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Mine closure commencing alongside business analysis

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Abstract

Anthropic activities impact more than 70% of the Earth's surface (IPCC, 2020). Historically, mining has modified landscapes, and its impacts have been the subject of numerous studies. It is estimated that globally, mining occupies five million hectares (Maus et al., 2020). In Brazil, mining covers approximately 366,000 hectares and is present in 459 municipalities, accounting for 8% of Brazilian municipalities (MapBiomas, 2021). There is no doubt about the mining sector's responsibilities towards the territories and communities affected by its activities. The market, shareholders, government, and society demand sustainable and restorative mining practices, making the practice of mine abandonment currently unacceptable. Mining companies have access to a set of guidelines and laws that guide mine closure to stabilize mining areas after operations. Based on these guiding instruments, Brazil is on its way to developing expertise in mine closure. However, it is necessary to incorporate actions beyond established in Brazilian law, such as utilizing ICMM tools and applying ISO standards, to align with corporate strategies, commitments, and market regulations. Through strategic basic research, our study considers mine closure as an opportunity for the mining sector to contribute to climate change adaptation and mitigation solutions. It also has the potential to contribute to the achievement of Sustainable Development Goals by promoting shared value. We believe that acting in the local social and environmental context is essential for the sustainable development of mining projects. Our findings indicate that starting the approach to mine closure together with business analysis enables the maximization of opportunities and the reduction of risks. As the mining project progresses, mine closure becomes more robust, allowing the implementation of closure criteria and strategies throughout the entire lifespan of the project. The inclusion of closure criteria and concepts in the FEL 1 stage allows for aligning the project development activities in such a way that future closure opportunities are expanded, ensuring greater sustainability of mining operations. In the subsequent stages of the project and operation, the criteria and concepts should be checked to ensure a better alignment with the initial vision.

Keywords: *sustainable mining, front end loading methodology, post operation*

1 Introduction

A depletion of mineral resources is raising concerns among society and governments, given the widespread issue of abandoned mines worldwide (Fernandes, 2021), which have left behind numerous socio-environmental and economic liabilities (Araújo, 2016). Mine abandonment, typically driven by economic factors, can also be attributed to the absence of legislation and a lack of alignment between planning and operations (Araújo, 2016). The problems associated with inadequate mine closure encompass health and safety risks, unemployment, revenue decline, and environmental degradation (Galo et al., 2022; Ngole-jeme & Fantke, 2017).

It is widely acknowledged that mining plays a vital role in ensuring the quality of life and well-being of modern society (Monique Mosca, 2017). However, it also has significant environmental impacts. Globally, mining operations occupy an estimated five million hectares (Maus et al., 2020). In Brazil, mining covers approximately 366,000 hectares and is present in 459 municipalities, accounting for 8% of all Brazilian municipalities (MapBiomas, 2021). Given the limited knowledge of the actual extent of mining activities, it is not surprising that there is little global understanding of the current rate of mine closures or the planned closure trajectory in different jurisdictions, let alone the social responsibilities associated with these closures (Bainton, Nicolas; Holcombe, 2018).

According to Brazilian legislation, a mine closure plan involves the comprehensive planning for the deactivation of all mining structures, considering environmental and socio-cultural aspects (ANM, 2021). Eduardo Vale, (2003) states that the primary objective of a mine closure plan is to safeguard the public interest by anticipating and addressing the expected social costs throughout the mine's life cycle, using technical, economic, and social alternatives. These plans are based on the legal framework and formal commitments made to the environmental regulatory agencies and local communities.

A study conducted by the International Council on Mining and Metal – ICMM (Brock, 2020) , which forecasts numerous mine closures worldwide in the coming years (Figure 1), has triggered widespread concern. The study provides a regional breakdown of mines expected to cease operations within the next 50 years, highlighting the need for immediate actions to mitigate the associated risks of mine abandonment and emphasizing the importance of initiative-taking closure planning.

