mining

Editorial

Editorial for Special Issue "Envisioning the Future of Mining"

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1. Introduction and Scope

According to the International Energy Agency, clean energy transitions significantly increase strategic minerals demand. As evidence suggests, from 2017 to 2022, overall demand for lithium increased by 300%, 70% for cobalt, and 40% for nickel. Regarding the forecasts, under the Net-Zero emissions by 2050 Scenario, critical mineral production is projected to increase by 350% of the values reached in 2030 [1] unless there are significant changes in urban infrastructure, transportation, and everyday practices [2]. Industry observers caution that a pervasive sense of urgency to meet the growing mineral demands of the energy transition can deepen social and environmental injustices if proper engagement procedures such as Free, Prior and Informed Consent are not followed, as a majority of potential new mineral developments are located on or near land held by Indigenous and land-dependent people [3].

Producing mineral raw materials has faced many challenges in providing the necessary supplies to almost any production chain. In addition to the traditional search for more efficient processes, cleaner and safer operations, and higher levels of community benefit and social acceptance, there is a need for the mining industry to become more sustainable, aiming to become a significant factor in the circular economy, decarbonization, and digital transformation processes. The articles in this Special Issue "Envisioning the Future of Mining" advance our knowledge of the interlinked technical, environmental, and social challenges facing the sector.

Citation: Menéndez-Aguado, J.M.; Restrepo Baena, O.J.; Smith, J.M. Editorial for Special Issue "Envisioning the Future of Mining". *Mining* **2024**, *4*, 1–6. https://doi.org/10.3390/mining4010001

Received: 14 December 2023
Accepted: 19 December 2023
Published: 21 December 2023

2. The Challenges in Future Mining

The trends of recent decades Indicate that current and future scientific and technological development will be marked by what could be called the "Era of Technological Convergence" [4]. Since the middle of the 20th century, a phenomenon of integration between different sciences and technologies has been taking place on an ever-increasing scale. Fields of science and technology that in past times did not seem to have any apparent relationship are now the protagonists of an unprecedented interaction that is shaping a new scientific–technological paradigm. This conception of research work makes it possible to address and attempt to solve complex problems, which are systemic in nature and common to different areas of knowledge, through inter-, multi- and transdisciplinary cooperation.

The term converging technologies was first used by researchers Roco and Bainbridge, who were the editors of the report "Converging Technologies for Improving Human Performance" [4]. For Roco and Bainbridge, the term converging technologies refers to the synergistic combination of four strategic areas of science and technology, each of which continues to progress on its own at an accelerated pace: (1) Nanoscience and nanotechnology; (2) Biotechnology and biomedicine, including genetic engineering; (3) Information technologies, including advanced computing and communication; and (4) Cognitive sciences, including neurosciences. To express this integration of approaches and knowledge in simplified form, the acronym NBIC (Nano, Bio, Info, Cogno) is used. The distinctive character of converging technologies lies in the strong complementarity between them in the study and the possibilities of controlled manipulation of interactions between living and artificial systems. The basic units of study that are fundamental to all converging technologies originate at the nanoscale.

Yet there is a high risk that the societal transformations driven by the convergence of physical, digital and biological technologies will lead to exaggerated technological optimism and transhumanist visions. In this case, it is important to insist that new technologies ought to adjust to the needs of society rather than society adapt to the progress of technologies. In this sense, the discussion on technological development should move beyond its technical feasibility and debate on the potential ethical, moral and social implications and limitations in the medium and long term.

Mining activity is not indifferent to these transformations and must be carefully considered in the future.

Technical challenges are top of mind in ensuring an adequate supply to the predicted exponentially growing demand. The *Technology and Innovation challenge* refers to the sustainable mining requirement of adopting new technologies and practices, which can be costly and require significant research and development. Often, these new technologies and practices are responses to environmental goals. For example, the *Energy Consumption challenge* addresses the vast amount of energy mining operations need, often from non-renewable sources. A transition to sustainable energy sources is occurring on many mine sites, and more could be spurred by recent multi-million-dollar investments in clean energy demonstrations on minelands by the United States Department of Energy.

Mining activity brings environmental change that must be better managed. The consumption of vast quantities of water in mining, which can lead to local water scarcity and contamination, constitutes the *Water Management challenge*. Sustainable mining practices need to reduce water consumption and manage it responsibly.

