local ecological conditions or be a place of experimentation of new techniques and attitudes, to reconcile land use with the maintenance of essential ecological processes. In Figures 6 and 7 one can observe the dotted area represents the APA of the Rio Peruaçu Caves and two other conservation units were created within the APA, namely: the National Park Peruaçu Caves State Park and the Headwaters of Peruaçu. The Parks are relatively large areas of land or water, containing information or national significance of landscapes, where species of plants or animals, geomorphological sites and habitats are of great scientific interest, education and recreation. In addition, the figure shows the presence of an indigenous reservation, which is not characterized as conservation area by brazilian law but has land use restrictions and comprehensive environment. In the figure 6 it should be noted: Green - State Park Headwaters (figure 7) – Orange - Reservation of Xakriabá People Indians – Red - Mineral Concession Area (19,000 ha) - Brown - National Park Caves Peruaçu.

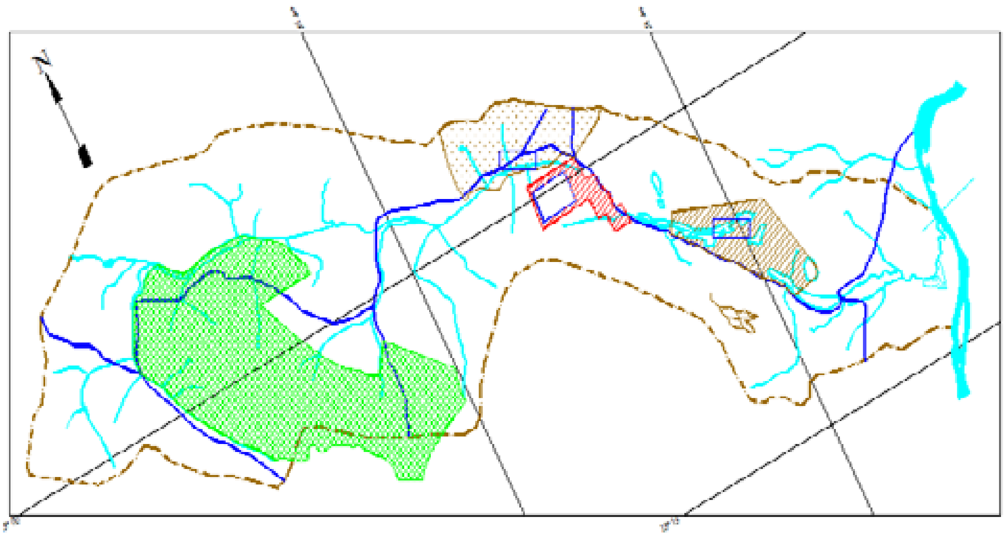


Figure 6 - Environmental Conservation Units within the River Peruaçu APA

Figure 7 - View of Footpaths State Park Headwaters of the River Peruaçu

## CONCLUSIONS

When considering the constraints of corrective environmental licensing of manganese mining in the middle reaches of the river valley Peruaçu, notably, the recovery of riparian forest that stretch of river, the acquisition of strips of land with native vegetation to be donated to the government and the rescue of the archaeological sites, in addition to the routine duties of environmental rehabilitation of mining areas, the mining enterprise was unfeasibled in the region, from the early 2000s. Importantly, no mining activities since the late 1970s, there would be no roads in the area, which were essential in expanding the geographic, human and biological research that resulted in the current configuration of the mosaic of protected areas of the river basin. The local economy, stabilized prior to the mining venture weakened up and the lack of vision of business and government that had to use the temporary economic growth of mining to prepare a new local development path towards sustainable tourism as beautiful spot stagnated.

The environmental changes produced by mining operations in the open, as in the valley of the river Peruaçu have the magnitude of their impacts related to environmental values characteristic of the territory where they were located. The existence of characteristics ecological, landscape and tourist features that was needed some form of protection were the major reason for the implementation of management measures and recovery of such resources, which did not materialize. The reordering of the territory within the restoration of landscape quality, it requires understanding of the transitional use of the affected rural land, where necessary, restore the original capacity thereof or point a distinct alternative use, depending on the conditions derived from ecosystems in the Environmental Protection Area (APA). It should be noted that the basic objective of this means of protection (APA), it is to preserve both the natural environment as there existing human occupation, so that we can have a development planning work, which contemplates the possibility of rational use of natural resources, as explains the Brazilian legislation.

The institutional backwardness of environmental government agencies resolutions seems to be constant in developing countries, and often brought about by the political will top the rapporteurs of each of the licensing process. It also provides for technological limitations of understanding or lack of knowledge because of who proposes or analyzes. exceptional cases as studied here, should have a different perspective of the technical framework of the parties involved, because waiting for ecological solutions arise for a comparison a posteriori in very onerous management decisions, delaying the implementation of regenerative measures and future vision. This type of reflection needs to be evidenced, for the purpose of it is to point to all the parties involved, the identification of benefits brought for more practical actions towards environmental management should guide the ways of the good sense of the negotiations, whose ultimate goal is the best approach to pro-action. The notion that major environmental improvements involves, necessarily, radical and costly changes to economic processes or even if the control of environmental measures is very complex, only increases the uncertainty about implementation of the benefits or even affect the real interest of the subject.

The basic set of environmental information in a particular area can be worked in order to set the locations with multiple skills, where there are the specific behaviors of environmental variables that generate intrinsic opportunities for land use planning. This in turn is the result of applying analytical procedures on the physical, biological, social and economic of a region, the geographical potential is the basis of integration of the collected environmental data. A number of aspects have to be thought of as the interrelationships of forestry activities, mining, agricultural, pastoral, tourist and industrial generally to the field of natural resources.

These issues are not only of geosciences, but put the geosciences contact and connection with other fields of scientific knowledge, allowing perform adequate reflection on the influence of these fields of knowledge in agricultural and environmental geosciences and the concept of the new reengineering Mines. Some special methods deserve the attention of the geologist and mining engineer, who should give them proper historical and dynamic perspective, as peculiar to "geotechnical thought".

To determine the cognitive fields of Agricultural Sciences, Mining and Environment, you have to set your goals, precisely, that their common cores are unquestionably characteristic and its well exact intersections, and to determine consensual relations related sciences, as traditionally established, because there are fundamental ways to address the issues that concern the management and ordering of territories on the environment, within a local or regional planning, which aims at a sustainable development project. In the fields on the Geology and Mining Engineering, it can be seen that the specific studies forecast the inherent suppressive effects of mining activity with the environment, by often they are misunderstood by the defensive posture of entrepreneurs in relation to real appreciation of the knowledge of these applied sciences. Especially when the actions of the mining industry are located in sensitive areas from an environmental point of view, for the extraction of minerals can be made impossible by the benefit/cost ratio.

Reflections on the implementation of preventive measures and implementation of clean technologies in the mining industry, as explicit Range (1998), It demonstrates the importance of environmental factors in this type of location, such, that was added fourth principle (the environmental protection) to the three fundamental principles of Mining Engineering (security, economy and good use of resources). Everything is evolving, coming from the past, and is realized in the present and opens to the future. Because of evolution should pay attention to localized circumstances, as they can be the balance of the entire sense of the universe and carry the guarantee of the quality jump.

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# THE LIFE CYCLE COST APPLIED INTO MINING EQUIPMENT: REPLACE OR REBUILD IT?

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# THE LIFE CYCLE COST APPLIED INTO MINING EQUIPMENT: REPLACE OR REBUILD IT?


## ABSTRACT

In a period that commodities super-cycle are in a down phase, the challenge for mining operations is to maintain the production capacity at the same time the cost is being reduced. In this context fleet replacement strategy could be revised in order to provide not only the minimum investment but also to minimize operational cost utilizing the equipment until it is technically and economically feasible. Most part of mining equipment have a long useful life and known it´s maintenance history and technical characteristics are the most important issues in this analysis aiming to provide useful information to predict future maintenances and important overhauls. It is possible to project big maintenances in the future to support the decision to rebuild, maintain the machines in normal operation or replace it. This article shows life cycle cost methodology applied into mining equipment such as shovels, excavators, off-highway trucks and a practical example supporting leadership decisions to choose the best option to each operation.



## KEY WORDS

Life cycle cost, mining equipment, replace, rebuild.


## INTRODUCTION

Budget tightening, low price of commodities and frequent demand to keep the production capacity create a challenging environment in mining companies nowadays. To achieve great results under those circumstances cited above it is essential to create an effective management of resources and assets. Currently, fleet replacement strategy could be reconsidered aiming to provide the lowest investment and discover the ideal moment to replace the equipment or overhaul it under the technical and economical perspectives. An important tool that may help in fleet management is Life Cycle Cost - LCC.

Life Cycle Cost of an asset can be defined as “the sum of all funds expended in support of the item from its conception and fabrication through its operation to the end of its useful life” (White, 1976 apud Woodward, 1997, p. 336). LCC was created by the United States Department of Defence, during the 1960 decade (Epstein, 1996 apud Gluch & Baumann, 2004). Three decades later, many researches have been developed on the construction industry focusing on the environmental context. In this context Kneifel´s (2010) paper explored the energy efficiency in new commercial buildings where LCC technique was utilized. Currently, other industries are using Life Cycle Cost methodology to support leadership decisions, including the mining sector.

According to Kumar and Nanda (2003) the goals of LCC are:

- To allow investment alternatives to be more efficiently analyzed;
- To consider the impact of all costs instead of simply initial acquisition costs;
- To help choosing among competing assets.

### The Life Cycle Cost Procedures

Some authors suggest a theoretical approach to make a Life Cycle Cost study following some steps (Kaufman, 1970 apud Woodward, 1997, p. 337). However, to create the Life Cycle Cost analysis presented at this paper, that method has been adapted in a practical way as listed above.

**Step 1:** Identify the entire cost elements that compose the LCC database. These elements are all the machine parts that are replaced or rebuild during asset´s useful life. It is also important to identify all the preventative maintenances. Other important issues are the other Operational Expenditures - OPEX, i.e tires, and the Capital Expenditure - CAPEX information. At this point is extremely important to detail as much as possible all the data in order to improve the accuracy of the analysis.

**Step 2:** Calculate all costs for all the elements of the previous step.

**Step 3:** Discount all costs to Present Value. As long as the cash flows involved in Life Cycle Cost analysis happen in different periods, and money has a time value, it is necessary to discount all the cash flows back to Present Value to ensure comparability.

**Step 4:** Sum the cash flows to calculate the Net Present Value. The last step of LCC methodology is summing all the cash flows involved to establish the Life Cycle Cost of the equipment. Woodward (1997) claims that comparisons among competing assets can be undertaken at this time.

The main elements which must be identified to generate a LCC are the initial capital cost, maintenance and operating costs, disposal cost and the discount rate. To summarize the Life Cycle Cost, Kumar and Nanda (2003) allege that “the LCC approach identifies all future costs and benefits and reduces them to their present value by the use of the discounting techniques” (p. 573).

## MATERIALS

At this section, it is explained how the data regarding to finances, operational and maintenance costs used on the LCC studies were obtained.

The financial information, which includes conversion rate from Brazilian currency to U.S dollars, acquisition and disposal costs for mining equipment and unit costs of operational supplies, such as fuel, electricity and tires are collected through the Financial Department and Enterprise Resource Planning’s - ERP software. Furthermore, operational supplies amounts of usage are gathered through the Mining Operation Department.

Alongside, the Corrective Maintenance - CM and Preventive Maintenance - PM data are obtained by the databases from the Maintenance Department in charge of the repairs of mining equipment. Corrective Maintenance “focuses on maintenance procedures that bring equipment back to production in the shortest possible time, and/or other alternatives that minimize the production loss while the machine is inoperative” (Sheu & Krajewski, 1994, p.1366). During these maintenances, parts or supplies, i.e., lubricants are commonly replaced and recorded at the ERP software. “Preventive Maintenance consists of actions that improve the condition of systems before they fail […] replacement of an element by a new one, cleaning and adjustment” (Bris, Châtelet & Yalaoui, 2003, p. 247). For both PM and CM it is also important to record the expenses involving labor costs in order to increase to accuracy of the study.

All these data are collected from ERP and the specific software’s databases and recorded as much as possible.

## METHODS

The first step to design the LCC is collecting the real data regarding to the Materials section. Precisely, the data utilized refers to the financial, operational and maintenance costs, quantities, frequency of intervention, necessary labor and costs after a currency conversion. Table 1 represents a summarized sample of the data spreadsheet utilized to develop a Life Cycle Cost applied into mining equipment.

Table 1 – Data Spreadsheet of an Excavator

| Item | Quantity | Frequency of intervention (Hours) | Labor | Maintenance/ Operation Cost | Cost after BRL/USD conversion rate |
|---|---|---|---|---|---|
| Mechanical PM | 1 | 300 | 30 | R$ A | $ A |
| Electrical PM | 1 | 1600 | 38 | R$ B | $ B |
| Lubricant PM | 1 | 1500 | 8 | R$ C | $ C |
| Air Conditioning PM | 1 | 300 | 7 | R$ D | $ D |
| Electric Motor | 2 | 34000 | 144 | R$ E | $ E |
| Power Take Off | 2 | 34000 | 72 | R$ F | $ F |
| Stick Cylinders | 2 | 11000 | 36 | R$ G | $ G |
| Boom Cylinders | 2 | 12000 | 30 | R$ H | $ H |
| Crawlers | 1 | 20000 | 30 | R$ I | $ I |
| Pumps | 6 | 9000 | 16 | R$ J | $ J |
| Bucket | 1 | 8000 | 120 | R$ K | $ K |
| Set of Ground Engaging Tool | 1 | 2640 | 2 | R$ L | $ L |
| Secondary Electric Motor | 1 | 10000 | 1 | R$ M | $ M |
| Travel Gearbox | 2 | 37000 | 72 | R$ N | $ N |
| Swing Gearbox | 2 | 29000 | 16 | R$ O | $ O |
| Set of Pins and Bearings | 1 | 6000 | - | R$ P | $ P |
| Set of Electrical Wires | 1 | 35000 | 12 | R$ Q | $ Q |
| Electricity | | | Y kW/hour | | |
| Acquisition Cost | | | X Million $ | | |
| Depreciation | | | 10% a year | | |
| Productivity | | | 2422 tons/hour | | |

At this point, it is represented the methodology utilized to obtain the data to fill the columns on Table 1.

*Item:* This information comes from the Corrective Maintenance (CM), Preventive Maintenance (PM), finances and operational data detailed in Materials section.

*Quantity:* This variable represents the number of parts that the equipment contains or the number of preventive maintenances. For instance, there are two Final Drives in an Off-Highway Truck and it is made one mechanical PM at certain moments. This information is extracted through the equipment's Service Manual and the EPR software.

*Frequency of Intervention:* This data consists on the period between 2 consecutives corrective or preventive maintenance. To find this information, firstly it is collected the history of CM of the entire fleet and afterwards it is analyzed in order to eliminate outliers. Rousseeuw and Hubert (2011) allege that outliers "may be errors, or they could have been recorded under exceptional circumstances" (p. 73). Practically speaking, it means that while analyzing the history of corrective maintenances of a component it is necessary to eliminate any outliers that might exist aiming to keep the quality of the database. Furthermore, Rousseeuw and Hubert (2011) claim that "when analyzing data, outlying observations cause problems because they may strongly influence the result" (p.73). In parallel the frequency of intervention of the preventive maintenances are collected through the Maintenance Management software.

*Labor:* This information refers to the number of workers and quantity of working hours necessary to replace a part after refurbishment or to execute a preventive maintenance. For example, after refurbishing an Electric Motor of a hydraulic excavator, it is necessary to spend a certain number of workers and working hours to replace it on the shovel. The goal to use this information is to improve the accuracy of the LCC studies.

*Maintenance/Operation Cost:* This data represents the costs to do the preventive and corrective maintenances in Brazilian currency. This information is also collected through the history database of CM and PM from the Maintenance Department. At this point, it is also extremely important to eliminate the outliers.

*Cost after BRL/USD Conversion Rate:* This rate is utilized to convert the maintenance and operation costs from the Brazilian currency to U.S dollars according to an assumption of the Financial Department in respect to the forecasted conversion among the U.S and Brazilian currencies.

After the data spreadsheet indicated by Table 1 is totally filled, the next step is to input all this information in a software called Mining Equipment Design and Management System - MEDMS designed to generate some financial parameters, such as the Cash Flow, Equivalent Annual Cost, Net Present Value and Unit Costs. The results generated by the software are used to make the Life Cycle Cost analysis.

One of the most important parameter to make the decision among replace or rebuild an equipment is the Equivalent Annual Cost - EAC. Brealey, Myers and Allen (2010) define the EAC as "the annual cash flow sufficient to recover a capital investment, including the cost of capital for that investment, over the investment's economic life" (p. 142).

The EAC also can be utilized for choosing among equipment with different economic lives. In this context the better decision is to select the machine with the lowest Equivalent Annual Cost (Brealey et al., 2010).

## RESULTS

At this section, it will be presented a case study exhibiting a LCC created to make a decision between replace or overhaul an excavator following the guidelines of the Materials and Methods sections.

Firstly, the data spreadsheet indicated in Table 1 was developed in order to identify all the costs of the equipment's economic life and create the LCC for a standard operation of a hydraulic loading shovel.

### The Life Cycle Cost Analysis

The next step was to analyze the financial parameters EAC and Cash Flow calculated through the database indicated by Table 1. The Figure 1 exhibits a chart where the X axis represents the operating hours and the Y axis shows costs in U.S dollars. This graph aims to discover the ideal moment to disposal the equipment and acquire a new one.

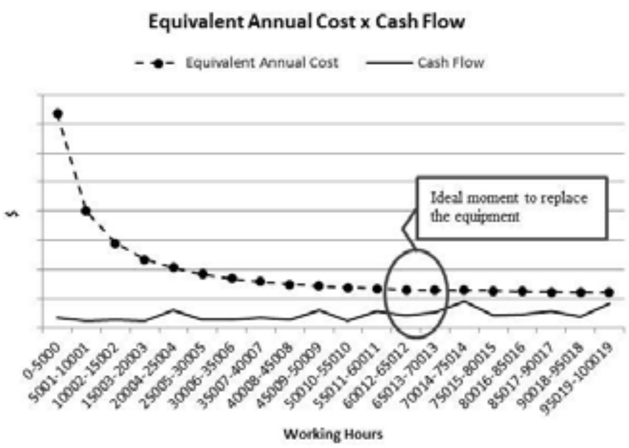


Figure 1 – Equivalent Annual Cost x Cash Flow Graph for a hydraulic loading shovel in standard operation

To decide the ideal moment to replace the equipment, the following criteria must be analyzed, which are:

- Full depreciation of the equipment. This equipment works in average 5,000 hours per year. According to Table 1, this equipment depreciates 10% a year. Thus, after 10 years it has been totally depreciated;
- Replace the equipment before a critical increase of the Cash Flows. Considering the years where the equipment is totally depreciated, this Cash Flow increase happens in the period indicated by 70,014 and 75,014 worked hours;
- Ensure that the Equivalent Annual Cost curve is steady or increasing. This criteria shows that the asset has reached its lowest EAC.