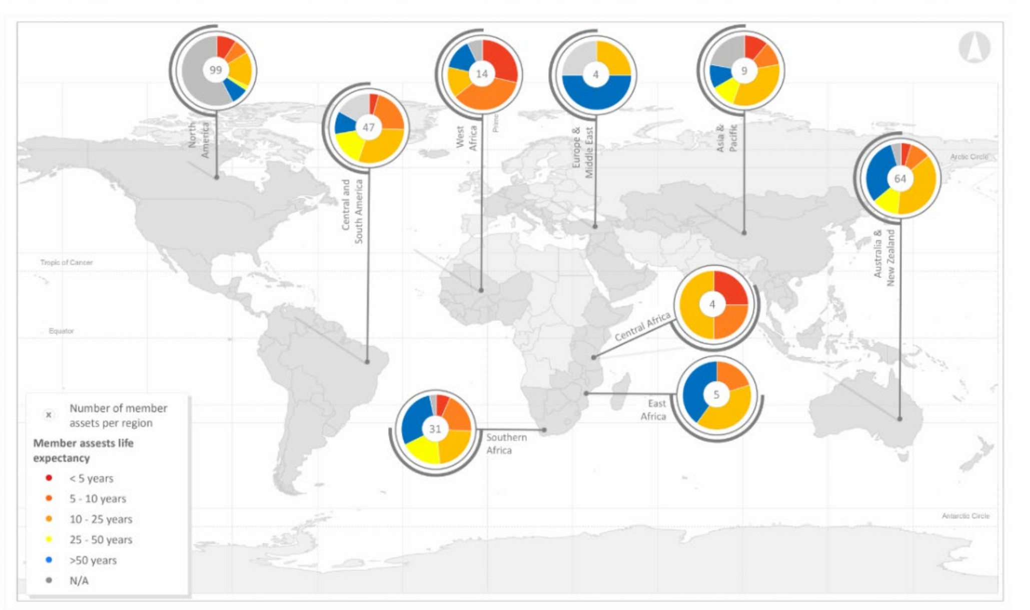


Figure 1 Projected closure of mines around the world. Source: Brock, (2020).

Records in the literature indicate that in the United States, there are 28,000 abandoned mines in Missouri, Montana, and Colorado. In Canada, there are estimated to be over 6,000 abandoned mines in the province of Ontario. In Australia, there are approximately 50,000 abandoned mines in the state of Queensland Schmitzhaus, (2018). In Peru, there are around 152 abandoned mines in just four cities (Huancavelica, Ayacucho, Apurímac, and Cuzco). In Chile, there are about 520 abandoned pits in the Andes Mountains (Araújo, 2016). In Brazil, specifically in the state of Minas Gerais, there are 119 abandoned mines and 401 suspended mines (FEAM, 2022).

The imminent approach to a tipping point of ecosystem collapse, due to global climate change, which threatens the provision of essential ecosystem services for human life (IPCC, 2019; 2020), coupled with concerns about the legacy left after mining operations, has been driving changes in the global mining landscape. Although some authors consider the use of the term sustainability in the mining sector controversial (L, Massaro; J, Calvimonte; M, 2022) , the market, shareholders, governments, and society are increasingly focused on the sustainability of mining ventures and actions promoted in the Environmental, Social, and Corporate Governance (ESG) agenda (Laurence, 2011).

Therefore, it is essential that mining activities be guided by the sustainability pillars established by the Conference of the Parties under the United Nations Framework Convention on Climate Change. Mining should be socially just, environmentally friendly, socially accepted, culturally diverse, economically viable, technically safe, and comply with all legal requirements.

Mine closure is the fourth-largest operational risk (MJ, 2017) and requires proper and careful planning. It involves a dynamic and interactive process with stabilization procedures (physical, chemical, and biological), environmental recovery, and the preservation of the interests of various stakeholders, including local communities, future generations, governments, investors, suppliers, and workers.

It is in the planning and execution of mine closure that factors of environmental, social, and economic protection and post-mining development will be safeguarded (Araújo, 2016; Brock, 2020; Jesus & Sánchez, 2013; Monique Mosca, 2017).

