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LANGUAGE OF MINING TECHNOLOGY EVOLUTION AND ITS ROLE IN ADVANCING ENVIRONMENTAL SUSTAINABILITY AND SAFETY STANDARDS

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SUMMARY

The research paper discusses the history of mining technology and the way it has contributed enormously to the advancement of the degree of environmental sustainability and safety in the mining industry. The paper will discuss the key technological developments in the mining sector, including automation, artificial intelligence, robotization, and environmental friendliness, including methods of cleaner mining and environmental surveillance systems to track the environment in real-time. It also explores the development of standardized language and communication practices, which are relevant in the deployment of these technologies in the international mining processes. The technological innovations have added a twist to the mining operations by making them efficient, less hazardous to the environment, and safer to the workers. Artificial intelligence (AI) and robotics have eliminated direct human interaction with hazardous environments, whereas managing resources through automation and robots results in the most efficient use of resources and can anticipate potential safety risks. Sustainability in mining through recycling of water and waste management technologies has minimized the impacts of mining on the environment. Harmony in language and direct communication have been very instrumental in enhancing the uptake of these technologies, as well as in supporting international cooperation among the stakeholders, such as governments, companies, and communities. Development of mining technologies, which is being facilitated through effective communication, is critical in the development of safer and more sustainable mining practices. The use of transparent and standardized terminology will remain essential to regulatory compliance and innovation.

Key words: *mining technology, environmental sustainability, safety standards, automation, artificial intelligence, standardized terminology, robotics, sustainable mining practices.*

INTRODUCTION

Mining is nothing new in the global economy since it has been the mainstay of the worldwide economy in providing raw materials to various industries such as construction and manufacturing, energy production, and technology [1]. It deals with mining minerals, metals, and fossil fuels on which infrastructure, transportation, and technological innovations run [3]. The mining business is essential, yet the problems related to it, environmentally and safety-wise, are grave [4]. Its extraction, particularly on a large scale, can lead to ecological degradation due to habitat destruction, water pollution, and carbon emissions. Furthermore, the mining process, such as cave-ins, explosions, and exposure to toxic substances, is life-threatening to the safety of the employees [5]. The challenges have been compounded by the fact that the world is experiencing increasing demand for natural resources, and there are calls to ensure that the mining processes are undertaken in a more sustainable way, and there is an enhanced safety consideration [6]. The governments, the leaders of the industry, and scientists are moving towards the use of technology to address such problems, and there is a tendency to utilize technologies that minimize the impact that mining has on the environment and to make sure that the working conditions at the sites are safe [7].

The developed mining technology has played a significant role in counterbalancing the adverse effects of mining on the environment, in addition to improving the quality of safety of the workers [8]. The recent few decades have been marked with immense technological advancement, not only in automation and robotization, but also in the form of data analytics and environmental control systems that have changed the way mining is currently being conducted [2]. In addition to causing more efficient and cost-effective mining processes, the innovations have also helped to reduce the environmental impact of the industry and made the mining staff safer [9]. In particular, the language used in the mining technology that refers to the words, speaking habits, and standard procedures in the industry has shifted with these technological changes [11]. This is attributed to the fact that the effectiveness in the implementation of these technologies entails good and transparent communication, which in turn is an element of a culture of safety and sustainability in the industry [10].

Key Contribution

- The Discussion on the exploration of the developmental history of mining technology in response to both environmentally sustainable and safety demands, with special focus on automation, robotics, and environmental monitoring systems.
- The particular role of the language of mining technology in the successful adoption of the new technologies and adherence to the safety and environmental norms, with regard to the terminology and similarity of the communication practices.

The paper has been categorized into the following sections: Section II covers the history of mining technology, which has gone from manual labor to automation and robotics. Part III discusses the impact of mining technologies on the sustainability of the environment, and it dwells on technologies that can minimize ecological footprints. The author addresses the mining safety improvements in Section IV, but the area concentrates on the technologies to make workers safer. Section V concerns the relevance of standard language and communication in the adoption of new technologies and ensuring safety and sustainability. Section VI also defines the residual industry problems and gives recommendations on how to deal with them in the future. At the end of the paper, the main findings and conclusions about the role of technology and language in the future of mining are provided.