Analyzing the criteria cited above, the best decision is to replace the equipment among 60,000 and 70,000 operating hours. In parallel to the financial analysis, it is important to highlight the uncertainty about the structural integrity of the excavator to reach an useful life above the previous range.

The following graph was developed in order to make a deeper analysis about the costs to operate the equipment hourly and to produce a ton of ore. It is possible to conclude that in the year 15 the total cost of ownership is the biggest one. In this is the year is expected to the excavator reaches 70014 worked hours.

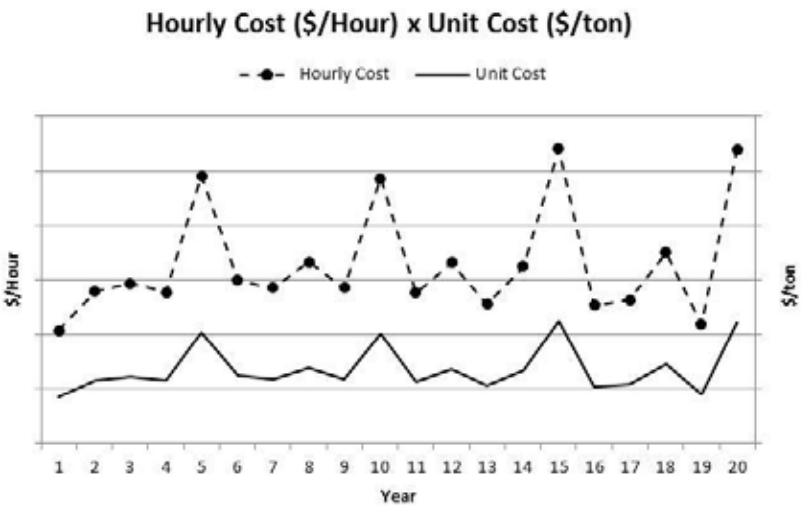


Figure 2 – Hourly Cost x Unit Cost graph for a hydraulic loading shovel in standard operation

Figure 3 represents a pie chart that splits the Capital and Operational Expenditures in different categories. The category Main Components consists in the most important parts of the equipment, i.e., Electric Motors, Power Take Off, Swing and Travel Gearboxes and Motors. The category Other Components refers to the smaller parts, such as pumps and radiators.

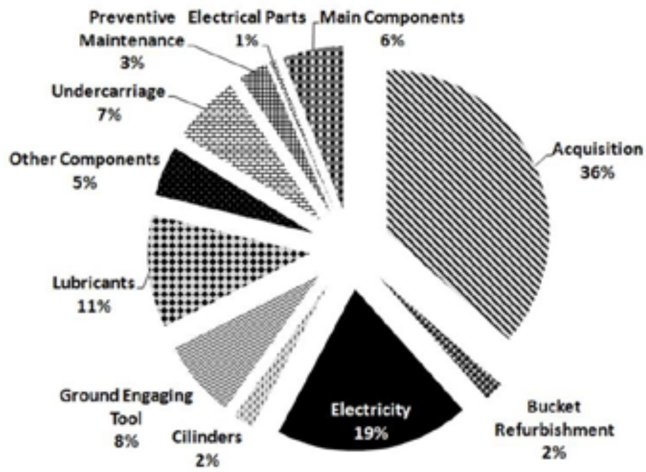


Figure 3 – Capital and Operational Expenditures pie chart for hydraulic loading shovel in standard operation

Figure 4 shows a bar chart that represents the Operational Expenditure in every operating year of the hydraulic shovel. Figure 4 also uses the categories indicated in figure 3, except the acquisition category.

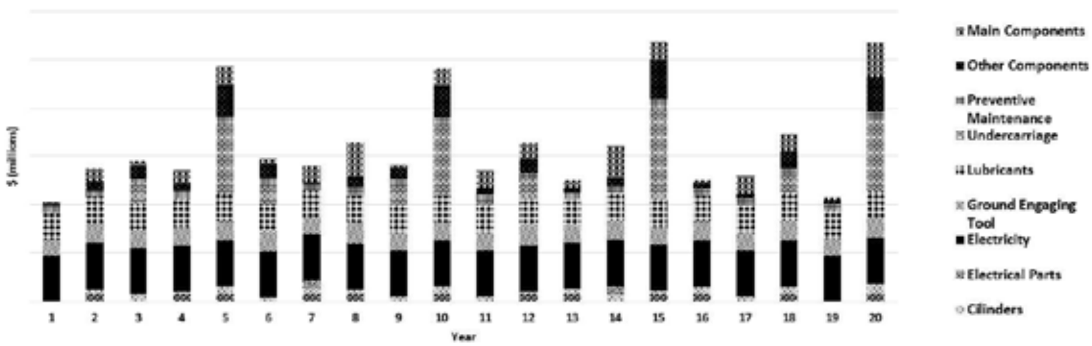


Figure 4 – Operational Expenditure bar chart for a hydraulic loading shovel in standard operation

The graphs presented in Figures 3 and 4 allow maintenance and mining operation departments to decide in which categories they must focus in order to reduce costs.

**The Life Cycle Cost Analysis: rebuild or replace an equipment?**

After a critical failure on the right crawler of a hydraulic loading shovel with 55,000 operating hours and a plenty of corrective maintenance to do, the Maintenance Department requested a Life Cycle Cost analysis to discover the best decision between replace or rebuild the excavator.

After the LCC without considering the crawler failure was developed, the next stage was to discover the cost to do the whole corrective maintenance, including the repair of the damaged truck, necessary to return the equipment to operation. After that, this cost was included on the Cash Flow related to the 55,000 operating hours and Equivalent Annual Cost calculation, as it can be seen in figure 5.

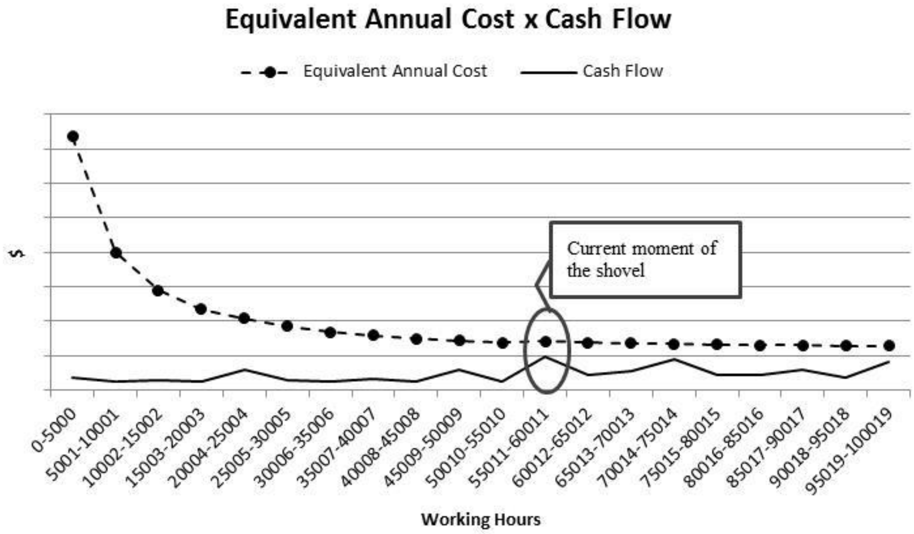


Figure 5 – Equivalent Annual Cost x Cash Flow graph for a hydraulic loading shovel considering the corrective maintenance

Analyzing the changes between figures 1 and 5, it is clear that the Cash Flow related to the current situation of the equipment increases considerably in reason of the corrective maintenance included. In the other hand, the EAC curve barely changes. At this point, the technical analysis is finished and it starts the asset's management decision.To discover the best option among rebuild or replace the equipment, it has been discussed the advantages and disadvantages of both choices under many perspectives. Firstly, it was compared the costs to acquire a new excavator and operate 70,000 hours, which is the highest useful life suggested by the LCC. After that, it was calculated the cost to rebuild the current shovel and operate it more 15,000 hours to reach the highest useful life. The results can be seen in Table 2.

Table 2 – Financial Comparison between Rebuild and Replace the Shovel

| Action | $ | $/Hour | Commentary |
|---|---|---|---|
| Acquire a new hydraulic shovel | X,XXX,XXX | A + 20% | Investment to operate 70,000 hours |
| Rebuild current hydraulic shovel | Y,YYY,YYY | A | Investment to operate 15,000 hours |

After that, it was considered the impact of the decision on the production of the organization. The necessary time to repair the excavator is 120 days. In the other hand, the necessary time to the dealer produce a new excavator, import it and assemble the shovel is 485 days. Looking at the safety perspective, the replacement has a clear advantage as long as it only consists on the disposal of the current shovel and assembling a new excavator, while the rebuild refers to a total disassembly, followed by the repair and the reassembly of the current shovel.

To finish the analysis, it was discussed the service reliability. Firstly, it was found similar hydraulic shovels around the world with more than 70,000 operating hours, which indicates that, if it is decided to rebuild the excavator, it might reach its highest boundary. According to the Maintenance Department, there were some uncertainties about the quality of the repair, since it had never faced a similar failure in past occasions. However, the equipment's Dealer ensured that the repair procedures could be done with quality and reliability. Table 3 summarizes all the perspectives.

Table 3 – Summary of Advantages and Disadvantages between Replace and Rebuild the Shovel

| **Perspective** | **Replace Hydraulic Shovel** | | **Rebuild Hydraulic Shovel** | |
|---|---|---|---|---|
| | **Advantages** | **Disadvantages** | **Advantages** | **Disadvantages** |
| Financial | Equipment totally depreciated Availability of parts to other shovels of the fleet | Highest Hourly Cost (20% more expensive than rebuilding) | Lowest Hourly Cost | None |
| Production | None | Necessary time to acquire and assemble a new shovel: 485 days | None | Necessary time to repair the current shovel: 120 days |
| Safety | Lowest risk: Disposal+ assemble of new shovel | None | None | Highest risk: Disassembly + repair + reassembly |
| Service Reliability | None | None | Other shovels with higher lifetime | None |

Thus, returning to the core issue of this case study, the question is: Should the company replace or rebuild the hydraulic shovel? The answer for this question depends on which perspectives are the priorities to the organization at the decision moment. Analyzing Table 3, it can be noticed that the Rebuild option is more feasible looking at the Financial, Production and Service Reliability perspectives. In contrast, the Replace choice wins when analyzing the Safety.

## DISCUSSION AND CONCLUSIONS

This paper shows the efficiency of Life Cycle Cost methodology to support the fleet management of mining companies and how important this tool might be in decision making moments about replacement or rebuild of mining equipment. A practical approach based on financial techniques is also proposed in order to exemplify how the LCC might be conducted. However, some issues must be discussed at this point.

Firstly, it is necessary to highlight the importance to use a precise database of maintenance/operation costs and a proper discount rate aiming to produce an accurate Life Cycle Cost. Otherwise, the LCC might not reflect the reality and it can bring managers to do not make the best decision.

Also, it must be understood that the site`s features influences the study. In other words, a Life Cycle Cost created in a specific mine must not be exactly used in other sites due to the mine`s features such as maintenance/operation costs and site’s severity.

In addition, it is important to analyze the LCC under many perspectives, such as Financial, Production and Safety aspects, as it has been explained through the Case study, rather than only analyzing the Financial matter to decide whether the equipment should be rebuild or replaced. Another important matter is to assess the structural integrity of the equipment in case of choosing the rebuild option.

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# THE MINING OF CLAY AS ORGANIZED IN THE FORM OF COOPERATIVES

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# THE MINING OF CLAY AS ORGANIZED IN THE FORM OF COOPERATIVES

## ABSTRACT

The red ceramic industry in Brazil has a wide territorial span and is an important segment of the Brazilian economy Estimates show a universe of about 7.500 industrial units dedicated to the ceramic sector with low unit values, low technological density, but large overall production value. Two main challenges can be identified: a) the need to reduce differences in quality of the raw material, which impact the supply chain competitiveness and b) the unfair competition from illegal production that infringes both mining and environmental law.

Clay mining in Brazil lacks investment in the technological and managing modernization which is needed to improve all phases of production (research, mining, stocking and the preparation of the raw material to be transformed into ceramic). An important trend in the ceramic sector is the sharp change in the supply of raw material systems, with the increase in importance of the so-called "Centrais de Massa", which are units where clay inputs from several sources are blended and prepared with quality control. Moreover the co-op clay mining model also achieved great importance recently. Several benefits arise from the adoption of these practices: cost reduction, increase in the quality of the raw material, optimization of mineral reserves. The objective of this panel is to present the advantages of this model and the pioneering initiatives in Brazil, examining the case study of COOPEMI.

## KEYWORDS

Clay, supply chain competitiveness, cooperatives, clay mining, managing modernization, raw materials

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## COOPEMI: a successful story in the Brazilian mining sector

The sustainability challenge in the sector of red clay extraction enabled the establishment of "cooperatives" with the objective of extracting and supplying raw materials to the ceramic industry. As a successful example of "cooperative", one could mention COOPEMI (Cooperativa de Exploração Mineral da Bacia do Rio Urussanga), established in 1998 in the region of Morro da Fumaça (State of Santa Catarina). COOPEMI operates in 15 municipalities of three micro-regions of the State of Santa Catarina: Morro da Fumaça, Jaguaruna, Sangão, Treze de Maio, Pedras Grandes, Orleans, Urussanga, Cocal do Sul, Siderópolis, Criciúma, Nova Veneza, Maracajá, Araranguá, Içara and Tubarão. COOPEMI holds 24 mining titles, covering an area of 2.656,33 hectares. Seven of these titles are currently being operated by the cooperative, which has around 170 members. COOPEMI operates within the legal framework of a "TAC-Termo de Ajuste de Conduta" (Conduct Adjustment Term), signed in 2009. Due to the high costs associated with extraction, the establishment of COOPEMI was the best solution to make the operation possible.

One of the main innovations brought by COOPEMI to its members is the provision of services of mineral research as well as the supply of high quality raw materialy. COOPEMI performs this task by guaranteeing variety and quality of the raw material. Currently, the whole process is made following all the

pertinent regulations and the quality of the material is guaranteed by a combination of adequate storage conditions, formation of lots, and placement of the lot in the open.
Since the member of COOPEMI has a guarantee of supply of quality raw material , he can focus onmarket considerations and on the optimization of the production process. The need to develop legalized and rational extraction of sand and clay, at a sustainable and competitive cost, was the main stimulus for the creation , strengthening and operation of COOPEMI. In the past, the producers of ceramic in that region faced a serious risk of having their activities embargoed for legal reasons.

In the area COOPEMI operates, there were 68 mining projects, held by 51 ceramists operating separately. Under the guidance of COOPEMI, these 68 projects were consolidated into 10, at the service of 170 ceramist. Raw-materials that are prospected and extracted by COOPEMI are sent to Labcer (a Red Pottery Laboratory) which functions at the same address as the cooperative. Labcer assesses the quality and the usage potential of the clay. Likewise, results serve as a parameter to the formation of blends of raw material, with a view to fully using the field. The increase in the quality control of the clay significantly reduced waste in every step of production.

In search of higher competitivenes, companies increasingly focus on their main activity: the production of ceramics. The model of production through cooperatives and "centrais de massa" is highly advantageous, because of the following factors:

- Better knowledge of the clay field and a more detailed mineral research;
- Higher production scale per mine, which are formalized and legalized;
- Field planning/ geological knowledge and better future use of the area;
- Better quality and blending of the raw-material and of the clay mix;
- Lower environmental impact and lower recovery cost of the area that was mined;
- Better allocation of human resources and shared use of experts (geologists, engineers, consultants, and so on);
- More efficient energy use;
- Lower clay freight cost (from the mine to the ceramist);
- Lower total investment cost and production cost (CAPEX and OPEX) in the mine;
- Better allocation and usage of equipment (trucks, loaders and so on) at the mine;
- Need for lower stock of spare parts at the mine;
- Raw material supply as the ceramist needs it (just in time)- lower need to immobilize capital in stock and better organization of the stock patio;
- Higher possibility of blending, making it possible the use of other materials (rock residues, less noble clay, and so on);
- Focus on the production of clay (the ceramist gets raw mateiral quality guarantee and can concentrate on the production of ceramic pieces);
- Ecoefficiency.