To support mine closure, mining ventures generally have a set of guidelines available that direct sustainable mine closure actions and the rehabilitation of areas through mitigation measures and environmental impact recovery. There are approximately 69 best practice declarations related to mine closure, which can be grouped into four categories: i) mine closure documents, ii) physical and chemical stability, iii) costs and financial provisions, iv) community engagement and social transition (Galo et al., 2022).

2 Brazilian regulation

At the global level, we have examples such as the guidelines proposed by the International Council on Mining and Metals (Brock, 2020; ICMM, 2008, 2019) and the International Organization for Standardization (ISO , 2023). Brazil has specific mine closure regulations. At the national level, companies must comply with the Resolutions of the Ministry of Mines and Energy established by the National Mining Agency, No. 68/2021, No. 104/2022 (ANM, 2021; ANM, 2022), and Mining Regulation Standard 20 (MME, 2023). For the Brazilian state of Minas Gerais, mining ventures must also comply with Deliberative Resolution No. 220/2018 of the State Council for Environmental Policy (COPAM, 2018) . In terms of good practices, there are also contributions from the Brazilian Mining Institute (IBRAM, 2019; Sánchez, L.E.; Silva-Sánchez, S.S.; Neri, 2013).

Considering that Brazilian regulations are recent, Brazil is moving towards developing expertise in mine closure, with few reported success cases (Jesus & Sánchez, 2013), and so far, no publicly disclosed case utilizing the recent regulatory instruments. Schmitzhaus, (2018) describes the Brazilian experience in mine closure as still limited, with companies being responsible for incorporating actions beyond what is established in Brazilian legislation, including the adoption of best practices, corporate policies, and market regulations.

In an optimistic scenario, every mine closure is planned considering ore depletion, but around 75% of closures occur prematurely, also referred to in the literature as sudden closure or unplanned closure (Laurence, 2011). These closures are caused by factors that are the responsibility of companies or factors that are beyond their control, such as price drops (Sánchez, 2011).

Therefore, the mining sector requires a planning process that minimizes uncertainties and risks associated with mine closure, aligns with the interests of stakeholders, maximizes investor confidence in the results, contributes to better strategic project selection considering mine closure, and enables the anticipation of possible deviations that could harm operations and post-operation phases.

To deepen the existing knowledge on the subject, this work aims to present an approach to sustainable development of mining projects from the perspective of mine closure starting from the initial stages of project development, using the Front-End Loading (FEL) methodology, commonly employed by companies to standardize planning actions.

Strategically, the discussion of the topic, in accordance with business language, aims to perceive the business needs regarding the effective application of connections between legislation, best practices, and ESG expectations for the execution of mining ventures, highlighting mine closure planning as an opportunity to minimize or even eliminate the risk of abandonment of still impacted areas. For this, one should consider that the application of closure aspects established as requirements at the initial stages of mineral exploration projects can improve sustainability and contribute to proper mine closure.

3 Material and methods

The analysis conducted in this work is based on a literature review and documentary research, consulting journals, articles, books, laws, and reports that address the topic of mine closure, with a focus on Brazil and the state of Minas Gerais. Another material used is the Front-End Loading (FEL) methodology, as it is a reference in the development of mining projects.

The FEL methodology is focused on the planning of capital projects (Joana, 2022), aiming to ensure project excellence while considering factors such as timelines, safety, and costs (Fernandez, 2016). Developed by the American company Independent Project Analysis (IPA), it enables project feasibility analysis by utilizing a detailed and parameterized database of the mine's life cycle (Fernandez, 2016). The detailed application of the FEL methodology is divided into three stages, as described by (André, 2022):

- FEL 1 - Business Analysis, opportunity definition, or pre-feasibility: This stage involves developing and evaluating opportunities through conceptual studies. The main outcome is the business case for the opportunity and its alignment with the company's strategic goals.
- FEL 2 - Alternative Selection or Conceptual Project: This stage involves studying the set of identified alternatives and selecting the recommended alternative. The main outcome of this stage is the conceptual engineering of the selected alternative, which will serve as the basis for the Basic Project.
- FEL 3 - Implementation Planning or Basic Project: This stage involves developing the work for implementing the selected alternative. The objective is to further detail and define the scope, cost, schedule, and implementation plan in preparation for the implementation phase of the project.