THE EVOLUTION OF MINING TECHNOLOGY

Early Mining Technologies

During the initial period of mining, mining was more or less labor-intensive and mainly depended on manual labor and primitive equipment [13]. Miners pulled the ores and minerals out of the earth using picks, shovels, hammers, and crudely built carts. Such methods were usually ineffective and unsafe, since the workers were subjected to adverse working conditions and significantly fewer precautions were taken towards them. These early ways of doing things left a significant environmental footprint, and an enormous amount of waste was produced, and the ecosystems were disturbed because there was no proper land reclamation strategy or waste management plan. Also, the mining techniques that were used were open-pit mining, which led to massive degradation of the terrain, and water pollution was rampant, as there were no drainage systems [14]. The ecological impact of conventional mining was tremendous, and the risks to workers were serious [15]. Nevertheless, this period formed the basis of more superior methods which would be developed with the advent of industrialization [12].

Table 1. Comparison of mining technologies

Technology Type	Efficiency	Environmental Impact	Safety Improvement	Cost (Initial vs Ongoing)
Manual Labor	Low	High (e.g., land damage)	High (risk of injury)	Low Initial, High Ongoing
Mechanization (Steam)	Moderate	Moderate (energy use)	Moderate (improved tools)	Moderate Initial, Moderate Ongoing
Automation (AI/Robotics)	High	Low (waste reduction)	Very High (fewer injuries)	High Initial, Low Ongoing
Sustainable Practices	High (recycling)	Very Low (eco-friendly)	High (environmental safety)	Moderate Initial, Low Ongoing

Table 1 presents various mining technologies regarding efficiency, environmental degradation, safety, and cost [16]. Manual labor is not only lowly efficient and high in environmental impact and low in safety risks, but also low in initial costs but high in recurring costs. Mechanization is moderate in enhancing efficiency and safety, and its environmental impact and cost-effectiveness are moderate. Automation (AI/Robotics) is very efficient, environmentally friendly, and its level of improvement in safety is high, but at a high initial investment with minimal costs of maintenance. Lastly, Sustainable practices are efficient, safe, reduce environmental effects, moderate initial but low maintenance costs, since they are environmentally friendly.

Modern Day to Industrial Revolution

The Industrial Revolution was a changing era in the mining industry as mechanization and the employment of steam power transformed the industry [17]. During the 19th century, technologies such as pumps powered by steam, drills, and mining carts were more efficient, thus making the mines deeper and more productive [18]. These innovations enabled large-scale mining activities, although they did not fully solve the problem of environmental issues and safety [19]. During the 20th century, the advent of electricity, hydraulics, and other more sophisticated mechanical tools made it possible to utilize even larger mining projects, which hastened the mining process and reduced the amount of manual labor [20]. However, automation, artificial intelligence (AI), robotics, and real-time data analytics brought a considerable change towards the end of the 20th and the beginning of the 21st centuries. These technologies reduced the human risks in the risky environment and optimized the mining plan that enhanced the mining efficiency and the safety standard significantly [21].

The nature and types of mining activities have been transformed radically due to the use of mechanization, automation, and AI, which have increased production and enhanced the safety of the mining activity [22]. Mechanization of the ore extraction process, reduction of manual labor, as well as minimization of the number of injuries incurred by the workers, was achieved by using electric drills, conveyor belts, and automated loaders. The automation technologies, like the autonomous vehicles and

robot exercises, allowed mining to be performed over long distances without subjecting the people working there to hazardous conditions like toxic gases and explosives [23]. Also, AI and data analytics enhanced efficiency with better resource extraction, equipment prediction, and tracking of the environment (air quality and emissions). Not only did these technologies allow improving the consistency of operations, but they also contributed to the reduction of environmental effects and improved the safety of the mining staff by offering real-time information about possible hazards and allowing them to act proactively to ensure safety [24].

