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THE FOUNDATION OF GREEN MINING – PRINCIPLES AND SUSTAINABILITY

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Abstract: This paper provides a theoretical overview of the definitions and principles of green mining, historical development and essential information. In particular, the pillars of sustainability of green mining are analyzed from an environmental, social and economic perspective. A selection of relevant international and national regulatory frameworks and industry initiatives that play a key role in shaping green mining is made.
Key words: green mining, environmental sustainability, social responsibility

INTRODUCTION

Mining, as one of the oldest human activities, has always been crucial for the advancement of civilization. However, the long history of industrial exploitation has often left a deep ecological footprint and caused social tensions. The concept of Green Mining represents a radical shift in this approach, offering a vision of an industry that not only provides essential raw materials but does so in a way that actively contributes to environmental preservation, improving the quality of life for local communities, and long-term economic sustainability. This paper lays the theoretical and philosophical groundwork for understanding this transformative paradigm, defining its key principles and positioning it within the broader global context of sustainable development. By analyzing the environmental, social, and economic pillars of sustainability, and by reviewing current global trends and regulations, this paper aim to provide a comprehensive framework for applying green principles at all stages of the mining cycle.

DEFINITION AND EVOLUTION OF GREEN MINING

Green Mining is an integrated approach to the extraction of mineral resources that aims to minimize negative impacts on the environment and society, while maximizing economic efficiency and sustainability [1]. It differs from traditional practices by its proactive and holistic approach, striving for mining operations to become part of the solution rather than a source of problems. Green Mining entails minimizing the footprint: Reducing the surface footprint of a mine, decreasing the amount of waste rock and tailings. It uses resources efficiently: optimizes the consumption of energy, water and other resources through innovative technologies and processes. Emission reduction occurs in Green Mining. Emissions of greenhouse gases, dust, and pollutants into water and air are controlled and reduced [2]. To protect biodiversity, there are planning and implementation measures to preserve local ecosystems and biodiversity [3]. Green mining reclamation is the crucial process of restoring land to a stable, beneficial state after mining operations cease, ensuring it's safe for future use. Reclamation and closure are mandatory after the completion of extraction [4]. Social responsibility of green mining is essential. Active involvement of local communities, respect for human rights and ensuring safe working conditions are the test of success [5, 6].

Historical perspective and evolution

For centuries, traditional mining has focused on maximum extraction with minimal consideration of environmental and social consequences. It has often resulted in massive landscape destruction, water and air pollution, and social conflict. The reactive approach (late 20th century) is reflected in the introduction of regulations in response to environmental disasters and growing public awareness. The focus is on "cleaning up" existing pollution and setting baseline standards. The proactive approach (early 21st century) developed from the understanding that prevention is better than cure. Technologies and methodologies are being developed to reduce the impact of pollution from the very beginning of a project. The integrated and holistic approach (modern green mining) is the concept that mining must be fully integrated into the natural and social ecosystem, aiming for a positive net impact. This includes the circular economy - where waste from one process becomes a resource for another, reducing the need for new raw materials and minimizing waste disposal in landfills [2].

Scientific Justification – Why Green Mining Is an Imperative?

The need for green mining is not just an ethical issue; it is deeply rooted in scientific evidence on the harmful effects of traditional mining practices and the urgency of addressing global environmental and social challenges. For climate change and decarbonization, the mining industry is a significant emitter [7]: Traditional mining is a major consumer of energy, predominantly from fossil fuels, and a significant contributor to greenhouse gas (GHG) emissions. Studies show that mining and metal processing account for approximately 4-7% of global GHG emissions [8]. The transition to renewable energy sources, the electrification of the fleet and the optimization of processes in green mining directly reduce this impact, which is key to achieving the goals of the Paris Agreement [9]. On the other hand, the development of green technologies (electric vehicles, solar panels, wind turbines) requires an exponential increase in the production of metals such as lithium, cobalt, copper, nickel and rare earth elements. The scientific community announces that this increased demand must not negate the environmental benefits of these technologies. Green mining ensures that these metals are produced in a sustainable way, minimizing their impact on the life cycle [10].

Ecosystem devastation and biodiversity loss occur due to habitat fragmentation and pollution. Open pit mines, tailings dumps and road networks fragment natural habitats, while wastewater and dust discharges directly threaten plant and animal species. Research shows that mining is one of the main drivers of biodiversity loss in certain regions [11]. Green mining, with a focus on footprint reduction and reclamation, is scientifically supported as a method to mitigate these effects and support ecological restoration. A particular problem is acid mine drainage (AMD), which is formed by the oxidation of sulfide minerals in the presence of water and air. It is one of the most serious and long-lasting environmental problems of traditional mining. AMD lowers the pH of water and releases heavy metals, resulting in lethal conditions for aquatic life and contamination of food chains. Scientific research has developed techniques for passive and active treatment of AMD, as well as methods for preventing its formation (e.g., covering sulfide materials), which are an integral part of green mining [12].

Water scarcity and pollution of water resources are widespread. Mining, especially ore processing, is extremely water-intensive. In water-scarce regions, this creates significant conflicts with local communities and agriculture. UN and World Bank studies indicate that by 2030, global water demand could increase by 40%, forcing the mining industry to drastically reduce consumption and improve water recycling [13]. Another water-related problem is heavy metal pollution. The uncontrolled discharge of mine wastewater, which often contains heavy metals (mercury, arsenic, lead, cadmium), cyanides and sulfates, has catastrophic consequences for human health and ecosystems. Numerous scientific studies document the bioaccumulation of these toxins in the food chain, with long-term health consequences.