In addition to the three established stages of the FEL methodology, the stages of Execution, Implementation, Operation, Progressive Closure, and Post-Closure Monitoring and Maintenance are also considered.

4 Results and discussion

The objectives of mine closure planning aim to fulfill all existing legal obligations at the national, state, and local levels, as well as the commitments made, and strategic requirements established by the company and investors. Additionally, it aims to involve stakeholders, both internal and external (regulatory bodies, NGOs, civil society), in the development of future land use.

The potentialities related to mine closure and appropriate future land use are connected to the legacy that mining companies aspire to leave for society. To achieve this, specific factors need to be assessed, such as the natural vocation of surrounding communities, safety and technical, environmental, cultural, touristic, economic, institutional, political, and social aspects (Araújo, 2016).

When considering two models available in the literature for conducting this closure planning, we observe that the first model studied presents a linear structure of the mining project life cycle (Figure 2), where activities are presented in five sequential stages: i) feasibility study considering the mineral deposit and production scale, ii) implementation, iii) operation, iv) deactivation, and v) post-closure (Neri, 2013; Sánchez, L.E.; Silva-Sánchez, S.S.; Neri, 2013).

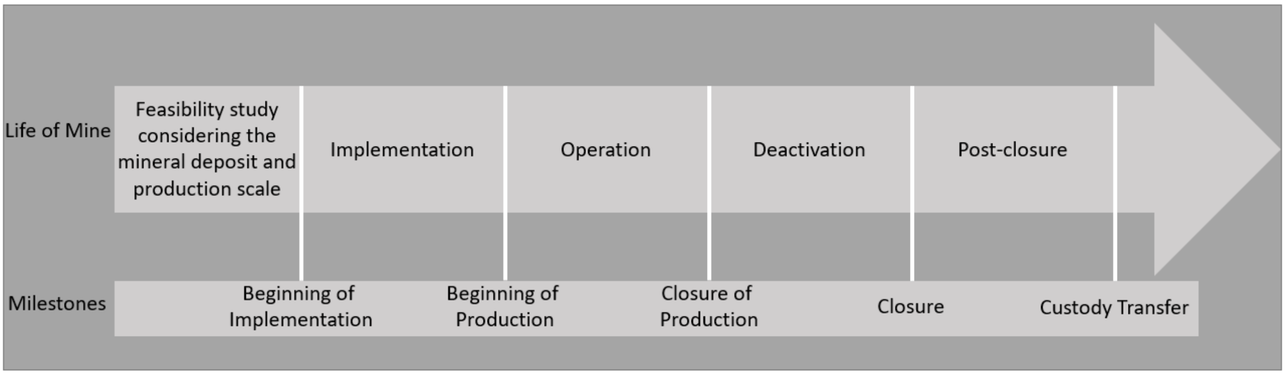


Figure 2 Stages of a mine's life cycle. Source: Adapted from Sánchez, L.E.; Silva-Sánchez, S.S.; Neri, 2013

Indeed, the linear representation simplifies the understanding of the stages, but it does not accurately reflect the reality of the process. In some mining projects, the stages may occur simultaneously, and the linear depiction of the mine life cycle is not an accurate representation. For example, when the deactivation stage begins in a specific asset, it does not necessarily mean that production is ceasing. Actions related to closure can and should take place concurrently with the mineral extraction phase, focusing on geotechnical, operational, and support structures of the mining operation.

In the second model studied, the progressive closure planning is represented through a vertical and horizontal view throughout the life of the mine (Figure 3). This model allows for the progressive closure of sectors by completely or partially closing assets, thereby reducing liabilities and risks while identifying opportunities. It also enables the implementation of measures to ensure the safety and stability of the area and contributes to the restoration of ecological functions.