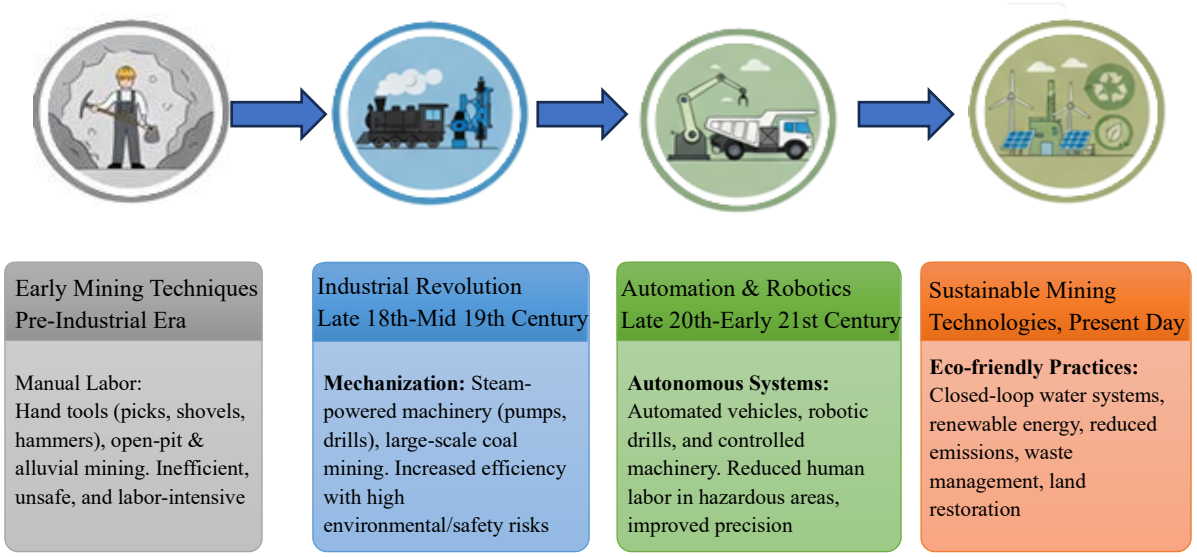

Figure 1. Evolution of mining technology over time

As depicted in Figure 1, the development of mining technologies has been marked by the following milestones: Early Mining Techniques (Pre-Industrial Era) dealt with the use of manual labor and manual cutting tools, such as picks and shovels, which were inefficient, unsafe, and labor-intensive; the Industrial Revolution (mid-19th century) centered on the existence of machine power and large-scale mining of coal, which again were inefficient, unsafe, and required a lot of labor; Automation and Robotics (late 20th early 21st century)[7].

Role of Communication and Terminology

With the development of mining technology, the language of the industry has changed in order to be more complex to accommodate the new systems [25]. Mining vocabulary was not difficult initially, yet the more advanced the technology became, the greater the necessity to use similar and specific language. This is because clear terminology has brought the stakeholders together, the engineers, operators, safety experts, and the regulators, so that there is a common understanding of technologies, their roles, and the safety measures. This standardization has made work easier, and it is easy to adopt new technologies. Listening to specialized language has also resulted in innovation, especially in the use of technologies to include automation systems, AI, and digital twins, which have been used in collaboration and faster integration of innovative solutions. Furthermore, the specific terminology has led to safety training so that employees would not be ignorant about new technologies and safety precautions, which is vital when working on a global scale and being monitored remotely.

MINING TECHNOLOGY'S ROLE IN ENVIRONMENTAL SUSTAINABILITY

Sustainable Mining Practices

To a great extent, the introduction of technological innovations helped to mitigate the environmental harm of the mining process, with the help of the fact that it reinforced environmentally-friendly practices. A significant innovation is the creation of cleaner extraction technology, e.g., hydrometallurgical types of processes that extract metals using chemical solutions, using less energy and fewer emissions than

the older extraction methods. There are also methods, such as in-situ leaching, which enable the mining of the minerals without digging up huge masses of soil and thereby eliminating land degradation and destruction of habitats. Improvement in waste management has also resulted in the design of more efficient tailings storage facilities and filtration systems, which help in avoiding pollution by dangerous wastes of the surrounding ecosystems. Recycling technology of water has also become paramount to the mining processes, and it allows the mining activities to use the water in mining and extraction processes. This will minimize the use of freshwater and will eliminate the impact on the local water resources, particularly in the arid regions where water scarcity is becoming a significant concern.

Model 1: Environmental Impact Reduction Model.

To determine the value in a number like the CO2 reduction of the shift from traditional mining to the contemporary sustainable process.