Not properly conducting mining operations can lead to deforestation, soil erosion, water pollution, and habitat destruction. The *Environmental Impact challenge* refers to sustainable mitigation through responsible land reclamation, reduced waste generation, and adequate water management. The *Waste Management challenge* is becoming ever more pressing, as mines generate larger and larger amounts of waste, including tailings and slag, as the ore grades of remaining mineral resources are generally lower than those of previous and current mines. Some companies are addressing this challenge by finding ways to reprocess tailings to recover more minerals. Finally, the *Biodiversity Conservation challenge* tackles the risk of disruption of local ecosystems and biodiversity threats due to improper management of mining operations. Sustainable mining should consider the protection and restoration of affected ecosystems. Without proper management, environmental problems can quickly become social conflicts [5].

Community challenges address the potential impact of mining operations on local communities, including displacement, loss of livelihoods, and health concerns [6]. Sustainable mining involves community consent and engagement, fair labour practices, and benefit-sharing agreements. Mining operations often face resistance from environmental groups and the general public, as is evident in the growing difficulties of permitting new mines, so gaining and maintaining social acceptance and trust is an ongoing challenge for sustainable mining. While many frame this challenge as one of public perception, which focuses on changing opinions about mining, this challenge could be reframed as one of alignment, which would instead focus on designing and operating mines in ways that are consistent with local expectations and values [7,8]. The *Legal and Regulatory Compliance challenge* signals that sustainable mining requires navigating complex and continually changing legal and regulatory frameworks, often across national borders. Lastly, the *Human Rights challenge* is essential: protecting the rights of workers and local communities is a fundamental aspect of sustainable mining. Ensuring fair labour practices avoiding human rights violations presently and in the future has no possible debate. The sense of urgency to plan and permit new mines cannot trump the protection of human rights.

The *Carbon neutral operations challenge* is ramping up in importance. With this, efforts are intensifying to find new materials that can totally or partially replace those that are traditionally exploited, using CO_2 capture methods, replacing traditional fossil fuels with alternative fuels and increasing efficiency in the production process, as well as seeking new uses and opportunities for traditional materials and their wastes by developing materials that are increasingly durable over time, among other impact measures.

In line with this objective and following the needs expressed in the industry, the importance of promoting the development of projects focused on the circular economy within the mining industry, within the framework of environmental sustainability, is recognised. The objective is based on promoting the adoption of circular practices in mining by identifying opportunities to reduce waste or generate new products from it, reuse materials and optimise extraction and production processes. Through research and collaboration with different actors in the sector, we seek to create innovative solutions that contribute to minimising the environmental impact of mining and preserving natural resources. The potential of the circular economy is considered fundamental to positively transform the mining industry and thus encourage its implementation through projects that foster sustainability and promote a responsible and efficient approach to the use of resources.

Finally, we can consider the *Global Supply Chain challenge* [9]. As mining operations are often part of complex global supply chains, ensuring responsible sourcing of minerals, traceability and transparency throughout the supply chain can be challenging but necessary [10]. The practice of artisanal and small-scale mining, and urban mining, are central to this challenge, as these activities are often performed informally, outside of the view of states and the private industry.

In the European context, the recently presented Raw Materials Act [11] proposes a regulatory framework designed to address the challenges faced by the European Union in the strategic sectors of decarbonisation, digitalisation, and aerospace and defence. The proposal establishes benchmarks for minimum shares of E.U. demand to be covered by domestically produced and recycled raw materials. Also, it aims to reduce dependencies on single third-country suppliers in all supply chain steps, stressing the importance of increasing supply security and sustainability through circularity, standardisation efforts, skill development, and strategic actions for research and innovation [12].

3. An Overview of the Published Articles

The Aguayo et al. article (Contribution 1) addresses the Technology and Innovation Challenge, discussing the potential productivity and safety benefits that incorporating a surge loader may bring to the load and haul system by analysing the system, component characteristics, and mine planning aspects. With the available data on the operation of this equipment and the incident data from Chile and Peru, they point out that the surge loader addition to the shovel–truck system is an innovation that can improve both the productivity and the safety of the loading and hauling activities.

The article by Afolayan et al. (Contribution 2) focuses more on the Community Challenge, dealing with health and safety issues and legal and regulatory ones in the case of barite mining in Nigeria. The exposure of artisanal miners to polluted air, water, and soil is thoroughly evaluated. Some recommendations are presented on the need for annual medical outreach to mining sites and the use of technology (AI) for future mining.