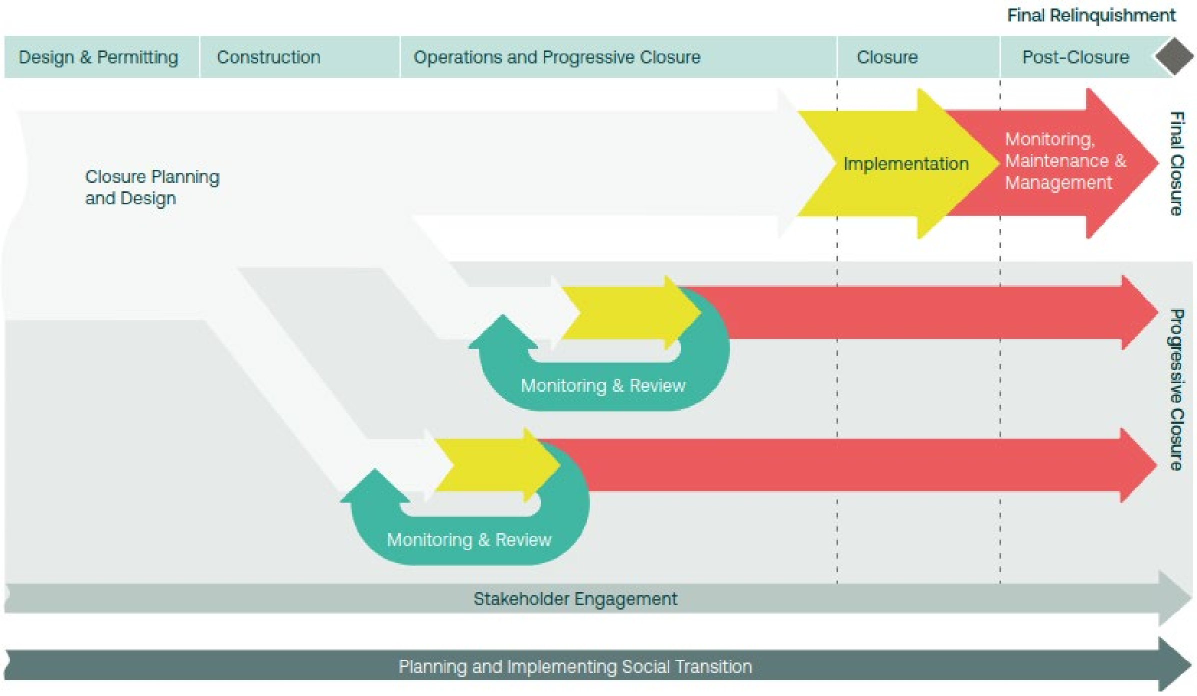


Figure 3 Progressive planning for closure throughout the life of the mine. Source: ICMM, 2019

The inclusion of the mine closure theme starting from FEL 1 (feasibility analysis) allows for the consideration of a maximum number of strategies and options, implementation with the lowest possible cost, and the achievement of future use after closure (Galo et al., 2022; Jones & Fawcett, 2004). It is crucial to maximize opportunities and ensure the necessary processes for closure are effectively managed (Figure 4), enabling a comprehensive understanding of costs, ensuring the appropriate strategy, and allocating resources without waste.