See below the evolution of the extraction of clay from 2009 to 2013:

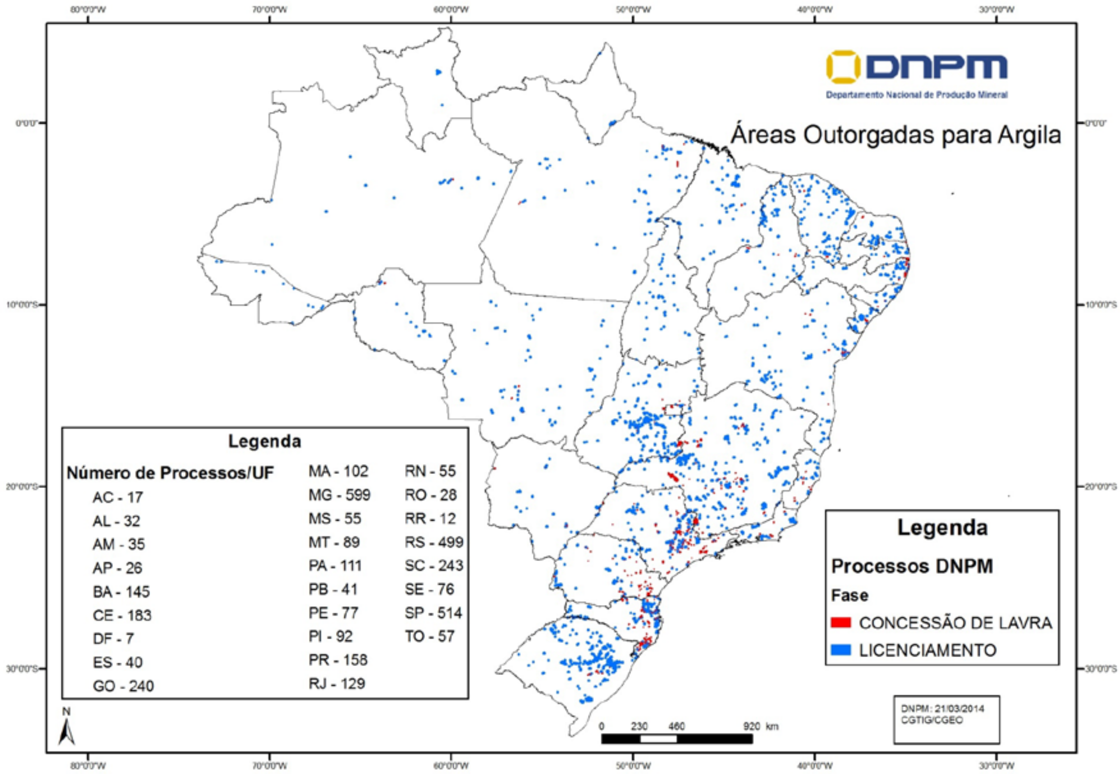
Picture 1: Clay extraction area in a COOPEMI organized field in the state of Santa Catarina
Source: COOPEMI

Figure 2: Clay extraction area in a COOPEMI organized field
Source: COOPEMI

Current situation in Brazil

According to the Yearbook on the Production of Non-Metallic Minerals organized by the Brazilian Ministry of Mining and Energy (MME), around 70,8 billion of ceramic pieces were produced in Brazil in 2013, which required around 141,6 million tons of clay.

Map 1 shows the clay production areas in Brazil.




Map 1: Clay mining in Brazil:mining concessions / license registration
Source: CGTIG/DNPM

As for the operation of cooperatives for the exploration of clay, the following figures apply: there are 160 active mineral claims for 16 cooperatives (specially in Santa Catarina, Bahia, Ceará, Minas Gerais and São Paulo); 94 claims associated with mineral research; 56 concessions. The National Department of Mineral Production (DNPM) has been supporting the sector with the following actions: elaboration of Conduct Adjustment Terms (TAC) with procecutors, negotiation of partial cession of areas that are already onerated, vertical cession of onerated areas, assessment and specific control of the size of the fields.

## CONCLUSION

The formation of clay extration cooperatives should be fostered, since it provides advantages to all the involved parties (public and private) and positive impacts as regards competitiveness and sustainability. Moreover, one optimizes the red clay ceramic production chain with the reduction of losses, better compliance with market demands and productivity and quality gains. The initial challenge is to regularize the supply sources of the raw material, but the organization in the form of cooperatives can bring more substantial gains, as we have mentioned in this paper. There is a significant potential in terms of developing this practice in Brazil, where currently there are 56 mining concessions(around 1,5% of the total).

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# THE POWER CONSUMPTION AS INDICATOR TO SUSTAINABLE DEVELOPMENT: VISION FOR THE INDUSTRIAL SECTOR MINING AND PELLETIZING

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# THE POWER CONSUMPTION AS INDICATOR TO SUSTAINABLE DEVELOPMENT: VISION FOR THE INDUSTRIAL MINING AND PELLETIZING


## ABSTRACT

The power consumption is an important indicator for sustainable development in the mining industry. The mining industry and iron pelletizing accounts for about 2.9% of the Brazilian GDP (IBGE 2009), and almost 8.6% of the Industrial GDP (IBGE). In order to analyze this influence in Brazil, a benchmarking methodology taking into account the data of the National Energy Balance 2014 and Sector Plan for Mitigation and Adaptation to Climate Change in Mining - Mining Plan for Low Carbon (MBC) were carried out. Factors that were considered in this research included comparative data for energy production and consumption, the number of industry jobs, revenue and greenhouse gas emissions as well as the analyzes of the principles of sustainable development such as environment, economy and society in comparison with energy. The energy efficiency gains are a reality in the Brazilian mining sector. Despite the historical series does not contemplate the energy crisis of 2001-2002, the sector was modernized and optimized industrial processes that led to savings and better efficiency.



## KEYWORDS

Brazilian Energy Balance (BEN), power consumption, energy, sustainable development, mining and pelletizing sector


## INTRODUCTION

The development of a nation and the welfare of its population do not exist without the intensive but rational use of the mineral goods (raw materials). Anyone who looks around can hardly identify objects of your life that do not contain minerals in its production or composition.

The postmodern society of XXI century becomes increasingly intensive in the consumption of natural resources. Improving the quality of life is directly related to the increase of mineral resources. However, the sustainable side of this consumption must be considered. According Ignacy Sachs (1996), the tripod of sustainability: economy, social and environment should guide decisions of any actors involved in these relations.

The mining and pelletizing sector accounts for about 3.3% of the Brazilian GDP (IBGE 2011), and 4,2% of the Industrial GDP (that is 24,9% - IBGE 2013). As a world supplier of raw materials Brazilian basic industries, mining and pelletizing are characterized by not being energy-intensive. Although mining is an industry with many technological innovations, particularly in mineral research and mining operation phase,  mostly of the energy is based on oil consumption.

The aim of this paper is to understand the interrelationship between energy consumption (in GWh) and environmental, social and economic criteria as indicators for sustainable development, based on iron mining and pelletizing.

The iron mining and pelletizing chosen to elucidate the relationship of sustainable consumption includes the following activities: mining, physical beneficiation, pelletizing and internal transport. Therefore, it was not considered mineral chemical processing activities and external transport.

The mineral commodities in this study are: iron ore (including pellet), potassium, phosphate, zinc, nickel, lead, gold, copper, bauxite, niobium, manganese, aggregates (sand and industrial gravel) and mineral coal.

Iron ore can be upgraded to higher iron ore content through beneficiation. This process generates iron ore filter cake which needs to be pelletized to be used in the steel making process. Also during the processing of high grade iron ores which don't need beneficiated, fines which are generated can be pelletized and used instead of being disposed of.

**The Iron Ore Pellets**

Iron Ore Pellets are formed from beneficiated or run of mine iron fines. The iron is usually ground to a very fine level and mixed with limestone or dolomite as a fluxing agent and bentonite or organic binders as a binding agent. If the ore is a Hematite ore, coke or anthracite coal can be added to the mix to work as an internal fuel to help fire the pellets. This mixture is blended together in a mixer and fed to balling discs or drums to produce green pellets of size typically about 9-16 mm. The green pellets are then fed to the induration machine. Both straight grates and grate kilns dry the pellets out in a drying section, then bring the pellets up to a temperature of about 800-900 °C in a preheat zone, then finish the induration process at roughly 1200-1350 °C. The pellets are then cooled to a suitable temperature for transporting to a load out facility. Both processes recycle the heat from the pellet back through the process to aid in energy efficiency and decrease fuel usage.

Both processes can be used to generate almost any type of desired pellet chemistry, from direct reduction pellets (DR pellets) to blast furnace pellets. By adjusting the amount of fluxing agent or limestone added, pellets can be made that are anywhere from acid (or non-fluxed) pellets to heavily fluxed pellets. For both processes the plants consist of many pieces of equipment. The major areas or processes in the plant are mixing, balling, indurating and product handling.

Mixing is where the properly ground ore is combined with binding agents like Bentonite or organic binders, fluxing agents like limestone or dolomite, and if the ore is a Hematite with coke or anthracite coal as an internal fuel. The mixing is done usually in vertical or horizontal high intensity mixers to achieve a homogenous blend of ore and additives.

From mixing the filter cake is sent to the balling area where the ore is agglomerated on balling discs or balling drums into green (or unfired) pellets. Both drums and discs ball the ore to about 9-16mm size. Drums typically have very high recycle rates so have a screening circuit to screen out undersize and oversize pieces to be put back through the drum. Discs usually do not have a separate screening circuit at the disc. Green pellets are then transported to the induration process.

Pellets that are oversized or undersized and any fines generated during the balling or transporting process are screened right before entering the induration machine and sent back to the mixer or the balling area. The on-size pellets are then fed to the induration machine. Both straight grates and grate kilns dry the pellets out in a drying section, then bring the pellets up to a temperature of about 800-900 °C in a preheat zone, then finish the induration process at roughly 1200-1350 °C. The pellets are then cooled to a suitable temperature for transporting to a load out facility. Both processes recycle the heat from the pellet back through the process to aid in energy efficiency and decrease fuel usage

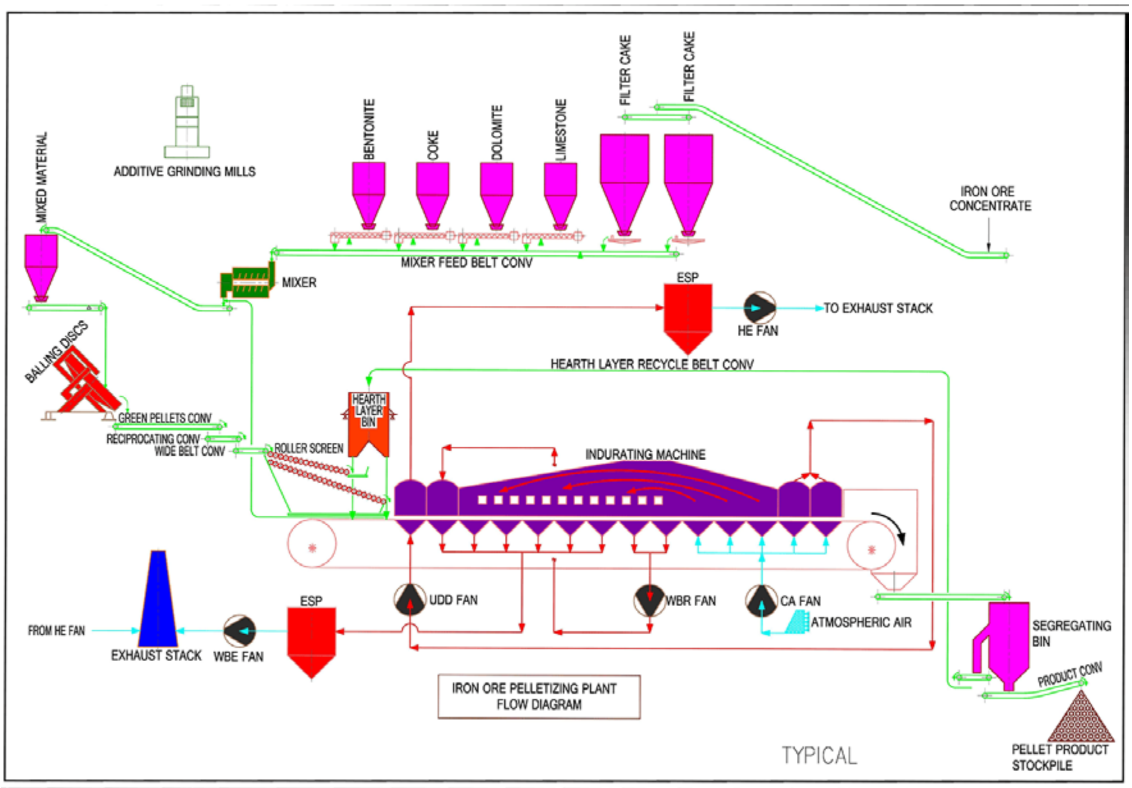


Figure 1 - Pelletizing process flow the company Source: VT CORP PVT. LTD.

**Sustainability criteria by Ignacy Sachs**

According to the author Ignacy Sachs, the Economic criteria: intersectoral balanced economic development; food security; continuous modernization of capacity of production tools; reasonable level of autonomy in scientific and technological research; sovereign insertion in the international economy. For this criterion, the mining and pelletizing sector is fully inserted in the world economy due to its main products are commodities and traded on major international markets in the world. The processes are well integrated and are in constant technological improvement, largely due also of own scientific research and support companies to research institutes, connected to the academy or not.

Social criteria - reach a reasonable level of social homogeneity; fair income distribution; full employment with decent quality of life; equal access to resources and social services. For this criterion adopted the number of employees in the sector, in addition to the assumption that all have access to the availability of energy.

Environmental criteria: respect and enhance the self-purification capacity of natural ecosystems. It was adopted emissions of greenhouse gases indicated, since this indicator affects the planet and cannot be considered in isolation. The mining and pelletizing sector is part of the natural ecosystems.

**Correlation Coefficient**

To answer the question if “the power consumption is an important indicator for Sustainable Development”, it was established that some sectorial indicators could lead to a satisfactory conclusion on sustainability and its relation to the linear correlation coefficient – Pearson´s Index. The Pearson's index coefficient is used to measure the strength of a linear association between two variables, where the value r = 1 means a perfect positive correlation and the value r = -1 means a perfect negative correlation, as in Figure 2.

The Equation is:

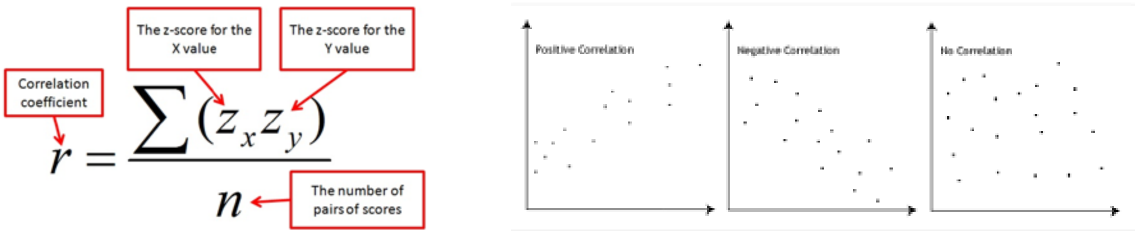


Figure 2 - Indicatives of Correlation Coefficient   Source: Statistics Laerd.com Statistical Guides

The Pearson correlation coefficient, *r*, can take a range of values from +1 to -1. A value of 0 indicates that there is no association between the two variables. A value greater than 0 indicates a positive association; that is, as the value of one variable increases, so does the value of the other variable. A value less than 0 indicates a negative association; that is, as the value of one variable increases, the value of the other variable decreases.

## PRODUCTION AND CONSUMPTION OF ENERGY

When compared to national electricity production and consumption by the segment of mining and pelletizing, it is observed in Figure 3 that by the year 2008, the indicators were aligned. However, as the global economic crisis of 2008-2009 strongly affected the sector, there was a sharp drop of 27% and it took almost three years for the sector's recovery. Pearson coefficient: 0.75 indicating direct/positive correlation.

For the production data and power consumption in GWh analyzed in Figure 3, it was considered Brazil's Electricity Production *versus* Consumption Total in the country. Secondly, it was found the consumption only of the Industrial Sector, and then calculated the consumption only segment of mining and pelletizing, it is inserted into the industrial segment. This relationship has been established to demonstrate that the sector has low electricity use, on average 2.43% of industrial consumption, and 5.53% of the total country's electricity consumption

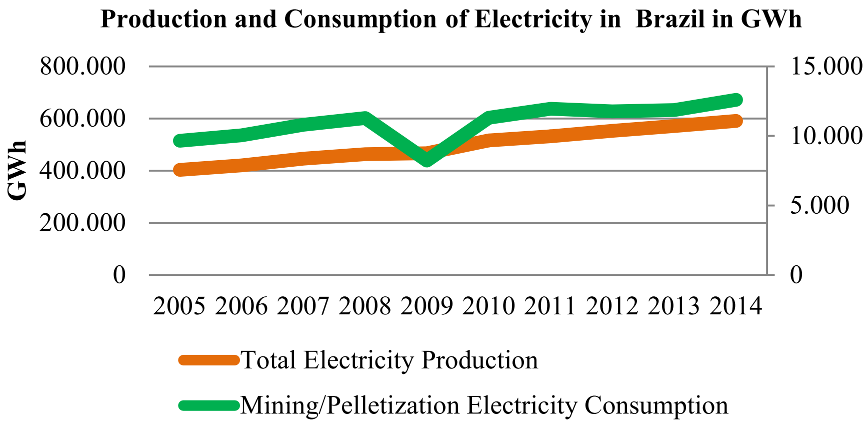


Figure 3 - Production and Consumption of Electricity per years. Source: BEN2015

Table 1 - Brazil Electricity Production, Total Electricity Consumption Brazil, Consumer Industrial Segment, Sector Consumption Mining and Pelletizing - Data in GWh, source: BEN2015

| Table 1– Electricity in GWh | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 |
|---|---|---|---|---|---|---|---|---|---|---|
| Total Production | 403.031 | 419.383 | 445.149 | 463.120 | 466.158 | 515.799 | 531.758 | 552.498 | 570.835 | 590.479 |
| Total Consumption | 375.193 | 389.950 | 412.131 | 428.250 | 426.029 | 464.699 | 480.968 | 498.386 | 516.174 | 531.080 |
| Industrial Consumption | 175.370 | 183.418 | 192.616 | 197.218 | 186.740 | 203.350 | 209.390 | 209.622 | 210.159 | 205.932 |
| Mining/Pelletization Consumption | 9.634 | 10.030 | 10.792 | 11.274 | 8.230 | 11.300 | 11.946 | 11.753 | 11.842 | 12.592 |

Table 2 - Brazil Electricity Production, Total Electricity Consumption Brazil, Consumer Industrial Segment, Sector Consumption Mining and Pelletizing - percentage data in GWh, source: BEN2015

| Table 2– Electricity in GWh % | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 |
|---|---|---|---|---|---|---|---|---|---|---|
| Total Production | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% |
| % Mining Sector x Industrial Sector | 5,49% | 5,47% | 5,60% | 5,72% | 4,41% | 5,56% | 5,71% | 5,61% | 5,63% | 6,11% |
| % Industrial Sector x Total Consumption | 46,74% | 47,04% | 46,74% | 46,05% | 43,83% | 43,76% | 43,54% | 42,06% | 40,71% | 38,78% |
| % Mining Sector x Total Consumption | 2,57% | 2,57% | 2,62% | 2,63% | 1,93% | 2,43% | 2,48% | 2,36% | 2,29% | 2,37% |

## EVOLUTION OF THE NUMBER OF EMPLOYEES AND ENERGY CONSUMPTION

The stock workers of the sector mining and pelletizing did not follow the curve when there was an interruption in the growth of final energy consumption in 2009 strongly affected by the global economic crisis of 2008-2009. In the social bias of sustainable development, there was a stock of maintenance workers even when facing the economic crisis 2008-2009. In this correlation, Pearson coefficient indicates: 0.68 indicating direct/positive correlation, as showed in table 3 and figure 4.