Green mining, through advanced treatment systems and closed-loop water systems, offers scientifically validated solutions to prevent this pollution [14].
There is a proven correlation between the proximity of mines and increased incidence of respiratory diseases, skin diseases and birth defects in local communities due to dust and toxic pollution (WHO reports). Studies in sociology and development economics show that traditional mining projects, without adequate community engagement and fair sharing of benefits, often lead to social tensions, migration and deterioration of the socio-economic status of the local population. Green mining, with its emphasis on social responsibility and participation, is a scientifically based approach to building positive relationships and improving living conditions [2].
There is also the issue of limited resources and the need for a circular economy. Scientific models of resource consumption clearly show that mineral resources are finite. The extraction rate of many key metals significantly exceeds their natural renewal rate. The concept of a circular economy, which is central to green mining, is scientifically supported as a way to extend the life of resources through recycling, reuse and waste reduction. Scientific approaches are being developed for "urban mining" – the extraction of metals from electronic waste and other discarded products [15]. Although not traditional mining, it is an integral part of the broader concept of green mining because it reduces pressure on primary sources and is an important aspect of the circular economy.

THE PILLARS OF SUSTAINABILITY IN GREEN MINING

Sustainability in mining rests on three interdependent pillars: environmental, social, and economic. None of these pillars can function independently without the support of the others.

Environmental Sustainability

Environmental sustainability in mining refers to minimizing the negative impact of mining operations on the natural environment and actively contributing to its restoration and conservation. This includes conducting detailed studies of flora and fauna before mining activities begin to identify sensitive species and habitats, as well as designing mines that minimize impacts on critical habitats. Sometimes, it is necessary to relocate endangered species and reintroduce them to protected areas.
Water management is crucial [2], such as:

- Implementing technologies that reduce the need for fresh water (e.g. dry milling, recycling process water).
- Treating mine water to standards for reuse or safe discharge into natural waterways. Removing heavy metals and sulfates.
- Protecting groundwater aquifers from contamination and monitoring groundwater levels.
- Managing stormwater to capture and divert precipitation to prevent runoff of pollutants.

Air and emissions management, as well as waste management (tailings and waste rock), are also important in Green Mining. Dust control possible through the use of water spray systems, enclosed conveyor belts and efficient exhaust filters [16]. In particular, tailings stabilization systems are being developed to prevent pollutant leakage and erosion [17]. Ultimately, the circle closes with land reinstatement and reclamation in parallel with mining operations, rather than waiting for the end of extraction.

Social Responsibility

Social responsibility in mining encompasses the obligation of mining companies to make a positive contribution to society, respect human rights and build trust with local communities.

This includes involving local communities in the project planning process from the earliest stages, openly communicating about the impacts, benefits and risks of mining operations, and establishing clear and accessible channels for expressing concerns and resolving conflicts. It is possible and desirable to form partnerships with local authorities, non-governmental organisations and the community to implement development projects. In the internet era, safety and health education for both green mining workers and the rest of the population around the mine, including children, is desirable. The availability of data on the methods of exploitation in a "green" mine enables peace and economic stability. For artisanal and small-scale mining, green mining would save many lives [18].

Economic Viability

Economic viability in the context of green mining goes beyond short-term profit, focusing on long-term financial sustainability taking into account environmental and social factors. Operating costs are reduced due to energy efficiency, water and waste recycling. Compliance with environmental and social standards reduces the risk of fines, lawsuits and work stoppages. Investors increasingly prefer green projects, which facilitates access to financing on more favorable terms. Due to the positive reputation of the mine, the value of the company increases [2]. This has enabled the formation of new business models of the circular economy (recycling and reuse of materials, extraction of valuable metals from waste and tailings, restoration of biodiversity).

GLOBAL TRENDS AND REGULATORY FRAMEWORKS

International and national regulatory frameworks, as well as industry initiatives, play a key role in shaping green mining. The following can be highlighted:

1. Initiative for Responsible Mining (IRMA) - a standard that covers a wide range of environmental and social issues, allowing for a transparent assessment of mining operations.
2. Towards Sustainable Mining (TSM) - A Canadian program that helps mining companies manage key environmental and social risks.
3. Principles for Responsible Investment (PRI) - A framework for investors to incorporate ESG factors into their decisions.
4. ISO standards: ISO 14001 (environmental management) and ISO 45001 (occupational health and safety) as key certifications.

National laws and regulations should be aligned with green mining principles. This should particularly apply to exploration and exploitation permit processes. Voluntary certification to international standards is evidence of commitment to green mining. Sustainability reporting: and the role of third parties are inextricably linked to the public data and the internet. This is why education on green mining is very important.

CONCLUSION

This paper has laid a solid foundation for understanding Green Mining as an integral and indispensable component of sustainable development. By adding scientific justification, we have clearly shown that the transition to green mining practices is not only an ethical imperative but also a scientifically grounded response to global challenges such as climate change, biodiversity loss, water scarcity, and social inequality. We have emphasized that the transformation of the mining sector is not just about technical innovations but also about a profound change in mindset and business practices. Embracing the environmental, social, and economic pillars of sustainability, along with aligning with global trends and regulatory frameworks, is crucial for creating a mining industry that is responsible, profitable, and

accepted by society. Thispaper serves as a basic platform from which we will build further, exploring specific techniques, models, and future visions in the subsequent papers.

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