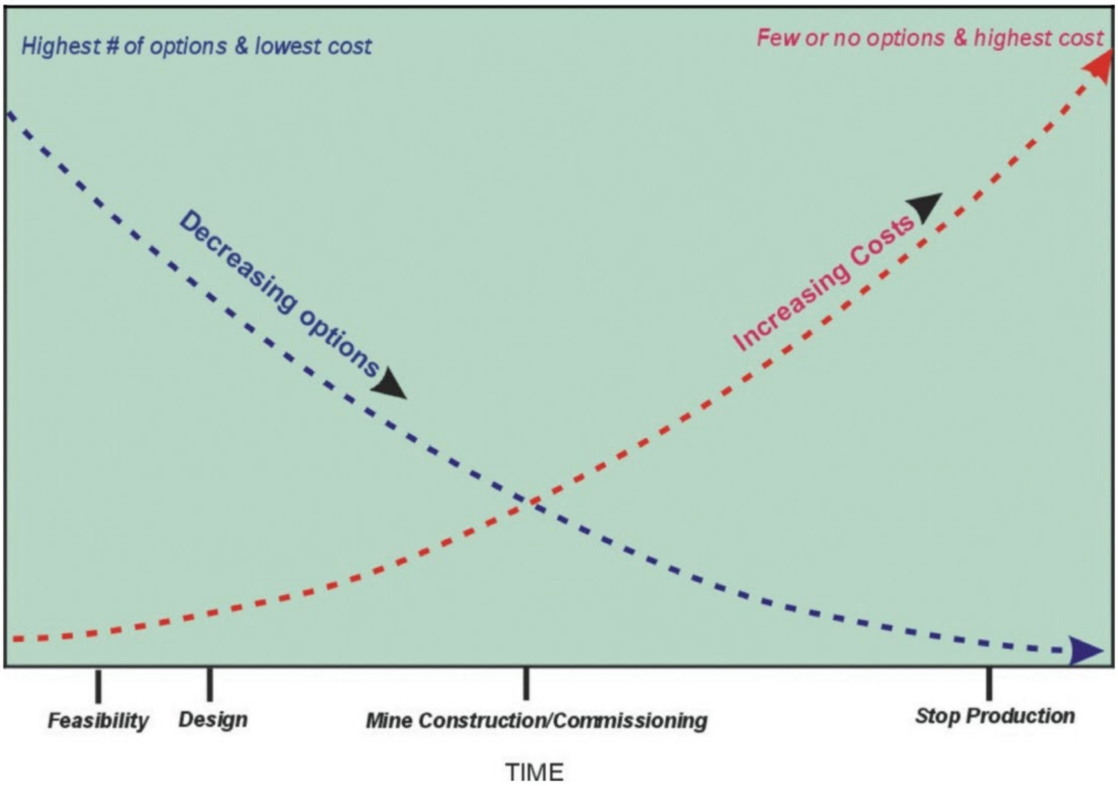
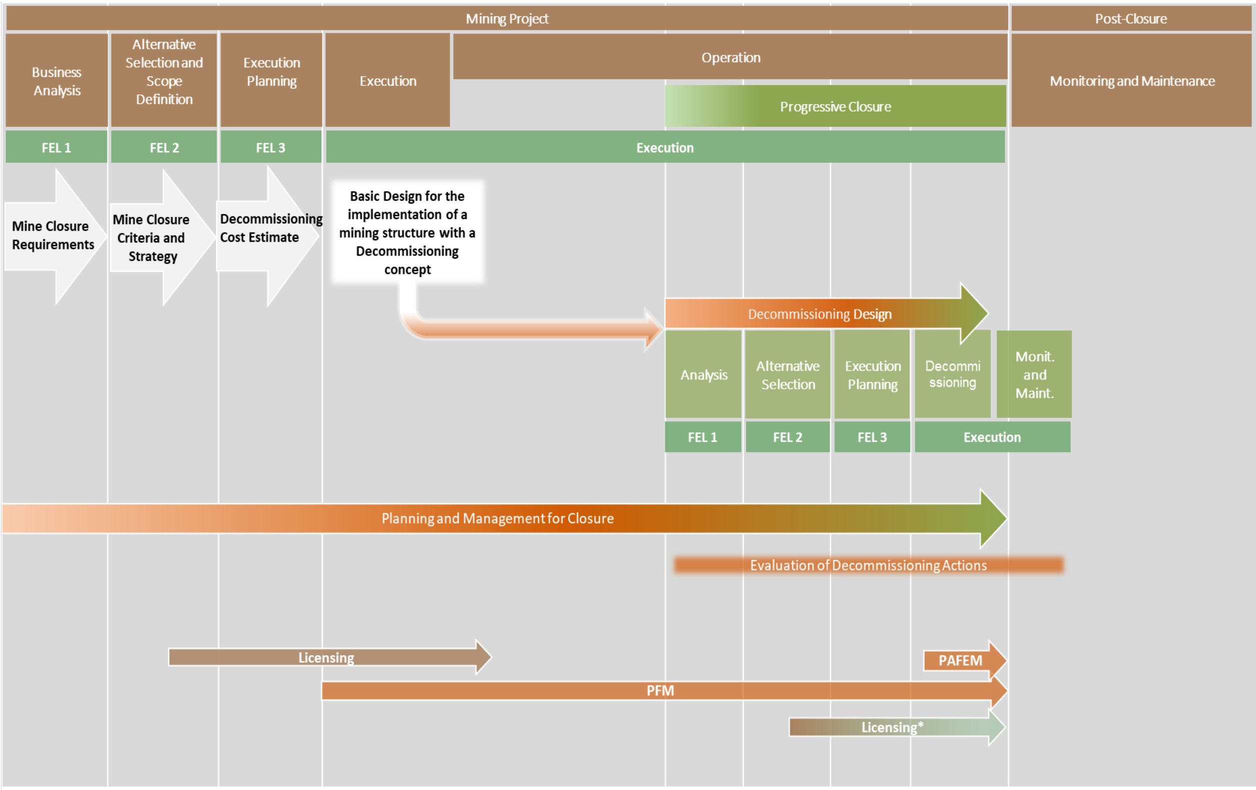