Table 3 - Number of Employees *versus* Mining/Pelletization Energy Consumption in GWh Source: BEN 2015; MTE-CAGED Establishment CNAE 1.0

| Table 3 – Electricity in GWh | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 |
|---|---|---|---|---|---|---|---|---|---|---|
| Mining/Pelletization Consumption | 9.634 | 10.030 | 10.792 | 11.274 | 8.230 | 11.300 | 11.946 | 11.753 | 11.842 | 12.592 |
| Number of Employees | 119.225 | 126.344 | 136.081 | 144.948 | 151.538 | 152.875 | 167.847 | 183.475 | 192.358 | 194.377 |

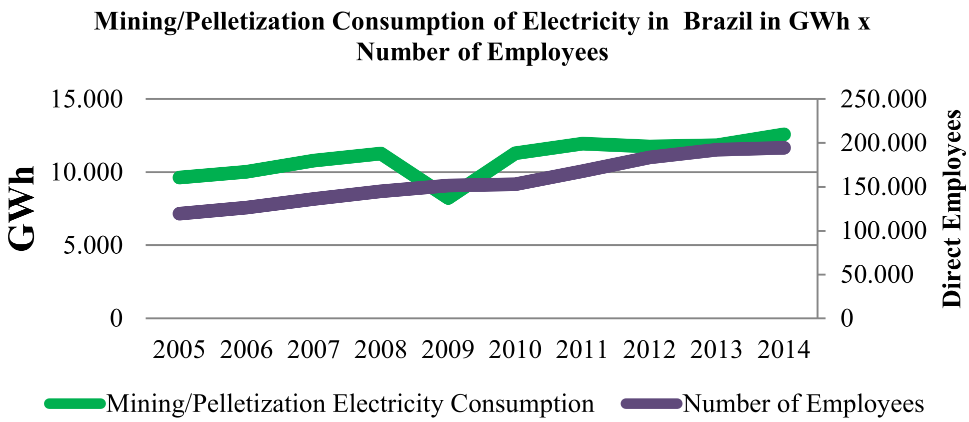


Figure 4 - Number of Employees *versus* Mining/Pelletization Energy Consumption in GWh Source: BEN 2015; MTE-CAGED Establishment CNAE 1.0

## ENERGY CONSUMPTION AND GDP OF MINING AND PELLETIZING SECTOR

BEN 2014 brings the Mining and Pelletizing Sector GDP (Gross Domestic Product) data expressed in $10^6$ US$ ppc (2010) until 2013. Estimated Sectorial distribution from the system of national accounts (IBGE), with values in 2010 constant *reais* converted to dollars in purchasing power parity (ppc) 2010. In this correlation the Pearson coefficient was 0.88 indicating direct/positive correlation, as in Figure 5 and Table 4. For the analysis of the year 2014, the BEN 2015 shows the GDP by Sector, the Mining as extractive sector including Oil and Gas extraction. So, it was disconsider 2014 and analyzed the previous year where we have this distinction of Oil and Gas extraction and Mining and Pelletization Sector.

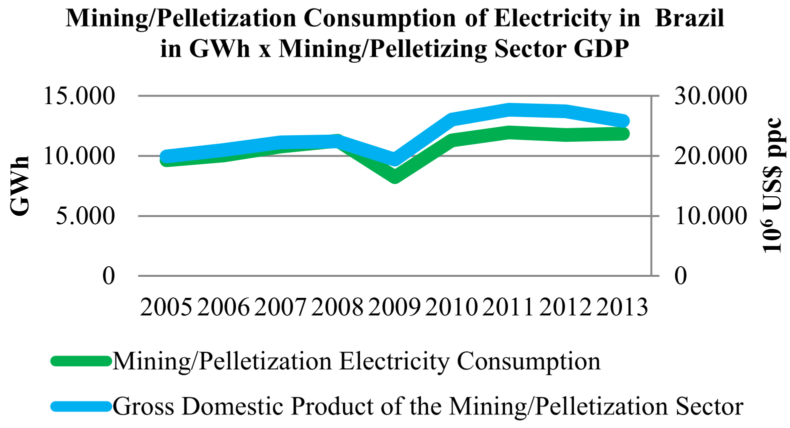


Figure 5 - Mining and Pelletization Sector Energy Consumption and GDP Sector. Source: BEN 2014

Table 4 - Energy Consumption *versus* GDP Sector in years. Source: BEN 2014

| Table 4 – Electricity in GWh | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 |
|---|---|---|---|---|---|---|---|---|---|
| Mining/Pelletization Consumption | 9.634 | 10.030 | 10.792 | 11.274 | 8.230 | 11.300 | 11.946 | 11.753 | 11.842 |
| Gross Domestic Product of the Mining/Pelletization Sector | 19.925 | 20.976 | 22.242 | 22.420 | 19.410 | 26.065 | 27.708 | 27.420 | 25.844 |

## BRAZILIAN MINERAL PRODUCTION ISSUE AND ENERGY CONSUMPTION OF MINING AND PELLETIZING SECTOR

Another indicator often used in mining and pelletizing sector is the Brazilian Mineral Production. This index is calculated by the Brazilian Mining Association (IBRAM), and considered production for the domestic and foreign market of minerals goods, estimated in US$ billion. Compared to the final consumption of energy Mining and Pelletization sector, the Pearson coefficient was 0.73 indicating direct/positive correlation as in Figure 6 and Table 5.

It is observed that the Brazilian Mineral Production (IBRAM methodology in Figure 6) does not follow the curve of Gross Domestic Product (IBGE methodology in Figure 5). They have different methodologies and deserve another study.

The large variation observed in the Figure 5 and 6 of sectorial GDP and Brazilian Mineral Production largely been accentuated due to the high volatility of commodity prices generated in industrial activity Mineral Extraction. In the case of primary products (raw materials and commodities), 9the prices of major metals and minerals have high rates of variation, especially those traded internationally, such as iron ore.

Table 5 - Brazilian Mineral Production and Mining and Pelletization Sector Energy Consumption. Sources: BEN 2015; IBRAM

| Table 5 – Electricity in GWh | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 |
|---|---|---|---|---|---|---|---|---|---|---|
| Mining/Pelletization Consumption | 9.634 | 10.030 | 10.792 | 11.274 | 8.230 | 11.300 | 11.946 | 11.753 | 11.842 | 12.592 |
| Brazilian Mineral Production | 13 | 17 | 19 | 28 | 24 | 39 | 53 | 48 | 44 | 40 |

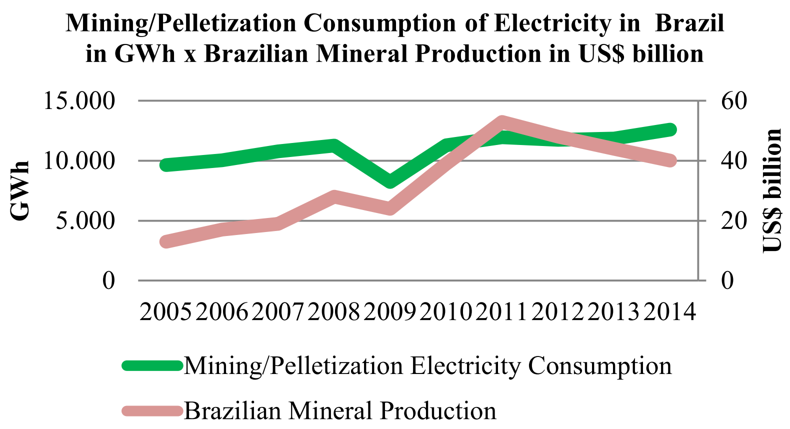


Figure 6 - Brazilian Mineral Production and Mining and Pelletization Sector Energy Consumption. Sources: BEN 2015; IBRAM

## EMISSIONS OF GREENHOUSE GASES AND ENERGY CONSUMPTION

Most experts consider the rise in $CO_2$ levels in the atmosphere as largely responsible for the intensification of the greenhouse or at least to trigger this process. This increase is attributed, in historical terms, particularly the burning of fossil fuels (coal, oil and natural gas) for power generation and, secondarily, to the destruction of natural vegetation, especially forests.

The machinery used in the field by the mining and pelletizing sector, mostly, are of diesel or fuel oil engines. The unavailability of the infrastructure of electricity makes the companies, in the first step on Mineral Exploration, and in the second step on mine opening use portable engines, read up generators. After mounting the mining venture, you enter with the electricity supply of the local distribution network. Another feature is the industry machinery of mobility and heavy use of generators.

The industry does not have a time series to compare the Sector Energy Consumption with Greenhouse Gas Emissions Data (GHG). There are inventories conducted by the Brazilian Mining Association for the years 2008 and 2011; and Sectorial Plan of Mitigation and Adaptation to Climate Change in Mining/Mining Plan for Low Carbon (MBC Plan). The latter with data for the years 2008, 2011, 2014 and others with projections up to 2030. It was chose to show the Figure 7 only with the points elucidated in the MBC and was not carried out last calculation since the sector document are not sufficient data to calculate the possible safety minimum, the historical since 2004. It would be necessary to have access to data from the studies related to the MBC Plan. The Pearson´s correlation coefficient was 0.75 indicating direct/positive correlation, as in Table 6 and Figure 7.

Table 6 – Greenhouse Gas Emission versus Energy Consumption in Mining/Pelletization Consumption Sources: BEN 2015; MBC Plan

| Table 6 – Electricity in GWh | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 |
|---|---|---|---|---|---|---|---|---|---|---|
| Mining/Pelletization Consumption | 9.634 | 10.030 | 10.792 | 11.274 | 8.230 | 11.300 | 11.946 | 11.753 | 11.842 | 12.592 |
| Greenhouse Gas Emission in $CO_2e$ | | | | 10 | | | 11,5 | | 13,3 | |

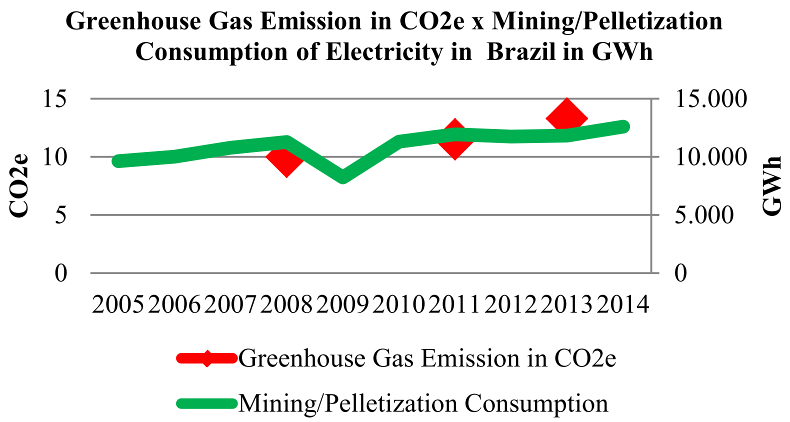


Figure 7 – Greenhouse Gas Emission versus Energy Consumption in Mining/Pelletization Consumption
Sources: BEN 2015; MBC Plan

It is also necessary to make a separation of scopes covered in the MBC Plan. "In establishing operating limits of GHG emissions were categorized as emissions from direct sources (Scope 1) and indirect (Scope 2 and 3). The Scope 1 emissions refer to emissions from the company itself (physical emissions), including emissions from fuel combustion, manufacturing processes, and internal transportation in mining. Emissions Scope 2 refers to those from the acquired power generation others, but consumed by the company (purchased or brought into the organizational boundaries of the company) - electricity and / or steam. All other sources of GHG emissions possibly attributable to the company's activities refer to Scope 3. In terms of organizational and operational boundaries, emissions from scopes were analyzed 1 and 2. However, in relation to an indicator of effectiveness of the plan. They were considered only scope 1 emissions due to non-reasonableness of the sector with regard to specific emission factor of the consumption of electricity and the possible duplication of efforts with other sectorial plans, such as Energy. The Scope 3 of GHG emissions, indirect, to the company's activity, were not considered in this plan to avoid overlapping with other sectorial plans. Regarding the limit of the production process for each ore analyzed were considered to mining activity, physical processing and internal transport. "

It should be noted also that the industrial mining and pelletizing sector has in pelletizing the higher GHG emissions due to its production process. The hardening process of the pellets can be performed in three furnaces: moving grid; rotary kiln; or shaft furnace.

Moving grid: the material does not undergo significant movement along the furnace. Rotary furnace: when the grid is shorter than the remaining material is added in the rotary kiln, which causes mechanical stress, abrasion, shock and pressure generating thin, since the pellets thus produced are not so spherical. In the shaft furnace: it is more suitable for magnetic ore. The energy of oxidation of $Fe_3O_4$ (oxidizing atmosphere) is released in greater quantities and supplied to the thermal cycle as part of the total energy for pelletizing. The shaft furnace must be fed green pellets, a solid load that must be percolated by the ascending gases resulting from fuel combustion in the combustion chamber. The gas temperature reaches the range of 1.300°C to 1.400°C: the thermal shock causes the green pellets disintegration of the material: the green pellets must have considerable percentage of binders, but still is some generation of fines. The remainder of the furnace is used for the cooling load. When the height of the oven is higher, better temperature distribution occurs. On the other hand, when the oven height is excessive, the height of the material column is too excessive, generating an intense pressure on the dry material, which has been heated by the gases, which transferred heat to the material, forming a zone narrow heat transfer, creating many fines.

In the rotary kiln and the moving grid formed pellets are less homogenous sizes and less sphericity. The material goes to the mobile grid and at the end of certain already suffering sintering (around 900° C), entering the rotary kiln with certain strength: heating the rotary furnace, the end to the beginning, complete thermal cycle. The process efficiency is lower than the traveling grate, on which the lowest mechanical stress causes less amount of fines. In the rotary furnace temperatures are reached near the unloading area are gases percolating the load in the rotary kiln are used to heat the material in the mobile grid.

Agglomeration in the pelletizing is done by burning external fuel mixture (combustion of oil, natural gas and other fuels), unlike sintering, in which case the sinter itself already contains fuel.

In the grid percolates the same material without significant shock (statistically) for drying, preheating, burning and cooling. In the mobile grille are those circulating gas, transferring heat to the load. This equipment is more efficient and modern.

According to MBC Plan 12 GHG reduction initiatives were grouped into three programs, as follows: 1) Changing the energy source used in the process - made replacement program initiatives of high fuel non-renewable carbon with renewable fuels or less non-renewable carbon content. An example of initiative is the substitution of fuel oil with natural gas in pelletizing plants; 2) optimization of mining assets - consisting program exchange equipment or installation parts initiatives to optimize the consumption of fuel or electricity. An example of initiative is the progressive renewal of the fleet of trucks with higher capacity and better level of fuel consumption. 3) Use of new technologies in mining - program consisting of design change initiatives of mining and use of new mining technologies. An example of initiative is crushing at the mine and the use of conveyor belts, replacing the use of trucks and crushing in the processing area.

## CONCLUSION

The diversity of raw materials is dependent on geodiversity, that are the rocks that determine the nature of the physical and biotic environments in which interacts life; also the exploitation and exploration of mineral resources are not easily perceived as essential to the quality of life of the population by the society.

To understand the dimensions of Brazilian mining, their features and involvement with small communities and large urban centers, the importance for the processing industry (transformation industry) and agriculture, as well as the conservation of the environment. It is worth highlighting that while promoting impacts on nature, is one of the most sustainable productive activities. The activity is endowed with locational rigidity, that is, mineral resources only occur where geological processes are allowed, and often these sites are poor of infrastructure (such as sanitation, energy, transport, and utility apparatus) as well as being an activity internalized and can occur in various forms throughout the country.

The sector works with large product inventories and these are seasonal. Besides having a variety of very large products, each has its specificity. This study considered only iron ore (including pellet), potassium, phosphate, zinc, nickel, lead, gold, copper, bauxite, niobium, manganese, aggregates (sand and industrial gravel) and coal. However, while mineral products exploited in the country, classified almost 200 mineral types. Only a more detailed study, product by product, would be sufficient to consider whether really the curve of energy consumption follows the production curve. In this sense, the indicator energy only meets part of the questions on Sustainable Development. On the economic side, you can make a good relationship with the indicators presented in the environmental and social bias; it would take more data beyond employment and GHG emissions.

Energy efficiency gains are a reality in this sector. Despite the historical series does not contemplate the energy crisis of 2001-2002 in Brazil, the modernized up sector and optimized industrial processes that led to savings and better efficiency. Since then, it has constantly seeking improvements in their processes with innovations aimed at cheapening of production costs, read: high rates of energy in Brazil.

According to Sachs, "conservation and rational use of nature can and must go together." In this sense, the natural resources sector to the mining industry has a lot to contribute, whether in the form of supply of new materials to bring the efficiency of processes, either in their sustainability indicators. Development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs, thus advocating the possibility of a default in the economic, social and structural changes through the qualitative improvement of the balance relating to the environment and the need for effective use thereof.

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# THE UPDATE OF MOATIZE COAL MINE CLOSURE PLAN, MOZAMBIQUE: A NEW VISION OF FUTURE USE

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# THE UPDATE OF MOATIZE COAL MINE CLOSURE PLAN, MOZAMBIQUE: A NEW VISION OF FUTURE USE.