Let:

- I_{trad} Environmental impact of traditional mining (CO2 emissions, waste generation, etc.)
- I_{mod} Environmental impact of modern mining technologies (e.g., AI, automation, green practices)
- R_{eff}: Efficiency ratio (percentage improvement in environmental impact due to new technologies)

The reduction in environmental impact ΔI can be modeled as:

$$\Delta I = I_{\text{trad}} - (I_{\text{mod}} \times R_{\text{eff}})$$

Table 2. Cost vs. benefit of mining technologies

Technology Type	Initial Cost (USD)	Ongoing Cost (USD/year)	Efficiency Gain (%)	Safety Improvement (%)	Environmental Impact Reduction (%)
Manual Labor	Low	High	0	Low	High
Mechanization	Moderate	Moderate	20	Moderate	Moderate
Automation & Robotics	High	Low	50	Very High	High
AI-driven Systems	Very High	Moderate	70	Very High	Very High
Sustainable Practices	Moderate	Low	High (Recycling)	High (Environmental)	Very High

Table 2 evaluates the costs and benefits of the various mining technologies, looking at both the initial and the running costs of a technology and the gains in efficiency, safety, and reduction in the environmental impact. It puts forward the trade-offs between manual labor, mechanization, automation, robotics, AI-driven systems, and sustainable practices. Manual labor, although cheap in the short run, is very expensive in the long run and has an excellent effect on the environment. Conversely, solutions such as AI-based solutions and automation have significant gains in efficiency, safety, and environmental sustainability, but they are expensive to implement. Sustainable practices offer a medium-cost and moderately expensive way with huge ecological advantages.

Environmental Monitoring and Compliance

The development of technology in environmental management has allowed the tracking of pollution, emissions, and sustainability indicators in the mining process with greater efficiency. There is now the usual availability of real-time monitoring systems in place that have sensors to measure the quality of air and water, the condition of soil, and the level of emissions at mining sites. The systems also allow the operators to identify potential environmental risks at an early stage and take corrective actions before causing a lot of damage. Due to the large mining areas, satellite imaging, in addition to drone technology, can give a panoramic view of the mining region since it can give information on vegetation and water bodies changes, and the ecosystem. The technologies help in making sure that the mining activities are

within the environmental requirements and standards, through providing transparency and accountability. In order to curb the negative emissions of greenhouse gases and other detrimental emissions, emission control systems, which encompass scrubbers and carbon capture technology, among others, are now becoming a common phenomenon in order to make the mining activities a bit greener and less harmful to the environment.

The Impact of Terminology on Standards

The sustainability operations within the mining sector should be typified by standardization and uniformity of terms used to ensure standardization and uniformity. With the changing mining technology and environmental practices, such concepts as sustainable mining, green technologies, and carbon-neutral mining should be well spelled out so that there can be a common understanding among all stakeholders, such as government, corporations, regulators, and local communities. Such standardization of terms guarantees that the mining firms are held to the same level of sustainability standards so that the stakeholders may carefully evaluate the environmental performance and adherence to the regulatory requirements. Moreover, accurate language of sustainability reporting promotes transparency, and the companies can state clearly the effects on their environment and their work towards sustainability. Such a standard language assists in establishing clear expectations of what sustainable mining should entail and develops universally acceptable guidelines that can be followed by the industry to cause long-term changes that make the mining industry environmentally responsible.