Figure 4 Opportunity cost of closure over the lifespan. Source: Jones & Fawcett, 2004

Based on the two models studied, a third model is proposed (Figure 5) consisting of six stages, which begins immediately after mineral exploration. These stages are: i) business analysis, ii) alternative selection and scope definition, iii) execution planning, iv) implementation, v) operation, vi) progressive closure, and vii) post-closure monitoring and maintenance.



*It may or may not be necessary

Figure 5 Mining project and the process for closure and decommissioning planning

The model presents a vision of how the mine closure planning process can occur through six stages. This model is not entirely new but provides an expanded and more objective view of where and how mine closure is integrated into the project development process, allowing for the visualization of key actions and the level of interventions expected in each stage. The following are the key points of this model:

In the first stage, Business Analysis (FEL 1), mine closure opportunities are identified and evaluated through studies based on secondary data. These opportunities must ensure compliance with current regulations, existing constraints, and the company's market position. The outcome of this stage is a set of requirements that should be adopted in the project development, both in FEL 1 and the subsequent stages. These requirements align the project with the vision of mine closure and allow for a connection with future decommissioning projects. This enables the development of new land uses and the establishment of a more sustainable model.

In the second stage, Alternative Selection and Scope Definition (FEL 2), the requirements identified in FEL 1 guide the development of project criteria and mine closure strategies. The criteria are established uniquely and specifically for each site, defining essential characteristics to make the closure process more sustainable. The main idea is to incorporate elements into the project that facilitate a favorable transition from operational to closure scenarios. The more closure-friendly characteristics implemented during the operational phase that meet the closure criteria, the better the decommissioning process, resulting in increased sustainability value. This stage also involves defining the closure strategy, outlining the concept of closure for each mine structure. Finally, studies are conducted to estimate decommissioning costs based on engineering implementation and decommissioning concepts.

In the third stage, Implementation and Execution Planning or Basic Project (FEL 3), the criteria and strategies are further developed and detailed, culminating in cost estimates and a schedule that will be initiated during project implementation. However, this stage does not involve the development of decommissioning projects. The focus is on ensuring that the closure criteria established in the previous stage are incorporated into the projects, allowing for future decommissioning project development. It is not recommended to develop decommissioning projects at this stage due to potential variables that may change over the course of time between the implementation/operation phases and the approaching closure of mining activities on a sectoral or general level.

In the fourth stage, Implementation, as described by Sánchez, L.E.; Silva-Sánchez, S.S.; Neri, (2013), specifically in Brazil, before the start of the Implementation stage, mining projects must submit a Mine Closure Plan (Plano de Fechamento de Mina - PFM) to the National Mining Agency along with an Economic Utilization Plan (Plano de Aproveitamento Econômico - PAE) as required by the Mining Code. It is also necessary to request Environmental Licensing from the State Environmental Agency in compliance with the National Environmental Policy through tools provided by regional legislation. The mine closure plan is a compilation of the actions developed in FEL 1, FEL 2, and formalized in FEL 3. These conceptual closure actions must be presented to regulatory agents to obtain installation and operation licenses.