## ABSTRACT

The Moatize coal mine is located in the central region of Mozambique and accounts for more than 120 years of history. It is one of the largest known reserves of this mineral and is now part of the Moatize Industrial Complex. The Initial Plan for Complex Closure was developed in 2007 as part of the project licensing process, involving a 4770 hectares study area, indicating as future use scenario the total restoration of the land interfered (Savannas). In 2009, Vale has decided to increase production from 12 to 24 million tons per year. This project required the adequacy of facilities and mine structures, which required the readaptation of the Closure Plan, considering the new reality of the complex. In this second version of the study, significant changes were made from the previous one considering the expansion of structures and new assumptions arising from the natural maturation of the enterprise and its surroundings. Seeking greater adherence of the Plan to the sustainability pillars adopted by Vale, three scenarios of future use were evaluated: i) ***Alternative 1 - Conservationist***; the same proposition established in the initial version, providing for the full restoration of the area with savannah; ii) ***Alternative 2 - Agricultural Use***; option studied with emphasis on agricultural and livestock uses traditionally practiced in the region; iii) ***Alternative 3 - Multiple Use***; proposal to consider greater diversification of uses, in order to adjust the natural vocations to the socioeconomic and cultural demands. The latter scenario was elected the most appropriate, highlighted, among other virtues, for the greater alignment with the vocations of land use and government policies. The study area has nearly doubled in comparison with the previous one, reaching 9533 hectares, while the cost of the plan has increased by 38%. Thus, the updated version of the Plan met the assumptions of economic reasonableness of closing stock and was more integrated with the local features, combining the agricultural production activities with forest and other institutional uses (tourism, education, research and other), subject to the conservationist bias.

## KEYWORDS

Mine closure plan, mine closure, mine decommissioning, decommissioning assets, future use alternatives.

## INTRODUCTION

This article is the result of the efforts of Vale and ERM Brazil teams considering the analysis and proposals related to the preparation of the first review of the Industrial Complex Closure Plan of Moatize.

The initial version of the plan, drawn up in 2007, was designed with emphasis on conservation of natural resources, adopting a very simplistic model before the local reality. On the other hand, the second version came from a broader strategic concept, which considered the demands, vocations and local potential, both in the environment as socioeconomic and cultural perspective. This new vision reflects the progress in the degree of maturity of the project, particularly regarding the definition of structures and closure activities, combined with the increased availability of general information about the environment and the communities involved.

This update of the Plan was drawn up based on secondary data, obtained in the various studies and past projects that supported the licensing of mine, as well as current public information provided by government agencies and other institutions. The work was carried out in five successive and complementary "Stages", described next, considering three scenarios of future use for areas of the enterprise. The selection of the most adequate alternative took into account both the social and environmental benefits and their running costs.

## CONTEXTUALIZATION

The Moatize Industrial Complex is located in Moatize Village, Tete province, northwest of Mozambique. The distance between the provincial capital and the complex is approximately 17 km through the national road EN103 (Highway N7) and exclusive access to the Complex entrance. Figure 1 shows the location map of Moatize Industrial Complex.

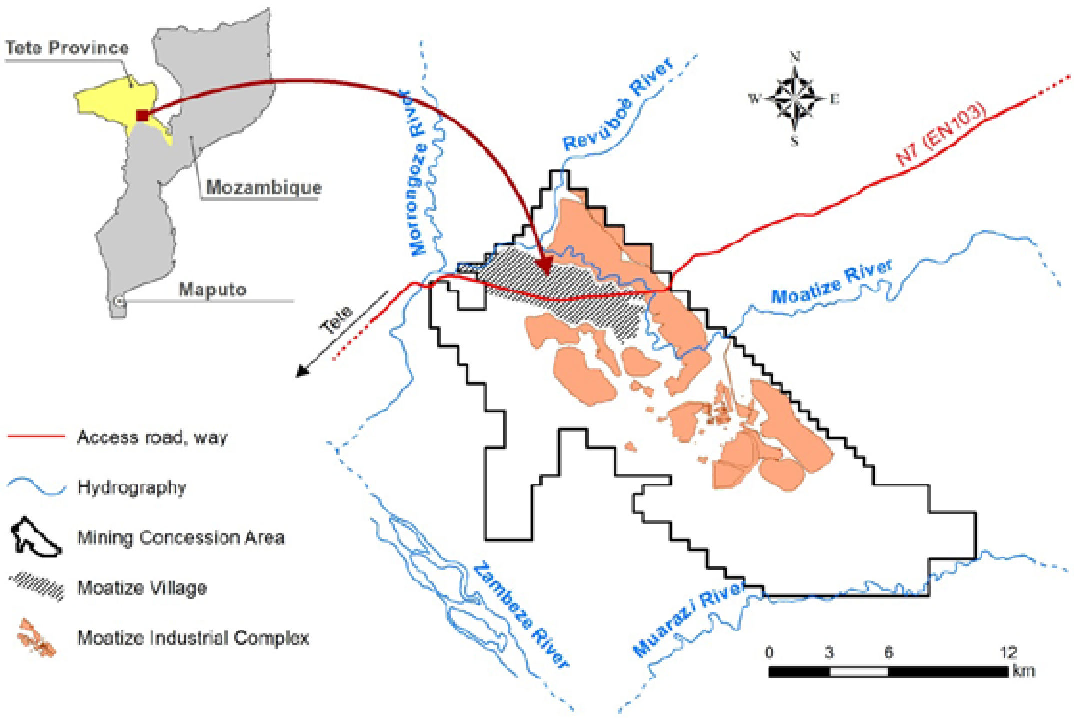


Figure 1- Location Map of the Industrial Complex of Moatize

The Vale's coal business in Mozambique involves different integrated projects: the Industrial Complex of Moatize (mine and associated infrastructure); the use of the Sena railway linking the Moatize village to the port of Beira; the Nacala Corridor railway, under deployment, linking Moatize to Nacala port; and the port terminals of Beira and Nacala. As part of the licensing process of the Complex, in 2007 it was drafted the initial version of its Closure Plan, which makes it worth saying, does not take into account the decommissioning or closure of the railways or port terminals.

The mineral extraction activity has great potential for the entire Tete Province, and is considered the main economic activity in the region. The Moatize District is located in a zone occurring minerals that take up most of the length of the Moatize village, which justifies the existence of approximately 40 mines concessions granted to mining companies of various sizes. Currently, the Moatize Village is completely surrounded by the Mining Concession assigned to Vale. However, beyond this concession, there are also other areas allocated to mineral exploration, either by concessions in fact or even just concessions for prospecting licenses.

Another important feature of the District and the Moatize Village is the infrastructure deficiency and basic resources faced by the population. The region has considerable poverty rate, with high demands for food, education, health and sanitation, among others.

**Moatize Mine**

The history of the Moatize coal mine dates back to 1895, through the Company Zambezi Hulheira. Since then, the project has the management of different companies, both private and governmental. Vale is present in the region since 2004 when it won an international competition promoted by the government, for the feasibility study for the Moatize Coal Project, receiving a grant of mining concession of a total area of 24,000 hectares. It is considered the largest reserve of this mineral, estimated at 1071 million tonnes ROM, with a potential production of approximately 340 million tonnes (Mt) of coking coal and 83 Mt of thermal coal, being mainly intended for export, with more participation of coking coal (Aurecon AMEI et al, 2010).

During the initial licensing of the mine, several specific studies and projects were developed by Vale Mozambique about the area, in compliance with the requirements of Mozambique legislation, among which stands out the initial plan for mine closure - Moatize Coal Project Initial Mine Reclamation and Closure Plan (Golder, 2007).

With the physical progress of mining operations, elapsed over the past few years in conjunction with the changes inherent in the expansion of the project, there was a significant change in the enterprise structures, a fact which required updating the Closure Plan, in order to maintain its applicability as a tool to support operational and financial management of the mine.

In October 2013 it was prepared the revision of the Initial Plan, by ERM Brazil, receiving the name Industrial Complex Closure Plan of Moatize. This revision was leveraged in order to meet several objectives: meet the internal guidelines of Vale for the upgrade of its closure plans; subsidize the renewal of the concession area of the license; incorporate the amendments relating to the expansion of the mine. The consolidated major methodological aspects adopted as well as the results obtained in the construction of the Closure Plan is presented below.

## METHODOLOGICAL GUIDELINES

**Stage 1: Enterprise General Characterization**

In the review of the Plan Industrial Complex structures of Moatize, licensed in 2007, added to those provided for in the 2010 expansion project were considered. It included the identification and design of all the typical structures of mining operations and mineral processing, utilities infrastructure, services, protection, environmental control and management.

The main product of this Stage consisted of the spatial distribution of the mine structures, current and projected, in superposition to natural attributes of the land (topography, hydrography, vegetation and human occupation, among others), creating the basis for planning future uses.

**Stage 2: Integrated Analysis of Environmental Characterization**

In addition to the "mapping" mentioned above, it was carried out a socio-environmental characterization of the area interfered by the project, based on the existing database, obtained from the studies produced by the project and other sources, expanding the reference information for the study of future use alternatives. This characterization was the basis for the assessment of impacts and risks related to the closing process, and the definition of actions and environmental programs for the Plan. The basis of available secondary data related to the enterprise insertion region allowed identifying some important features such as migration, the economy, urban infrastructure and the form of appropriation of the use of rural land, as well as environmental results arising in the physical and biotic environment.

**Stage 3: Defining the Future Use Area**

Considering the area of the Mining Concession is much greater than the one actually designed for the enterprise, efforts were made in order to establish the boundaries of the study area for Potential Future Uses (Figure 2), by means of several analysis criteria, such as limits for the Concession of Moatize Project; urban limit of the Moatize Village; the mine structures and other interfered areas, closing object, and for the latter it was established a buffer zone ranging between 100 and 500 meters depending on the structure and general characteristics of the analyzed section (relief, slope, drainage system, soil suitability for agricultural use and livestock).

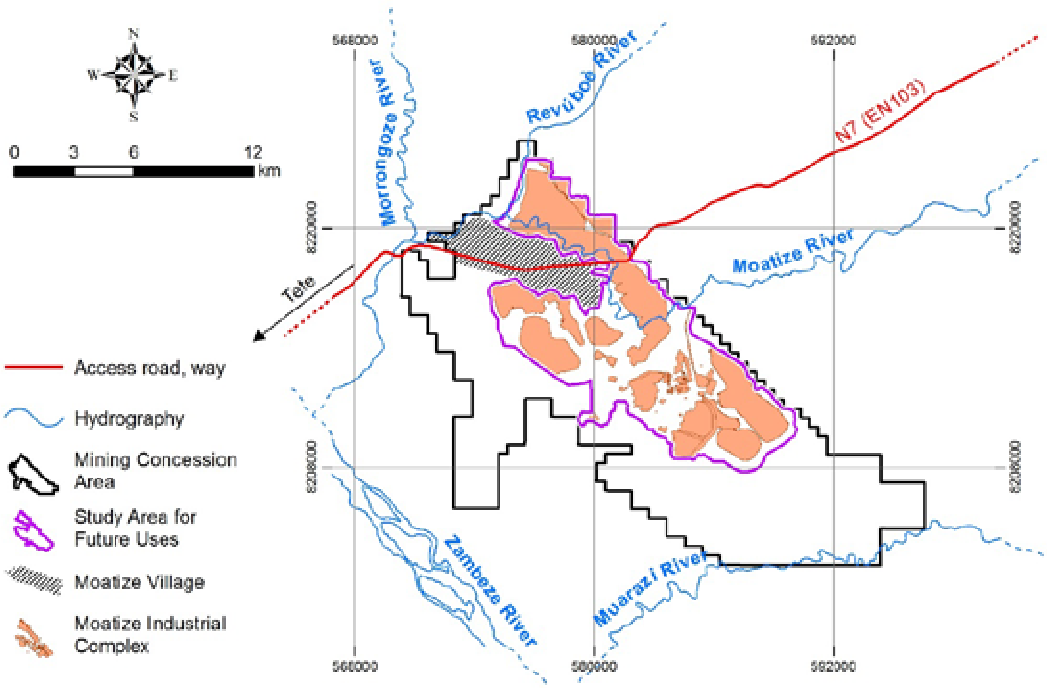


Figure 2 - Study Area for Potential Future Uses

**Stage 4: Analysis of Social and Environmental Attributes and Potential Futures Uses in the Defined Study Area**

In this stage steps were adopted and analysis were developed until reaching the selection of Alternative of Future Use to the area of Moatize Industrial Complex in its closure.

From the analysis of environmental data (Stage 2), it was characterized the situation of the enterprise's study area, fundamental subsidy to reply projections of the components of the physical, biotic and socioeconomic medium modified by mining activity. This allowed establishing a framework for the study of Future Use Alternatives and definition of the Industrial Complex Closure Plan of Moatize.

It is important to note that the alternatives for potential future use, defined in Step 3, presented below, are aligned with the district development scenarios proposed for the next eight years, in the District Plan of Use of Land (PDUT 2011 Include these references to the end of the text), prepared by the Government of Moatize District. Moreover, these alternatives were based on current knowledge of the mining project, which established an estimated useful life of 26 years from the present (2016), i.e., with closing expected to the year 2042.

Alternative 1 – Conservationist: the predominant feature of the study area is the high concentration of urban population, unlike the characteristic of Tete Province, where the majority of the population is rural. Another important aspect is that a significant portion of the rural population performs seasonal migrations. These migrations are explained by the search for fertile land and/or water availability for subsistence agriculture and livestock. However, this population return to their places of origin after the harvest period.

For the Industrial Complex of Moatize and its surroundings it was found that the vegetation is predominantly secondary, it has low diversity and is generally very altered by the intensive use of forest resources. All groupings of soil units occurring in the concession area show signs of development of erosive processes and mass movements in specific sectors, exacerbated by torrential rainfall incident in the region (October to March). In the concession area there are some potentially unstable sites, which are confined to the embankments of the mining areas and in some aspects the banks of the Rivers Revuboé and Moatize.

In the context of the closure of the industrial complex of Moatize, the conditions relating to the areas degraded by agriculture and intensive use of forest resources, associated with the characteristics of soil and local geotechnical aspects, indicate a first future use alternative (Figure 3) of conservative nature, giving priority to the protection and/or recover of the natural environment. This first alternative does not consider the economic use of natural resources, but its conservation, assuming therefore the conversion of agricultural areas in natural formations.

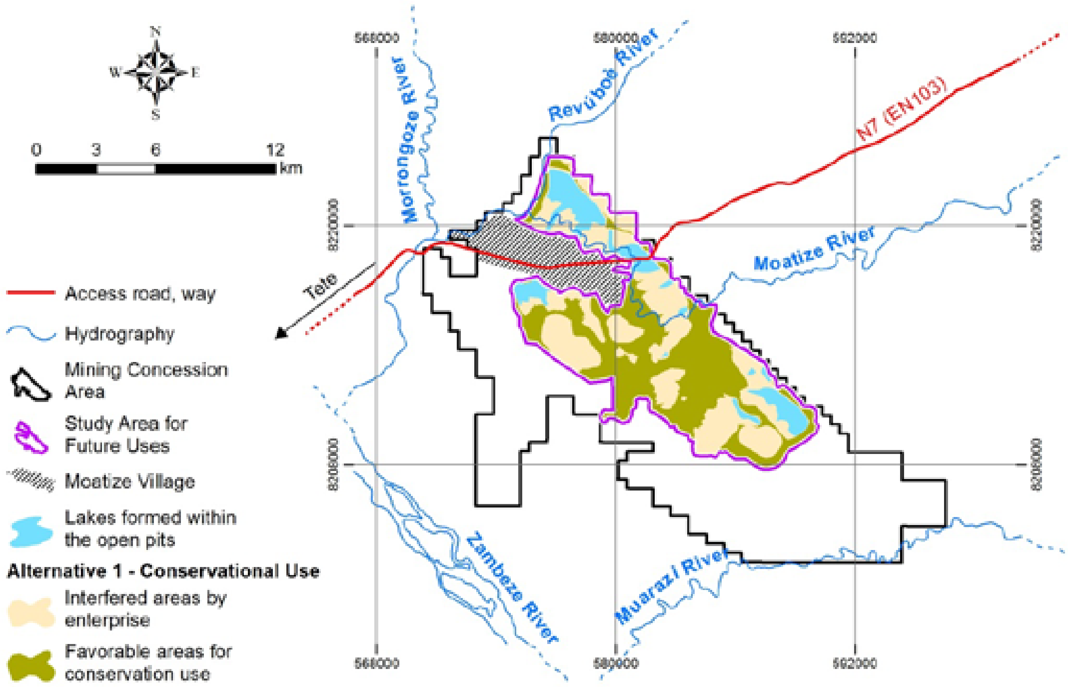


Figure 3 - Alternative 1 - Conservationist Use

Alternative 2 - Agricultural Use: In the district of Moatize, agriculture is the predominant activity and involves almost the entire rural population. Production is primarily focused on self-consumption and to a lesser extent, for the marketing of surpluses. Cash crops are represented by tobacco, cotton and sesame, practiced by the household sector. The production of Moatize Village has different characteristics from those activities developed by other rural communities, since the Village population cannot have a direct economic dependence of this activity as rural populations.

With respect to livestock, in the Moatize Village this activity is practiced by households, and the creation of goats and, to lesser extent cattle, is directed to the sale and exchange for various other food crops available elsewhere and, to a lesser extent, to the consumption of meat.

A limiting factor of agricultural production is the lack of availability of water, which was found in studies of water resources in the context of the characterization of the physical medium. Water availability of rivers present in the area of interest is generally low. The characteristics of average annual rainfall and potential evaporation collaborate to low water potential.

A relevant aspect in relation to water resources is the quality of surface water, which has a close relationship with low water availability, with marked seasonal influence on deterioration, with negative impact on groundwater quality, which have high concentrations of alkalinity and salts (Aurecon AMEI *et al*. 2010).

In the context of the closure of the Industrial Complex of Moatize, social and environmental conditions described above indicate a second future use alternative (Figure 4), which would be considered agricultural use. This alternative is premised on the decommissioning of industrial structures and the support of the Industrial Complex and other areas would be converted to agricultural use.