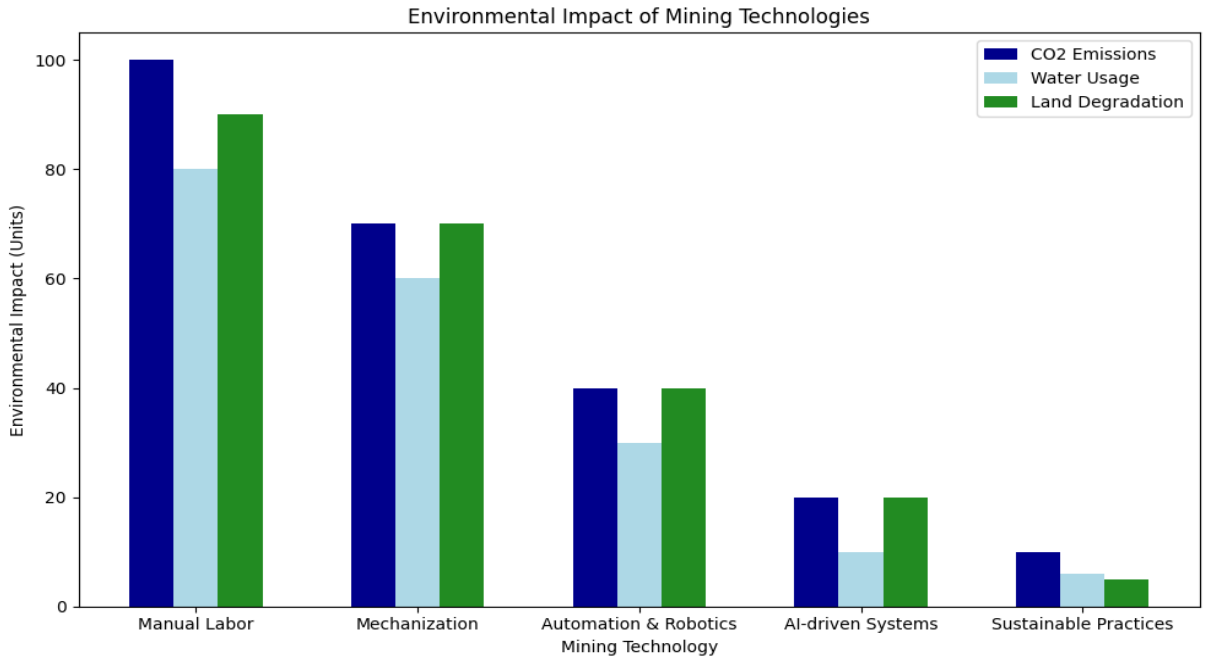

Figure 2. Environmental impact of mining technologies

Figure 2 shows the comparative environmental impact of different mining technologies in terms of CO2 emissions, water consumption, and land degradation in five major mining technologies, which include Manual Labor, Mechanization, Automation & Robotics, AI-driven Systems, and Sustainable Practices. The X-axis will be the various mining technologies, and the Y-axis will be the relative impact on the environment (the higher the value is, the more adverse the environmental impact). According to the graph, Manual Labor has the most significant ecological effects, particularly when it comes to CO2 emissions and land degradation. Mechanization has an intermediate effect, where there is a bit smaller CO2 emission, and at the same time, land use is considerable. There are fewer impacts on Automation and Robotics and AI-driven Systems, and the CO2 emissions and land degradation decreased significantly. The effect on the environment of Sustainable Practices is the least in all categories, and it is possible to discuss the relevance of environmentally friendly technology in the sphere of modern mining.

ADVANCEMENTS IN MINING SAFETY

Technological Innovations in Safety

The safety practices in the mining industry have changed drastically due to the technological innovations that have resulted in the minimization of workplace accidents and related deaths. Robotic machines like autonomous haul trucks, robotic drills, and remote-control machines have reduced the number of human employees who have to be exposed to dangerous activities in high-risk areas, including, but not limited to, blasting zones and underground tunnels. Real-time monitoring systems and safety sensors have also become crucial towards identifying and acting upon dangerous situations such as gas leaks, equipment malfunctions, or structural instabilities. These technologies provide the capability of early warnings, and hence, the operators can take corrective measures immediately prior to accidents. To illustrate, collision avoidance systems in mining trucks are helpful in avoiding the instances of accidents caused by collisions between the mining machinery and obstacles located around it by detecting them and automatically altering the movement of the vehicle, which will go a long way in alleviating the chances of accidents involving heavy machinery.