Contribution 3 (Young and Rogers) revisits the Technology and Innovation Challenge on mine hauling, focusing on dumping operations and proposing a method for generating high-fidelity models of dump profiles. They develop photogrammetric models of dumps using unmanned aerial vehicles with mounted cameras. The research identify the factors that influence these profiles, mainly the truck's location relative to the dump crest, the movement of the underlying dump material during the dumping process, and the differences in the dump profile before dumping.

Continuing with the same technological challenge, Amoako et al. (Contribution 4) introduce machine learning algorithms to model rock fragmentation in mine blasting operations. The paper successfully demonstrates the potential of achieving higher accuracy in mean rock fragment size prediction using a multilayered artificial neural network and support vector regression, improving the conventional Kuznetsov empirical model. The trained models could be incorporated into existing fragmentation analysis software to provide blasting engineers with more accurate estimations.

Contribution 5 (Mammadli et al.) also addresses computational tools, but in this case, the analysis focuses on evaluating co- and by-products. The proposed methodology is applied to assess the production status of different commodities in a polymetallic deposit located in Azerbaijan. The evaluation outcomes quantify the production potentials for several commodities in the deposit. The authors justify using this tool to evaluate all kinds of polymetallic deposits concerning the co- and by-production of several minor critical raw materials.

In the case of Contribution 6 (Talebi et al.), the focus leaps again to health and safety issues, but this time using advanced I.T. procedures. In particular, the paper provides an approach to using operational data sets to find the leading indicators of truck operators' fatigue. A machine learning algorithm is used to model the individual's fatigue, and a model is proposed with the algorithm and an extensive data set. The results show that the model can find the importance of the individual factors along with work and environmental factors among operational data sets.

Bao et al. (Contribution 7) review the electrification alternatives for open pit mine haulage, facing one of the most significant challenges posed by the net zero emissions target to the mining sector. In the paper, the authors examine options for decarbonising the haulage systems in large surface mines, comparing electrification alternatives for large surface mines, including In-Pit Crushing and Conveying (IPCC), Trolley Assist (T.A.) and Battery Trolley (B.T.) systems. These emerging technologies provide mining companies and associated industries with opportunities to adopt zero-emission solutions and help transition to an intelligent electric mining future.

The Schlezak and Styer article (Contribution 8) directly addresses the Community Challenge with the proposal of the *inclusive urban mining* concept. They illustrate that inclusiveness and the circular economy can come together in new forms of urban mining, analysing the cases of construction and demolition waste and e-waste sectors in Colombia and Argentina from a sociotechnical perspective. As a result, they highlight the importance of promoting community-based research methods and concepts to be included in mining, materials, metallurgical science, and engineering academic programs to address these challenges.

Contribution 9 (Smith et al.) stresses the importance of a sociotechnical approach to future engineers of natural resources to understand and promote social justice and sustainability in professional development. The future changes that current challenges will produce need the engineer contribution and promotion as active parts of society. This research is carried out with two different groups of engineering students from the Colorado School of Mines and the Universidad Nacional de Colombia. The researchers find that collaborative, interdisciplinary teaching about authentic problems enhances student abilities to understand their professions from a sociotechnical perspective.

Finally, Contribution 10 (El Hiouile et al.) presents a case study of the application of artificial intelligence to monitor a screen unit in a phosphate processing plant. Using artificial intelligence and image processing techniques, this research evaluates the performance of machine learning and deep learning models to detect the screening unit malfunction in the open pit of the Benguerir phosphate mine in Morocco. The results prove the robustness of models based on convolutional neural networks (CNN) and the Histogram of Oriented Gradient (HOG) technique.

4. Conclusions

Under the sustainable development principles framework, further insight must be gained to overcome the potential challenges in mineral raw material production [13]. This issue, "Envisioning the Future of Mining", covers new sources of raw materials (urban mining, deep sea mining, ultradeep mining, extraterrestrial mining), the continuously growing levels of digitalisation and automation, and the use of safer, healthier and cleaner technologies in raw material processing and extracting. It also spans or scales from artisanal to large-scale mining activities and includes perspectives from education research that point the way to training the next generation of industry professionals to address these and other challenges in sustainable and socially responsible ways.

Conflicts of Interest: The authors declare no conflict of interest.

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