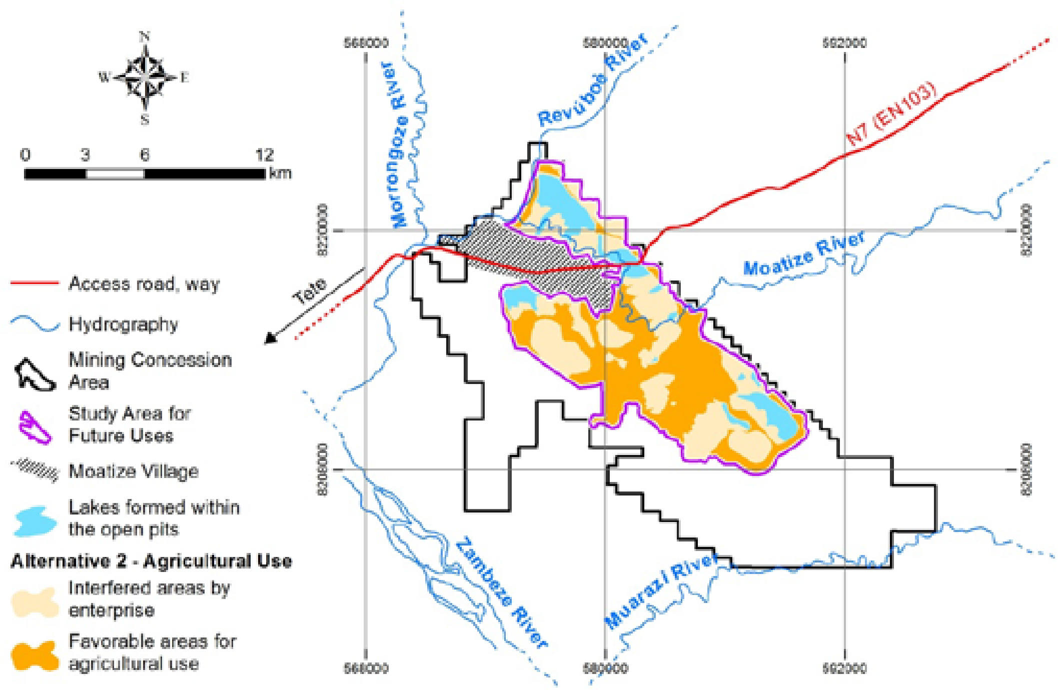


Figure 4 - Alternative 2 - Agricultural Use

Alternative 3 - Multiple Use: the extractive activity of mineral resources has great potential for exploration and production for the whole province and the District and Moatize Village, being considered, currently, the main economic activity of the region.

The wealth of Moatize District in terms of high-value mineral resources, especially coal, makes the district attractive for their operation, with the installation of large mining projects, which in a way will raise the expectations of economic growth. Thus, the existence of mining companies and the labor they require, increase the expectation or perception of the population that the Province of Tete and in particular the Moatize Village, are a point of attraction and constitute in areas of great opportunities. The development of this economic activity, on a larger scale, means a structural change in the local and regional economy.

With the growth of mining concessions, the areas currently used for subsistence agriculture will definitely be changed depending on the mineral extraction, changing the productive vocation of families. However, a big number of the work stations of mining companies require skilled labor, with different specialties which is an aggravating factor when considering the limitations of educational infrastructure and vocational training in the region (Aurecon AMEI *et al*. 2010). According to Cumbe (2007), Mozambique has a huge "geotouristic" potential related to its large geodiversity, but that has not been properly organized and exploited.

These characteristics are clearly in favor of maintaining the future use linked to mining, with the possibility of continuation and/or diversification of current operations. Therefore, it is an indication of a third alternative future use for the closure of the industrial complex of Moatize, i.e. the multiple use of the area (Figure 5), considering three main uses: the recovery of native vegetation with a view to future sustainable exploitation of plant resources; support agriculture in suitable land; industrial and/or institutional use of part of the industrial, administrative structures and support to complex in which the facility may be used, for example, to the development and training of professionals in geology and mining and/or development activities related to geotourism and geoconservation.

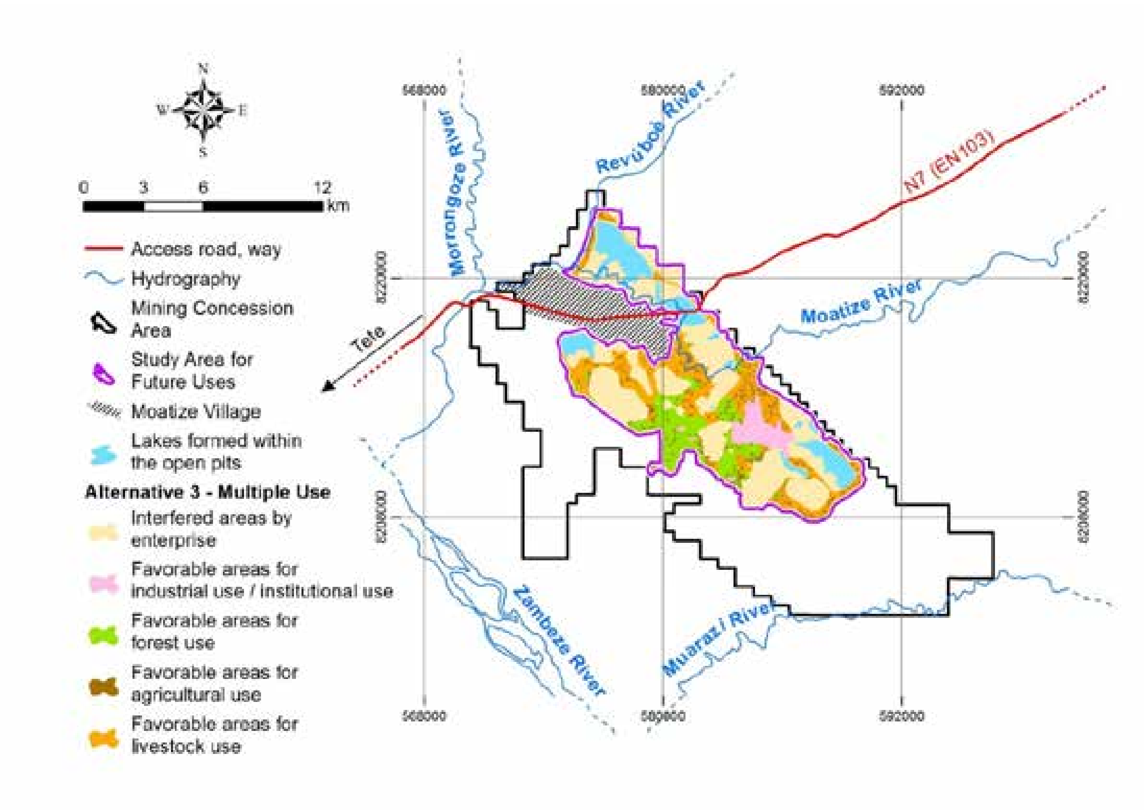


Figure 5 - Alternative 3 - Multiple Use

**Stage 5: Analysis of Cost-Benefit of the Potential Alternatives of Future Uses in the Defined Study Area**

Although the closure of Moatize activities are planned for a relatively distant period, estimated for 2042, the Complex Closure Plan considered a cost-benefit analysis of potential alternatives for future use, in order to support the selection of the most appropriate alternative, considering engineering, economic, environmental, social and financial aspects. This analysis was developed from information obtained from the environmental characterization, concepts, assumptions and each alternative costs proposed in Step 4. It is known that the more remote the closure, the greater the uncertainty about the future use alternatives. However, the alternatives were evaluated in terms of its positive aspects, weaknesses and risks.

## RESULTS

After a comparative analysis of the three alternatives, taking into account the positive aspects, weaknesses, preliminary estimate of costs and risks, we came to the conclusion that the most appropriate option for the study area of Moatize Industrial Complex is the Alternative 3 - Multiple Use.

The positives aspects of Alternative 3 are: the positive legacy to the population with the optimization of the use and occupation of land for agriculture, livestock and forest management; alignment with the regional vocation (mining), with the use of the mine site, for example, for education and professional training and the needs identified by the government as lack of basic and educational infrastructure and support to tourism and/or health, with the use of structures; the lowest cost of deployment.

The weaknesses of Alternative 3, it was point out the need for maintenance of part of the structures that will remain, by future users, who may not have the knowledge and/or human and financial resource for both; most of the area has no agricultural capability, therefore soil irrigation and fertilization costs are high; the soil has a high potential for salinization (inadequate irrigation management); and low water availability, both in qualitative and quantitative terms, resulting in additional cost for water collection system.

From the definition of the Alternative 3, the identification of impacts of closure and post-closure residual risks in physical, biotic and socioeconomic environment was carried out in order to guide the proposition of plans and programs to mitigate and minimize the impacts, which are in progress. For mitigation, prevention and/or control of risks associated with the scenario considered, measures were indicated to be adopted with the proposed environmental programs to mitigate and/or minimize impacts that are adverse.

## CONCLUSIONS

The second version of the Closure Plan promoted a significant conceptual change from the initial study, through the full restoration scenario of interfered areas to a multiple use proposal, which is more aligned with the local reality, without prejudice to the protection of the environment. Changes of this nature arise from advances in the level of maturity of the enterprise in conjunction with the development of the knowledge about the environment and the socioeconomic and cultural characteristics of local communities. These characteristics reinforce the dynamics of Closure Plans and its importance as a tool for planning of mining projects, especially with regard to the alignment of closure guidelines with social aspirations, vocations and environmental constraints.

Considering the mining vocation of the Moatize region, where there are more than 40 mining concessions, it is reasonable to infer that in the near future the enterprises should develop their Closure Plans in an integrated way in order to optimize the applied resources and to reduce costs. In this sense, the methodology of Regional Planning for the closure has great applicability to the conditions of the study area.

## ACKNOWLEDGMENTS

Our gratitude to Vale for providing important examples of studies. We also thank ERM Brazil for encouraging us to publish this paper.

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# THE USE OF THE BLENDS ZEOLITE/ BACKFILL FOR THE REMEDIATION OF ENVIRONMENTAL IMPACTS

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# THE USE OF THE BLENDS ZEOLITE/BACKFILL FOR THE REMEDIATION OF ENVIRONMENTAL IMPACTS


## ABSTRACT

The Brazilian coals presents both high ash and high sulfur content, that is more susceptible to lead to the acid mine drainage (AMD). Furthermore the combustion of this kind of coal generates huge quantity of ashes, which are basically constituted of amorphous silicon and aluminum oxides that allows the alkaline hydrothermal processing of such waste in zeolites. These versatile compounds have been suggested as an alternative material for remediation of AMD. This study aims to evaluate the use of zeolite NaP1 in backfill blends to be used in coal mines. The tailings used as backfill were obtained in the coal beneficiation process, carried out in jig and separated by gravity. The synthetic zeolite (NaP1) was produced by use of coal fly ash generated in Thermoelectric Power Plant in south of Brazil). Leaching experiments in laboratory scale were performed and several parameters (XRD, SEM-FEG, F AAS, ICP-MS, Ion Chromatograph, pH and conductivity) were monitored over time, to assess the AMD remediation and the mobilization of ions in leachates using different blends zeolite: tailings. The preliminary results indicate that the addition of zeolite produced from coal ash caused the remediation of metals concentration in water generated by acid mine drainage. A considerable reduction was observed in the concentrations of aluminum, iron, calcium, magnesium, zinc and manganese. The blend with zeolite (50%) allowed high concentrations of these metals to be reduced in 100, 98, 39, 55, 94 and 41%, respectively, in 7 days of leaching. The increase in pH caused by the addition of zeolite promoted the precipitation of metal ions and sulfate reducing their concentration in the aqueous medium. The addition of zeolite at the rate of 50% in the residue used as backfill was more favorable in the metal ion removal process. Addition of 50% or 25% of zeolite in the sample backfill caused an increase of 6 or 2.3 pH units, respectively, in period of 1, 3 and 7 days.



## KEYWORDS

Backfill, zeolite, acid mine drainage, environmental, remediation.


## INTRODUCTION

Currently due to growing concern about the preservation of the environment near to urban settlements and mines, researches in relation to environmental impact caused by the mining and use of coal are in constant progress (Depoi, 2007; Kortnik, 2003). In this aspect it includes the filling of mine areas already mined with backfill tailings. Backfill refers to any material (waste) that is placed in the empty underground mine in order to eliminate or to perform some functions such as engineering structural stability of the mine. (Zingano et al, 2011, Heemann et al (2008)).

Coal in Brazil presents on average 50% ash, composed mainly of clay minerals, high sulfur content, and is usually classified as low-rank (Sánchez et al., 2002; Kalkreuth, 2009; Fallavena et al, 2014). It is important to consider this because of the concern with the oxidation of pyrite in coal-rich mineral that makes them more susceptible to lead to acid mine drainage when in the presence of water. In this situation occurs the mobilization of iron ions and sulfate to the medium in a pH range 2-14 (Carrillo et al, 2009;. Mukherjee et al., 2004; Baruah et al., 2007). Furthermore, in Brazil, it is generated about 3 million tons per year of ash from burning coal to generate thermoelectricity (Kalkreuth, 2009). These coal ash derived from thermal power plants consist primarily of silica and alumina, and it can be used for transformation in zeolitic material through heat treatment in an alkaline medium (Cardoso et al, 2015). Zeolites have been suggested as an alternative material due to its high ion exchange capacity and mechanical stability (Rahman et al, 2009 Fungaro and Izidoro, 2006). Synthetic Zeolites are hydrated aluminosilicate synthesized by hydrothermal treatment with strong alkali (NaOH) in fly ash from coal. They are crystalline aluminosilicate and micro porous formed by tetrahedrons type $TO_4$ (T = Si, Al).They are Present in the structural cavities and interconnected channels of molecular dimensions in which water molecules are found, compensation ions or other adsorbates. This structure allows the transfer of matter between the intracrystalline space, but is limited by the diameter of the pores of the zeolite (Cardoso, 2012, Gianneto, 1989 apud Luz, 1995; Auerbach et al., 2003).

The objective of the study was the chemical and morphological characterization of the material used in filling the galleries abandoned and to evaluate on a laboratory scale, the release of metal ions and sulfate to the solubilization and leaching of the filler water in period of 1, 3 and 7 days. The work also aimed remediation with the mobilization of ions in leachates using a mixture composed of zeolite type $NaP_1$ and backfill.

## EXPERIMENTAL

The backfill sample was collected in the northern portion of the basin Carboniferous on Southern Santa Catarina, mine called Bonito Mina I, owned by Carboniferous Catarinense Ltda, located in the city of Lauro Müller-SC. The location selected for the application of the mineral filler is located near the entrance to the mine and coal beneficiation plant. The panel was mined between October and November 2000 and covers a total area of 10,890 m². Coal waste used as mineral filler material traverses 200 m distances to 1000 m to the point of discharge and pre-established storage (Zingano and Karas, 2009). The site remained dry during all period. In the synthesis of zeolites NaP1, used in this study, fly ash generated by Unit B coal combustion Thermoelectric Plant Presidente Médici were used in Candiota (UTPM) (Rio Grande do Sul - Brazil) and NaOH (Merck, 99.5 %) and metallic Al (Synth, commercial grade). Zeolite was synthesized per collaborator group belonging to the LQAmb-FAQUI-PUCRS and according to the methodology presented by Cardoso et al (2015). The study of the elements leached by backfill waste when in the presence of water follows the methodology present by Ward et al (2010). 32 g of the sample were added (particle size <2.30 mm) to glass bottles and added to 112 g of deionized water. After, were maintained under agitation of 110 rpm (table incubator with agitation model 430 - RDBP New Ethics), the temperature of 25 °C for periods of 1, 3 and 7 days. The tests were performed in triplicate. After the samples were centrifuged and filtered (cellulose acetate membrane filters of 0.22 µm). Due to the period tested the results should be seen as characteristic of the first stage of leaching, that could not be representative of long-term environmental stability and associated discharge quality. It is important to consider factors such as mineral types, surface area, pH, and temperature, source of water, oxygen and others as responsible for sulphide oxidation, and the release of other toxic substances to the environment when coal tailings are exposed to the environment. Sulfide oxidation is generally restricted to the portion exposed to the atmosphere.The duration of effects from sulphide oxidation from tailings can range from decades to centuries. (INAP 2014). Tests are ongoing to verify the long-term leaching behavior to improve the estimate of AMD to real conditions.

New tests were performed with mixtures of zeolite: backfill in the proportion of 25:75 to 50:50. In these new tests, 32 grams of the total mixture of solids (particle size <2.30mm) as indicated above proportion, were placed in glass flasks and added 112 grams of deionized water and maintained under the same conditions applied to the backfill samples. The diffraction analysis X-ray (XRD - Model XRD-7000 Shimadzu) and X-Ray Fluorescence (XRF - Model WXRF - Shimadzu 1800) were performed in the Laboratory of Materials and Nanoscience -LMN FAFIS. Morphological and elemental analysis qualitative by Scanning Electron Microscopy for field emission (SEM-FEG) was performed in the model Microscope Inspect F-50, FEI (voltage 0.3 to 30 kV) in Microscopy and Microanalysis Center of PUCRS. The determination of total sulfur content by LECO equipment, and forms of sulfur were carried out in CIENTEC (Foundation of Science and Technology of the State of Rio Grande do Sul). The forms of sulfur (sulfate, pyritic and organic) in the sample backfill were determined using ASTM D 2492/1990 (1994). The parameters of the proximate analysis - moisture, ash content, volatile matter, fixed carbon - were determined following standardized procedures (ABNT-NBR 8293, 8289, 8290, ASTM 3172/0a). The determination of the concentrations of Fe, Mn, Ca and Al was performed by Atomic Absorption Spectrometry by Flame - FAAS (Varian AA55). For minors elements concentrations was employed to Mass Spectrometry with Inductively Coupled Plasma - ICP-MS (Agilent 7700x). The determination of the sulfate concentration was carried out in Chromatograph Dionex DX-500 with detection by conductivity and chemical suppression ED40 for the determination of anions. To the determination of the pH was used a pH meter Digimed (Model DM - 20) and measuring the conductivity was used Digimed conductivity meter (Model DM - 31).

## RESULTS AND DISCUSSION

### Physical, chemical and mineralogical characterization of raw backfill

Table 1 shows the results of proximate analysis, total sulfur, sulfur forms and chemical composition of the sample backfill.