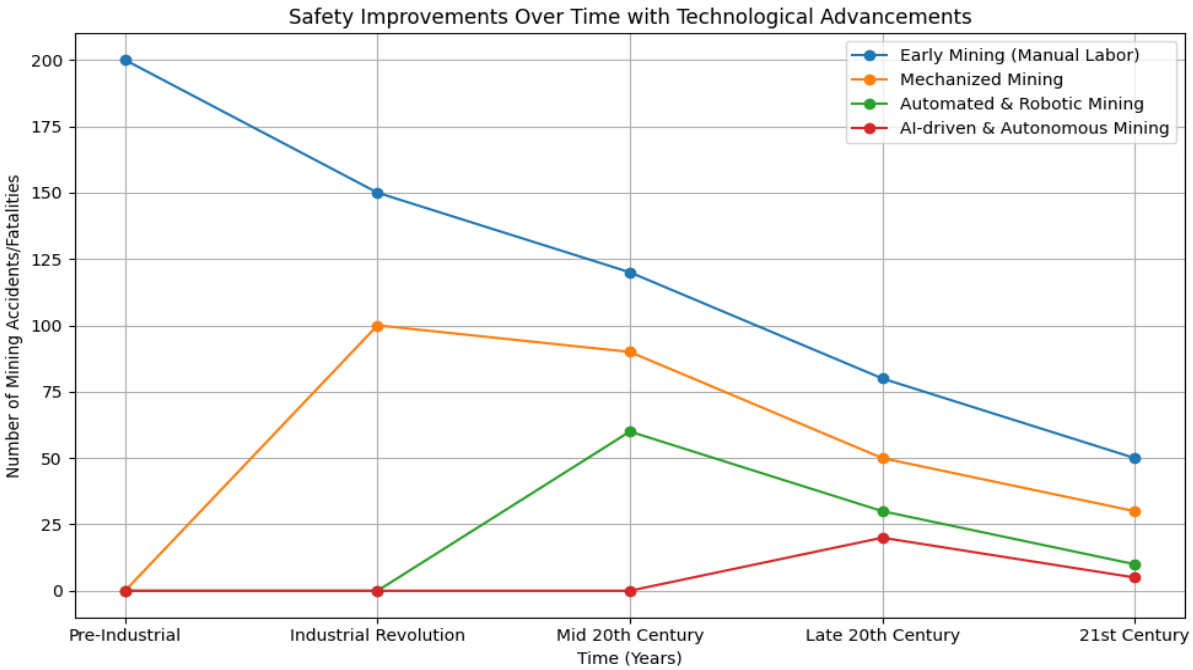

Figure 3. Safety improvements over time with technological advancements

Figure 3 shows how accidents and fatalities in mining have been decreasing with time, which evidences the intervention of technology in the mining industry. In the X-axis, the various periods are the Pre-Industrial Era all the way to the 21st century, whereas the Y-axis is the number of mining accidents/fatalities. It follows four significant steps, Early Mining (Manual Labor), which is the stage with the most number of deaths due to the hazards and manual labor; Mechanized Mining, where the fatalities number declined with the introduction of steam power and mechanical tools; Automated and Robotic Mining, where the number of fatalities dropped again with the introduction of AI and autonomous tools that made work safer and made people less exposed to hazards; and AI-driven and Autonomous Mining, where the number of fatalities is the lowest due to the introduction of AI and autonomous systems that made the work safer. This chart shows that technological advancements have helped in the continuous safety enhancement in the mining industry.

Model 2: Mining Efficiency and Safety Model with Automation

The effect of automation on mining efficiency and safety can also be quantified by the use of a mathematical model.

Let:

- E_{before} the Efficiency of mining before automation
- E_{after} the Efficiency of mining after automation
- S_{before} the Safety level before automation (measured by accident rate)
- S_{after} Safety level after automation (measured by accident rate)

The efficiency gain $\Delta E$and safety improvement ΔScan can be modeled as:

$$\Delta E = E_{\text{after}} - E_{\text{before}}$$

$$\Delta S = S_{\text{before}} - S_{\text{after}}$$

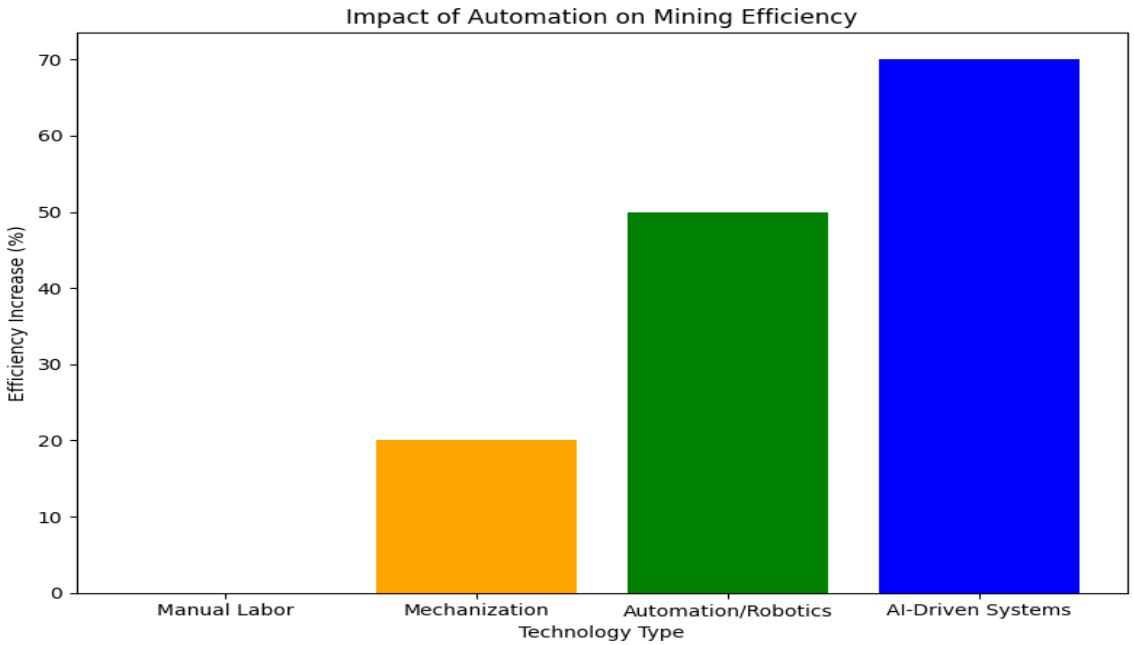

Figure 4. Impact of automation on mining efficiency

Figure 4 shows that mining efficiency greatly improves with the adoption of different technologies. The X-axis shows the various types of technology used (Manual Labor to AI-Driven Systems), whereas the Y-axis indicates the percentage of efficiency growth. There is no efficiency effect in Manual Labor (0%), because it is based on traditional and labor-intensive approaches. Mechanization also brings a middle level of efficiency gain (20%), which can be attributed to steam-powered tools and mechanical equipment to a large extent. An increase in efficiency (50) in many jobs is higher when it comes to automation/Robotics, and much of the labor is substituted by automation and robotics. The greatest efficiency argument (70) is located in the example of AI-Driven Systems, where artificial intelligence will be able to streamline mining practices, resource allocations, and predictive maintenance, and this will create a vast speed and accuracy increase.

Enhancing Worker Safety and Evolving Regulations

Mining technologies, such as AI, drones, or wearable devices, have made workers safer. AI-based systems are predicted to be preventive of accidents by analyzing data, and drones are used to inspect dangerous zones and reduce human exposure. Wearables, including smart helmets, track vital signs and locate dangers in the environment to warn workers about possible risk factors. Such technologies have reduced injuries and deaths. Also, there are new safety rules, such as autonomous machines and constant environmental control, as a result of the development of automation and real-time control. Regulations have served to offer better working conditions by means of systems like gas detection and automatic systems.

Language and Safety Measures

Mining safety procedures use standard language, which makes communication between all parties involved effective. The ability to avoid misunderstandings and establish consistency in undertaking safety measures will be possible through the adoption of the same terminology, which will be used to refer to terms like emergency evacuation and hazardous zone. Such uniformity is essential to training and emergency exercise and regulatory compliance to allow workers and regulators to concur on safety practices and requirements in various mining sites.

THE ROLE OF COMMUNICATION AND TERMINOLOGY

As technology in the mining industry continues to grow, it is crucial that a common language be adopted so that there can be effective communication in the mining industry. These terminologies, like autonomous mining, should be standardized at all times to ensure that all parties, including the engineers, operators, and regulators, are accorded the same understanding of such terminology. Homogenized terms will help the interaction and reduce ambiguity, as well as make sure that the goals of safety, environment, and functioning are represented via the global mining teams. There is a need to use standard language that will minimize the communication gap that exists between various stakeholders, such as governments, companies, and local communities. It provides a common knowledge of technologies, safety guidelines, and environmental regulations. The terms used to describe such terms, such as sustainable mining, should be defined in a manner that will remove any misunderstanding and promote open discussions. Regulatory compliance also relies on well-defined language and assists in aligning technology adoption to corporate and public interests, aiding in building trust and achieving the goals of sustainability.

Vibrant digital platforms and analytics of data are altering the definition of mining technologies, their communication, and tracking. These platforms enable mining firms to observe real-time data on the effects on the environment, safety, and extraction of resources, making the information available to all stakeholders. Digital platforms also contribute to better sustainability and safety standards in mining activities by allowing improved transparency, accountability, and communication with external stakeholders such as regulators and investors, and by offering a centralized source of data.