During the operation, the fifth stage, expansions, process changes, new mineral research activities, and enterprise management may occur (Sánchez, L.E.; Silva-Sánchez, S.S.; Neri, 2013). During the operation, the Mine Closure Plan (PFM) must be updated every five years and submitted to the National Mining Agency (ANM, 2021). This document should address decommissioning, structure demobilization, physical and chemical stabilization, monitoring, and preparation of the area for new mineral utilization or future Agency (ANM, 2021). Two years before the mine's expected end of life, an Environmental Mine Closure Plan (Plano Ambiental de Fechamento de Mina - PAFEM) must be submitted to the state environmental agency. The PAFEM is an environmental management tool consisting of technical information, projects, and actions for monitoring and recovery in social, economic, and environmental dimensions. With the completion of the PAFEM, the Mine Closure Planning is concluded. Therefore, two distinct documents are presented to regulatory agencies: one to comply with environmental legislation and another for mineral legislation. The mineral aspect focuses more on ensuring the defense of mineral resource sovereignty, while the environmental aspect places greater emphasis on socio-environmental issues.

The progressive closure of assets, a key component of the closure strategy, allows for the reduction of liabilities, environmental and geotechnical risks, and the identification of more affordable opportunities. It should be noted that the closure process also involves maintenance and monitoring activities, which can take years to complete. This stage occurs concurrently with the operation stage. During this phase, studies and decommissioning projects for sectors or the entirety of the operation are developed. As part of the decommissioning project development, a preliminary analysis is conducted to validate the decommissioning criteria and concepts established in FEL 2 and FEL 3, considering potential changes in input variables (Figure 5). This resembles the process established at the beginning of the initial implementation project (FEL 1). Thus, the process of developing a decommissioning project becomes a new project for implementing a new phase of mining known as decommissioning. The objective is no longer operation and connection with mine closure but decommissioning and connection with the development of a new land use plan. Therefore, all the stages described earlier in the operational model are repeated. It is necessary to develop requirements for land use, criteria and strategies for land use, cost estimates for decommissioning implementation, and finally, establish success criteria, monitoring, and maintenance for the various areas occupied by mining and that will be adapted to the planned future use.

The last stage, post-Closure, involves implementing deactivation measures, which include monitoring, maintenance, temporary or permanent care, and social programs to achieve closure objectives (Sánchez, L.E.; Silva-Sánchez, S.S.; Neri, 2013).

5 Conclusion

The process of mine closure is complex and multidisciplinary, involving aspects such as environment, governance, finance, community relations, and government engagement. Thus, initiating mine closure discussions with the relevant stakeholders from the business analysis phase (FEL 1) allows companies to maximize opportunities and mitigate social, environmental, and economic risks. Mine closure gains strength as the mining project progresses, incorporating closure criteria and strategies throughout its entire lifespan.

It is crucial to integrate mine closure planning from the initial stages of the mining venture to establish comprehensive closure criteria and strategies that will be implemented throughout the mine's lifecycle. By involving key areas such as environment, governance, finance, and community and government relations from the outset, a holistic and collaborative approach to mine closure can be ensured. This approach helps to mitigate potential negative impacts, promote project sustainability, and facilitate the transition to post-closure, encompassing environmental, social, and economic aspects.

By adopting an initiative-taking approach, companies can anticipate potential environmental impacts, minimize risks to local communities, and ensure proper management of the financial resources required for closure. Additionally, engaging stakeholders early on and maintaining transparent dialogue contributes to building strong and trusting relationships.

As the mining project progresses, it is essential to continuously adjust and update the criteria and closure strategies, considering technological advancements, regulatory changes, and industry best practices. This way, the mine closure process becomes more robust and tailored to the specific project conditions, maximizing benefits, and reducing negative impacts.

A responsible and integrated approach to mine closure is fundamental to ensure a smooth and sustainable transition, preserving the environment, protecting communities, and promoting corporate social responsibility.

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