Table 1 Proximate analysis, forms of sulfur, and chemical composition (by XRF (HTA ash)) of raw backfill sample

| Proximate Analysis (%, dry basis) | | Chemical Composition (%) | |
|---|---|---|---|
| Moisture | 3,19 | $SiO_2$ | 52,87 |
| Ash | 74,55 | $Al_2O_3$ | 24,88 |
| Volatile matter | 16,51 | $TiO_2$ | 1,02 |
| Fixed carbon | 8,94 | $Fe_2O_3$ (total) | 14,36 |
| | | MgO | 1,04 |
| **Forms of Sulfur (% dry basis)** | | CaO | 0,57 |
| Pyritic | 2,12 | $Na_2O$ | 0,36 |
| Sulfate | 2,72 | $K_2O$ | 2,98 |
| Organic | 0,49 | $Cr_2O_3$ | 0,09 |
| Total | 5,33 | $ZrO_2$ | 0,05 |
| | | ZnO | 0,05 |
| | | $Rb_2O$ | 0,04 |
| | | SrO | 0,03 |
| | | $SO_3$ | 1,66 |

The results indicated characteristics expected for this type of sample with high ash content (74.55%) since it is originated from waste coal that have high levels of mineral matter (~ 50%) (Fallavena et al, 2012; Kalkreuth et al., 2009; Depoi et al., 2008). The total sulfur content was high (5.33%), and 40% of the total refer to the pyritic sulfur content (2.12%) and 51% to sulfate sulfur content (2.72%). The chemical composition of the sample backfill determined by XRF and expressed as oxides was determined in the ashes (HTA) of the sample. The results obtained for the sample backfill demonstrate that the predominant oxides were the Si (52.87%), Al (24.88%) and Fe (14.36%). Other important components are the oxides of Ca (0.57%) and K (2.98%). The high Si and Al contents are related to the presence of aluminosilicate, mineral phases present in the majority of coal tailings. It was also observed low contents of elements Ti (1.02%), Mg (~ 1%), Na (<0.35%) and P (0.003%), expressed as oxides.

Analysis by XRD to verify mineralogical composition identify the presence of quartz ($SiO_2$), kaolinite ($Al_4(OH)_8(Si_4O_{10})$), muscovite ($KAl_2Si_3AlO_{10}$ $(OH)_2$, pyrite ($FeS_2$), gypsum ($CaSO_4.2(H_2O)$ jarosite $KFe_3(SO_4)_2(OH)_6$, albite ($NaAlSi_3O_8$) as major minerals, confirming the results of XRF. The XRD pattern obtained for the sample is shown in Figure 1.

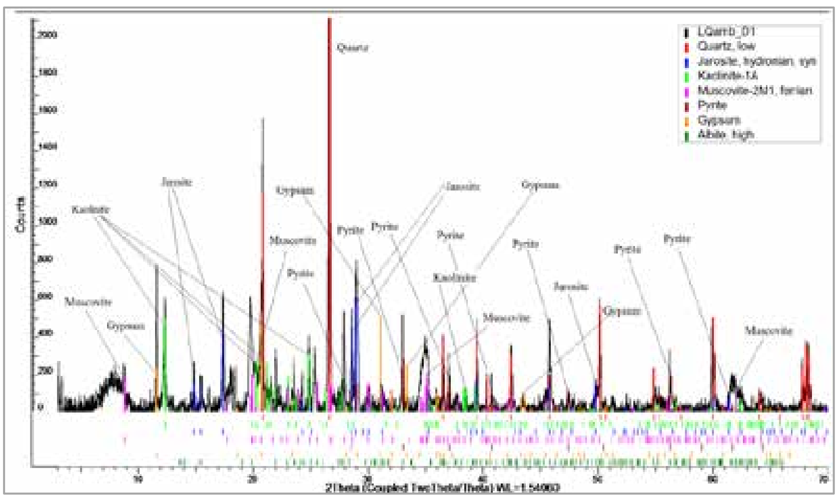

Figure 1 X-ray diffractograms of backfill ray sample

Part of substantial amount of calcium and sulfur observed in the results of XRF comes from the presence of gypsum ($CaSO_4.2H_2O$) and sulfur is mainly coming from the pyrite and jarosite in the samples. The results are consistent with the literature, which cite clays, sulphides, carbonates and quartz as the most common minerals in coal. The percentage of these minerals in coal is very variable from one basin to another (Nahuys et al., 1984 Speight, 2005).

**The use blend zeolite / backfill for the remediation of environmental impacts**

pH and conductivity

The pH and conductivity results obtained on the leaching of the mixture of zeolite/backfill in the proportion of 25:75 (ZB25) and 50:50 (ZB50) in a period of 1, 3 and 7 days are shown in Figure 2. The results for the pH values showed that the addition of zeolite promoted a significant increase in pH. Zeolite (NaP1) used in the test was not washed and presented a pH of 11.07 when added in an aqueous medium,which justifies the increase of pH observed when comparing the mixture zeolite/backfill with raw backfill. It is observed that with the addition of 50% zeolite in the sample backfill pH showed an increase of 6 pH units during the period of 1, 3 and 7 days. In the mixture containing 25% zeolite the mean increase was 2.3 pH units during the period of 1, 3 and 7 days of leaching.

The results of the conductivity measurements obtained for the mixture of the sample of zeolite / backfill showed a conductivity profile that accompanies the pH. The highest conductivity values were observed for the mixture of zeolite / backfill because the zeolite has a high ion exchange capacity. In this case the exchange cations that form insoluble compounds at higher pH are exchanged for $Na^+$ cation forming compounds which keep dissolved in the medium and thus increasing the conductivity of this means.

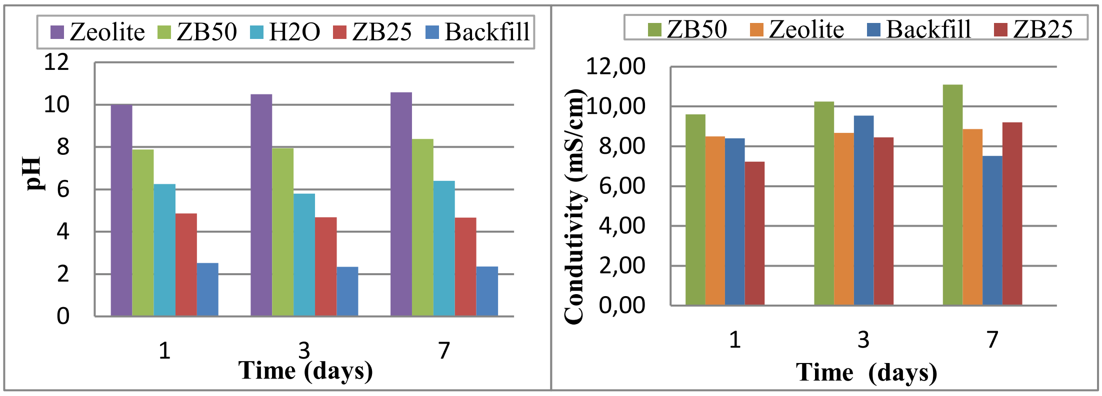


Figure 2 – Evolution of pH and conductivity of the sample backfill and mixed with zeolite in water as a function of time.

Concentration of metal ions majority, minority and sulfate

The results of the concentration, in mg $kg^{-1}$, of the elements present in greatest concentration (Al, Fe, Ca, Na, Mg, Zn, and Mn) dissolved in the extract resulting from the sample leaching backfill or in combination with zeolite/backfill ZB 25% (25/75) 50% and ZB (50:50) at 7 day period are presented in Figure 3.

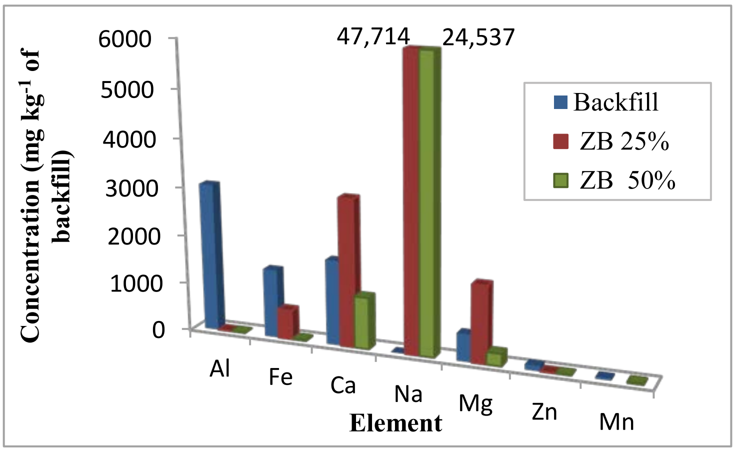


Figure 3 – Concentration of major ions, mobilized during the leaching of the backfill mixture with zeolite sample (25% and 50%) in the period of 7 days. The values that extrapolate the axis (ordinate) are shown as the label data in the figure.

According to Figure 3, it is noted that there has also been significant reductions in mixing ZB 25%. In this case the iron reduction was 57.6%, but lower than that obtained for the mixture ZB 50% (98%). According Fungaro and Izidoro (2006), $Fe^{3+}$ has a high affinity for ion exchange sites of $Na^{1+}$ zeolite in relation to most of the divalent metals. A reduction of 58 to 99% for metals has been achieved with the use of ZB 25%. It should be noted that however there was an increase in the concentration of Ca and Mg in the leachate mixing ZB 25% compared with leaching of backfill. According to Cardoso (2015), Paprocki (2009) and Pires and Querol (2004), significant concentrations of $Ca^{2+}$ and $Mg^{2+}$ were observed in the leaching NaP1 zeolite used in this study. This is justified because the fly ashes from Candiota that originated zeolite appear significant amounts of Ca and Mg. With the lowest concentration of zeolite and the high concentration of Fe and Al in the leached positions available for other metal ions are reduced. According Fungaro and Izidoro (apud Dyer, 1995), the configuration and dimensions of the channel, charge density in the zeolite channels, size, shape and valence of the metal ions are factors that influence the affinity of the zeolite in the adsorption process.

Figure 4 shows the concentration of minor elements present in the leachate backfill and mixtures ZB 25% and ZB 50%. The analysis of this figure shows that the concentrations of minor elements are in a range of 1 to 99 mg $kg^{-1}$. With the addition of 25% zeolite or 50%, removal of cations was approximately equal with the removal rates of 10 to 97%.

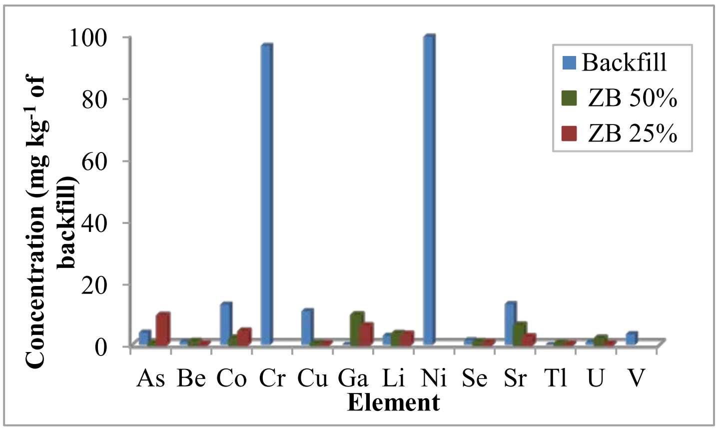


Figure 4 – Concentration of minority metals of the backfill sample and mixed with zeolite in water (7 days).

The results of sulfate ion concentrations obtained from the leaching of backfill, ZB 25% and ZB 50% for 1, 3 and 7 days is presented in Figure 5. The results of the total sulfur contents and forms of sulfur present in the sample backfill and the resulting solid leaching for 7 days showed a reduction of 38% in $S_{total}$ (5.33 to 3.32%), 21% $S_{pyritic}$ ( 2.12 to 1.67), 51% of $S_{Sulfate}$ (2.72 to 1.34) and 37% in $S_{organic}$ (0.49 to 0.31). Analysis of the contents of sulfur forms carried on raw backfill sample showed an $S_{sulfático}$ content (2.72%) pointing to a maximum sulfate concentration of 81481 mg $kg^{-1}$, subject to solubilization. Also, 2.12% of S pyritic, which if oxidized to sulfate, would release 63507 mg $kg^{-1}$ of this ion.

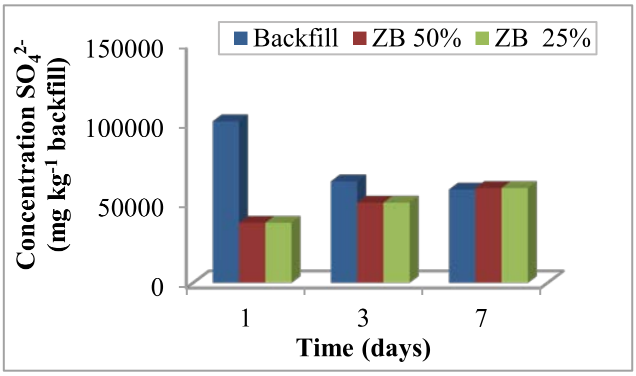


Figure 5 – Concentration of sulfate ion mobilized on backfill sample leaching process and mixed with zeolite (50 to 25%) and ash (50%) as a function of time.

Figure 5 also shows that the sulfate concentration in the leachate, after 1 day, was 101505 mg $kg^{-1}$ thereby indicating a possible oxidation of pyrite with the sulfide converted into sulfate. However sulfate content was reduced to 58863 mg kg-1 in 7 days leaching. According Querol et al. (2011), when the dissolved sulfate concentration is high (values above 50 mg $L^{-1}$), part of Fe is precipitated as jarosite ($KFe^{3+}(OH)_6(SO_4)_2$) lowering the stoichiometric relationship (2 mol $SO_4^{2-}$:1 mol Fe) when pyrite is oxidized. It is also observed that the concentration of Fe and Ca increases with increasing leaching time (days 1 and 7), but the variation in concentration was small, 1225 to 1422 mg $kg^{-1}$ and 1674 to 1758 mg $kg^{1}$ for Fe, and Ca, respectively. This fact may indicate a possible re-precipitation of these elements in the form of sulfate. $Ca^{2+}$ and $SO_4^{2-}$ ions can result in precipitation of gypsum (Gitari, 2008). Besides precipitation processes, due to the increased concentration of ions which promote the formation of less soluble compounds, it may occur occlusion process, or drag or trapping ions in the interstitial water of the precipitates which also justify the decrease in their concentrations in the liquid phase (Silva, 2010). When 50% of zeolite was added to the backfill on a day of leaching, the concentration of $SO_4^{2-}$ was reduced from 101505 $kg^{-1}$ mg to 54399 mg $kg^{-1}$, similar to that observed concentration backfill for 7 days of leaching. The same behavior was observed for the ZB 25% sample. This behavior can be explained by the increased concentration of Ca and Fe ions present in the zeolite used. The major components of fly ash, used in the synthesis of zeolites, are aluminosilicates and salts (sulfates, chlorides and oxides) formed in high temperature fired power plants. Some of these phases are highly unstable in the presence of water and might be dissolved completely, and then the more stable and less soluble mineral phases may precipitate (Gitari, 2008). With the increase of pH it may be formed $Fe_{16}O_{16}(OH)_{10}(SO_4)_3$, (schwertmannite), which probably justify the decrease in concentration of $SO_4^{2-}$ and Fe with the addition of zeolite to the reactional means (Ramos et al, 2014). The addition of zeolite to the backfill in the proportion of 50% allowed the largest decreases for Al, Fe and Zn, reaching levels of acceptable water quality, the values for these elements are 0.2 to 5 and 5 mg $L^{-1}$ respectively (Resolution CONAMA 357/2005).

Figure 6 shows the concentrations of metal ions mobilized before and after treatment with addition of 25% zeolite or 50 to backfill after 7 days leaching.

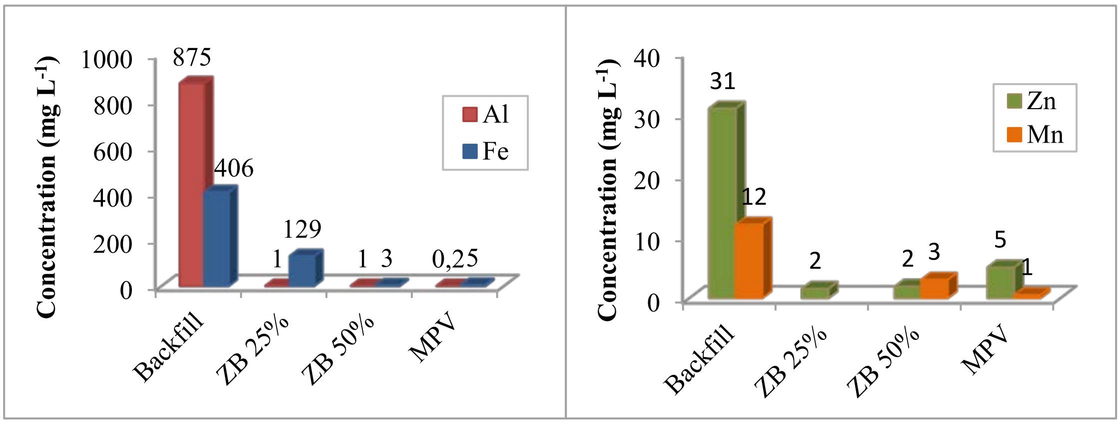


Figure 6 – Concentration of metal ions, mobilized before and after treatment with addition of 25 zeolite, 50% to backfill time of 7 days. MPV = maximum permitted value for effluent second CONAMA 357/2005.

According to Figure 6 it is noted that the Al concentrations were reduced from 875 to 1 mg $L^{-1}$, Fe from 406 to 3 mg $L^{-1}$ and Zn from 31 to 2 mg $L^{-1}$. Mn showed a reduction from 12 to 3 mg $L^{-1}$, still well above the maximum permitted value (0.5 mg $L^{-1}$). Removal of $Mn^{2+}$ by precipitation requires that the ion is oxidized to the states 3+ or 4+, and therefore an unfavorable and slow process (Fungaro e Izidoro (2006)). $Fe^{3+}$ has high affinity per ion exchange sites of the $Na^+$ zeolite, however the use of zeolite 25% still remained high Fe concentration in the leachate (129 mg $L^{-1}$), representing a reduction of 68%, while for zeolite 50% reduction observed was 99%. The removal of $SO_4^{2-}$ ions was less effective, since the concentration (16819 mg $L^{-1}$) was in levels well above the permissible limit (250 mg $L^{-1}$). There was a reduction 12807 and 7902 mg $L^{-1}$ when mixed with zeolite 25 and 50%, respectively.

<u>Morphology and qualitative elemental analysis</u>

Figures 7 and 8 show the results of the solid surface microscopy ZB 50% and ZB 25%, respectively, submitted to leaching in deionized water for 7 days. It is observed in Figures 7 and 8 that the morphology of the sample exhibited a surface with high concentrations of Na, Fe, Ca and Mg. The presence of carbonaceous material and mineral matter besides Al, K, Fe, Ca, Mg, Ti, Si e C was confirmed by EDS spectrum .

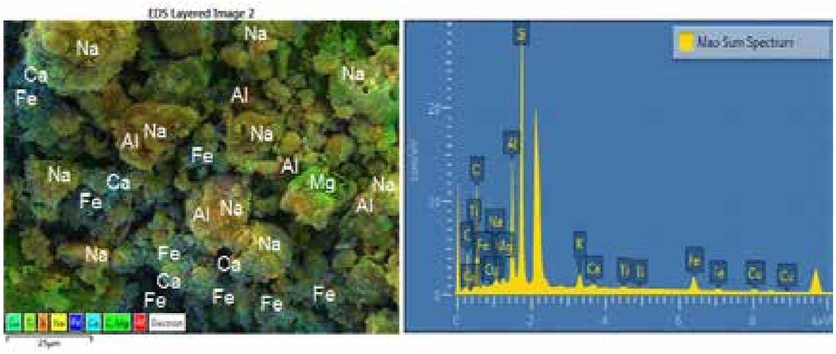


Figure 7 – Scanning Electron Microscopy - SEM-FEG sample backfill + zeolite (50%) leached for 7 days and their Spectra Energy Dispersive.

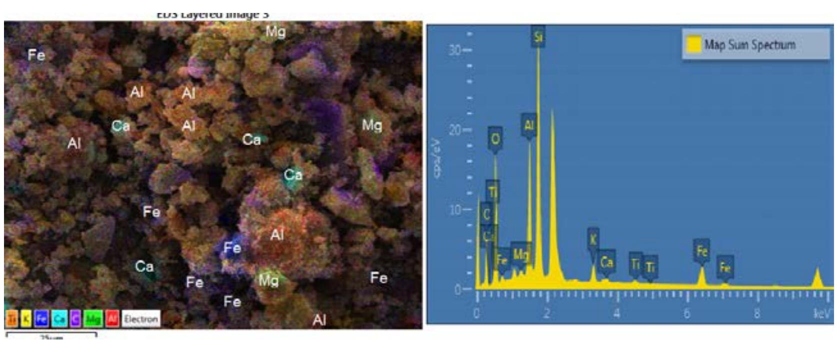


Figure 8 – Scanning Electron Microscopy - SEM-FEG sample backfill + zeolite (25%) leached for 7 days and their Spectra Energy Dispersive.

## CONCLUSIONS

The results demonstrate acidification of the resulting water leaching backfill comprised from coal residuals. This filling also causes the release of high concentrations of metal ions (Al, Fe, Zn and Mn) and $SO_4^{2-}$ when in contact with water in a possible inundation of the mine, generating acid mine drainage (AMD). The pH of the leached was on average 2.00. The mixture of zeolite NaP1 / backfill allows minimize the generation of AMD to yield a leachate pH approximately 8.0 and 5.0 for the blends ZB 50% 25% ZB, respectively. A reduced concentration of metals (Al, Fe, Zn and Mn) for these mixtures was obtained. The concentration of $SO_4^{2-}$ was also reduced but due to the high initial concentrations, the maximum permitted values has not been reached, however reduced when adding zeolite to backfill. The increase in pH caused by the addition of zeolite promoted the precipitation of metallic and $SO_4^{2-}$ ions, reducing their concentration in the aqueous medium. The addition of the zeolite at a backfill rate of 50% was more favorable in the process of removing metal ions and $SO_4^{2-}$. The mechanism responsible for the minimization of AMD after the addition of zeolite into coal tailings as backfill used is related to the ion exchange process in conjunction with the process of precipitation that occurs by increase of pH with addition of zeolite. Given the short period tested, new leaching tests are in progress to confirm the obtained results.

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# WATER QUALITY ASSESMENT IN CATCHMENT AREAS OF OPEN PIT MINES – A METHODOLOGICAL APPROACH

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# WATER QUALITY ASSESMENT IN CATCHMENT AREAS FOR OPEN PIT MINES – A METHODOLOGICAL APPROACH


## ABSTRACT

This paper presents a methodological approach that indicates which routes should be followed for the environmental assessment of water quality to ensure that the chosen variables are measured and classified throughout the different mining phases of an open pit mine project. The methodology was applied at N5S iron ore mine in Carajás, Pará state, Brazil. It was possible to make environmental measurements for the surrounding drainage network for three distinct phases: planning, installation and operational, where initial results allowed that changes in operational procedures were performed successfully for the maintenance of water quality in the vicinity of the mine.



## KEYWORDS

Quality water indicators, environmental quality, environmental monitoring plan, open pit mine, Carajás


## INTRODUCTION

In several specific studies for the development of a mining project, there are those directly associated with the environmental impacts of land use change. Although the data indicate that the natural conditions change throughout the project development, it should be considered periodic reassessment of these conditions, so adjustments can be done if necessary.

It is therefore essential apply mature and consistent methods and technics during the development of new open pit mine projects, setting the procedures to be adopted from the planning phase, heading to the mine installation and operational phases, including the mine closure activities. It is important that environmental quality can be measured before, during and after the start of mining operations enabling adjustments of procedures.

Among the environmental variables, special attention has to be dedicated to the evaluation and monitoring of water quality in the direct influence area of the open pit mine project. This ensures that the initial quality conditions are preserved or indicate that changes can be planned and managed. Methodologies for assessing water quality are always being discussed among enterprises and environmental licensing agencies.

Geochemical baseline studies are directly related to mining projects correlating the observed water mineralization changes on the impacted area, defining the natural availability of elements in the drainage system. Based on the concepts of anomalous concentration used to compose the geochemical background studies, this paper proposes a method for water quality assessment in the catchment area of a new open pit mine project based on comparisons of monitoring results for all mining phases.

## OBJECTIVE

This paper presents a workflow for water quality assessment in catchment areas of open pit mine projects to monitor the impact at the direct influence area, based on natural conditions (background). It was applied at N5S iron ore mine in Carajás, and it has considered the main issues:

1. Monitoring plan well established to drainage area evaluation for all mining phases.

2. Setting the minimum sampling network for the truly direct influence area of the planned open pit mine project.

3. Election of the right indicators for water quality assessment aligned to the operational aspects of the mine.

## METHODOLOGICAL APPROACH

During a mine-cycle, many questions about possible water quality impacts arise from lack of mature methodologies to ensure the mapping and identification of pre-existing abnormal conditions particularly in the planning phase. The water-monitoring plan is often applied without warranty of assertive responses on different quality conditions of those originally established.

A relevant fact about water quality assessment methods is to use the same criteria in different mine development phases. The present workflow is a dynamic proposal, which does not have a lock on a particular phase, but considers supplementary information between them.

The proposed workflow for water quality evaluation during different mining phases of open pit mines can be summarized on the following five main steps:

**Step 1 - Environmental studies analysis prepared for the environmental licensing stages**

It were evaluated the hydrological and hydrogeological parameters, the monitoring plan applied for the planning phase, the environmental control plan and the results of water quality characterization during seasonal periods, as well as the environmental impact matrix.

**Step 2 - Evaluation of ore production plans**

It were evaluated the production master plan and preliminary executive plans such as surveying, opening accesses, fleet sizing, blasting methods, production volumes, ore grade quality and its geometalurgical route and impacted drainage basin.

**Step 3 - Definition of key operating points and schedule**

It were assessed the executive general schedule along with initial topographic activities with delimitation of deforestation areas, evaluation of the geological profile of the first phase, the ore physical characteristics to be mined, strip ratio/ore on the mining opening, amount of explosives, volume of material in the stripping, surface drainage direction.

**Step 4 - Establishment of the main stakeholders involved and their responsibilities**

Reviewed responsibility matrix for the whole mining activities in order to have quick response for operational adjustments if necessary.

**Step 5 - Monitoring model design for planning and operational phases with systematic reassessment for comparisons and search for consistent results**

It was implemented the monitoring model with systematic reassessment to validate the first results based on comparisons.

## RESULTS

Figure 1 shows the workflow processes range from the analysis of environmental monitoring data in the planning phase to the mine closure phase; settings check points and procedures when deviations in water quality are detected. It is important to consider that the proposed processes are to run over the whole mine cycle and can be adjusted according to operational need and that it is essential the participation of operation, mine planning and environment teams in the implementation.

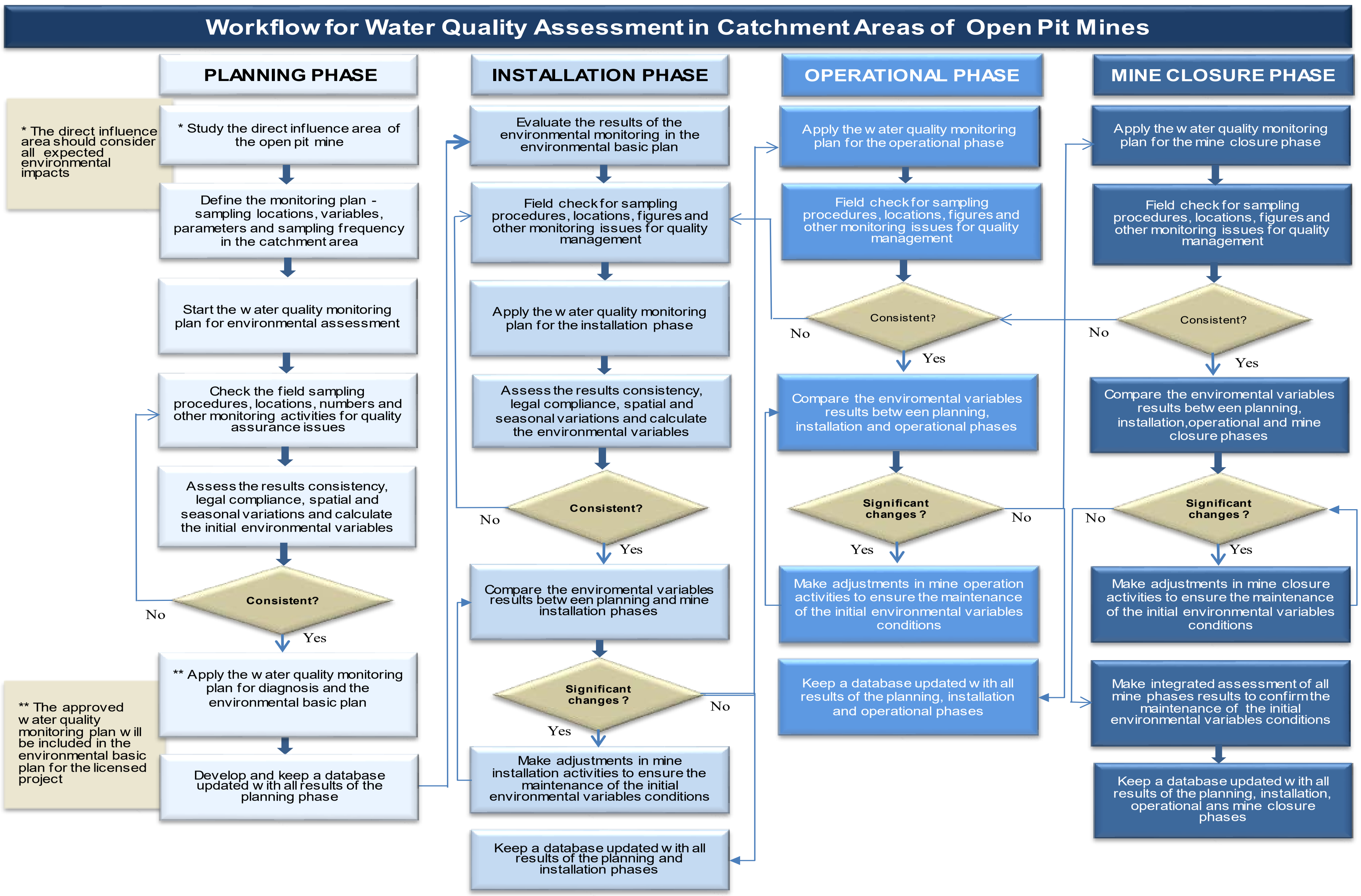


Figure 1 – Workflow for water quality assessment for open pit mine projects

The development of the processes and the workflow design was finished during a new open pit mine project - Iron Ore Mine N5S, started in April 2011 and lasted until December 2013 when the workflow proved to be mature with good monitoring results.

**N5S Iron Ore Mine Case Study**

The definition of the direct influence area of the new open pit mine has been made in the mine planning phase within the environmental study prepared to subsidize the environmental licensing considering two main steps. The first step uses cartographic bases as topographic, geological, geomorphological, hydrographic allowing interpretation of the preliminary limits of the direct influence area, mainly its catchment basins. The second step consists of fieldwork and recognition of its main features as vegetation type, soil, drainage, geology, fauna and anthropogenic events.

After the definition of the direct influence area and catchment area, a monitoring plan was elaborated with location of a strong sampling network, the main quality variables and parameters to be analyzed and frequencies of collection, as well as the possible environmental indicators.

To the implementation of the initial monitoring a field check was required to confirm the sampling locations and planned sample quantities. This process is very important in the methodology because a wrong diagnosis results can lead to a non-existing or over- or under-estimating environmental impacts.

Figure 2 shows the implemented sampling network during the planning, installation and operational phases.

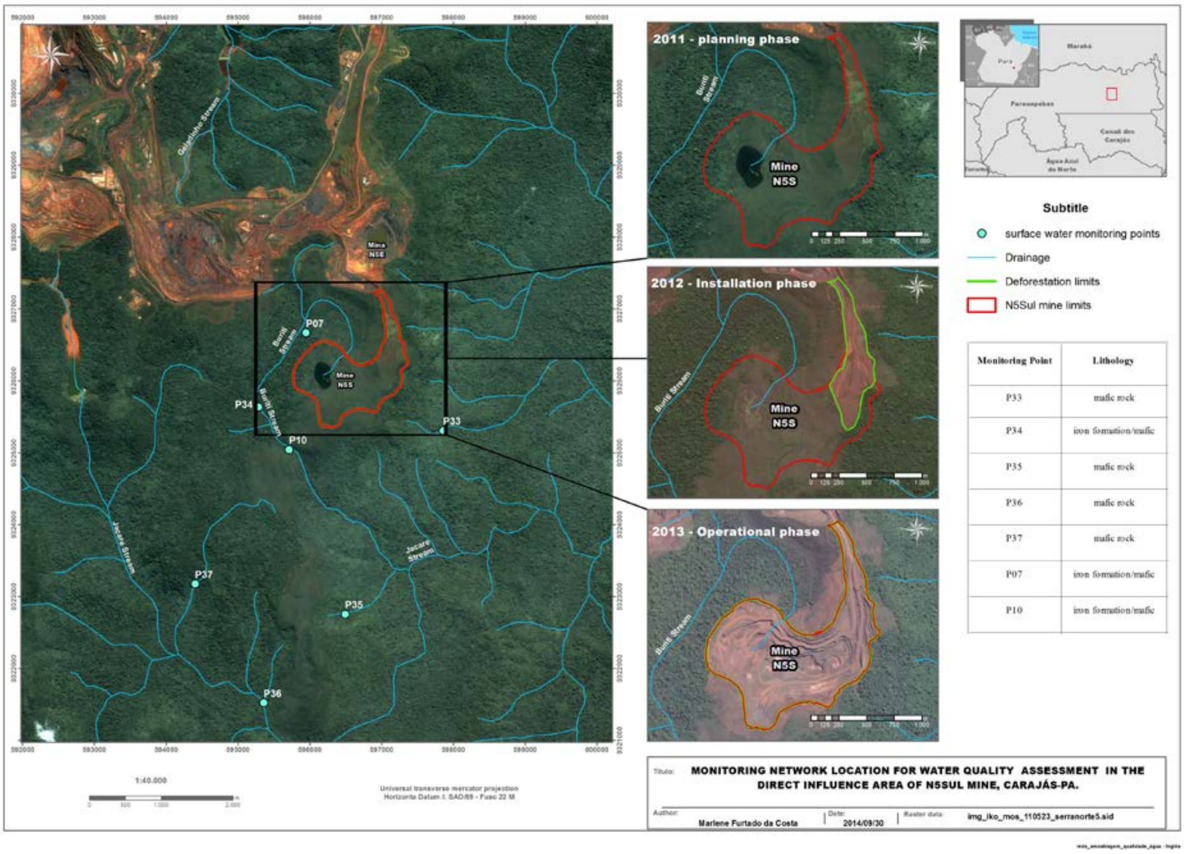


Figure 2 - Location map of monitoring network during mining phases of N5S iron ore mine.

Once obtained the first analytical results it is important to assess their consistencies with federal environmental legislation, seasonal variations and thereafter starting the environmental variables calculation. This step is essential for proposing adjustments both in sampling locations as in eligible parameters for monitoring, sampling frequency and definition of water quality indicators. When it does not exist initial environmental characterization for the area, the evaluation of the initial results should be done using data from the literature and the applicable environmental legislation.

A data time-series classification is recommended at this stage if there are significant changes in land use near the sampling network as well as grouping the results in seasonal and different stages periods. During the opening of an open pit mine, the main changes range from the removal of vegetation pre-stripping and mining. With the deepening of the pit at the operational phase, there is possibility of water drawdown from aquifers, which can provide increases in the water flow and the possibility of change in the surface water quality.

After performing the consistency of the monitoring plan results, it was possible to design and implement the final environmental monitoring plan that can be the same for the following phases – installation, operational and mine closure. The monitoring plan is the tool used to validate the selected points, evaluating sampling interference and procedures and requires team's routine discussions.

With the completion of data validation from the monitoring in the different phases and periods, statistical analysis were applied determining framework classes, preparation of quality indexes and determination of background values Galuszka (2006), Galuszka (2007a). These results should be promptly discussed with the mine operation to enable adjustments of operating procedures if necessary. Comparisons of integrated results between phases ensure the maintenance of the initial environmental conditions.

Finally, a database was structured and updated along all phases and it can be used to future studies and applied for new sites.

## CONCLUSIONS

This paper presented a workflow for water quality assessment in catchment areas of open pit mines. It was designed and tested since the opening of N5S iron ore mine, started in April 2011 and lasted until December 2013, when it proved mature with good monitoring results. This mine is still operating with the same water monitoring model.

In order to provide adjustments in all monitoring phases the workflow has check points when critical analysis and comparisons of all results should be done, allowing on time changes in operational procedures in case of irregular environmental variables.

A consistent database should be structured and kept in the project with the data from all phases ensuring preservation and future use.

Finally, the workflow proved very useful and allowed the complete water quality management during all phases of an open pit mine.

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