Table 3. Global adoption of mining technologies

Region	Automation (%)	AI Integration (%)	Sustainable Practices Adoption (%)	Challenges to Adoption
Developed Countries	70	65	80	High upfront cost, regulatory barriers
Developing Countries	30	25	40	Lack of infrastructure, technical expertise
Remote Mining Areas	15	10	20	Harsh environments, political instability

Table 3 outlines the rates of adoption of the different mining technologies, which include automation, integration of AI, and sustainable mining technology, between the developed, developing, and remote mining regions and the disparities between these regions. The developed nations are the most advanced, as three-quarters of the mining activities have adopted automation, and two-thirds of them have incorporated AI due to good infrastructure and a regulatory framework. Nonetheless, initial investments and regulations remain a problem. The adoption rates in developing countries are lower; 30% of them are already using automation, and 25% are applying AI mainly because of the infrastructure and technical skills. Remote mining regions are the last, as only 15 percent of their processes are automated and only 10 percent involve AI, and they have to overcome severe conditions and political uncertainty.

PROBLEMS AND ANTICIPATED FUTURE SCENARIOS

Technology adoption and management remain problematic areas, regardless of progress, particularly in underdeveloped regions and isolated mines. Due to a lack of resources (both financial and human), automation and AI are now impractical. The presence of outdated regulations and the inability to implement them further slows down the progress. The severe weather and political instability in isolated communities make the adoption of technology challenging, and this leads to inefficiencies, damages to the environment, and also jeopardizes safety. The challenges will only be overcome through flexible and low-cost technologies and tougher regulatory systems to endorse sustainable practices.

Autonomous mines, AI-based exploration, and environmentally friendly mining will determine the future of the industry. Self-motivated vehicles and robots will be more efficient, safe, and low-priced. The discovery of a mineral will be accelerated by AI, whereas environmentally friendly technologies, such as technologies that capture carbon and recycle water, will be used to reduce the impact on the environment. Standardized and transparent terms will be crucial in making these innovations spread globally, where all stakeholders will find it easy to collaborate, and these innovations will take shorter durations to be applied broadly.

Scalable solutions that are cost-effective for developing regions should also be studied in order to build up technology, sustainability, and safety. The world should unite in order to harmonize the metrics of sustainability and safety standards and make sure that the rest of the industry is equally comfortable with them. Adoption of green technologies can be funded through public-private partnerships, and investment in training programs will provide the workforce with skills to safely use new technologies. Through these issues, the mining industry will be in a better position to be more sustainable and efficient, and minimize its environmental footprint.

CONCLUSION

The research has discussed the development of mining technology and its importance in improving the levels of environmental sustainability and safety. Early manual methods and the adoption of automation, AI, and robotics have made technology a more effective way to make mining more efficient, less harmful to the environment, and safer for workers. The cleaner extraction methods, real-time monitoring systems, and other innovations that include self-driving machinery have changed the industry, as the main issues related to the industry have always been safety and environmental impact. Further technological advancements in the mining sector are necessary to support the increasing demands for resources in the world, reduce ecological impacts, and provide optimal safety to the mining sector employees. Nevertheless, these developments are only achievable in full capacity due to clear and standardized communication among all the stakeholders. Through a set of uniform terminology and good communication habits, the implementation of new technologies will be smooth, and sustainability and safety objectives will be attained at the global level. To summarize, the future of mining is going to be safer and more sustainable, which will be promoted by the constant evolution of mining technologies, a standardized language, and clear communication, which will benefit the environment and the workforce in the world in general.

REFERENCES

[1] Onifade M, Said KO, Shivute AP. Safe mining operations through technological advancement. Process Safety and Environmental Protection. 2023 Jul 1;175:251-8. https://doi.org/10.1016/j.psep.2023.05.052

[2] Zoitl S, Angelov N, Douglass GH. Revolutionizing industry: Real-time industrial automation using embedded systems. SCCTS Journal of Embedded Systems Design and Applications. 2025;2(1):12-22.

[3] Rybak J, Adigamov A, Kongar-Syuryun C, Khayrutdinov M, Tyulyaeva Y. Renewable-resource technologies in mining and metallurgical enterprises providing environmental safety. Minerals. 2021 Oct 18;11(10):1145. https://doi.org/10.3390/min11101145

[4] Dash SR, Sinha R. Assessing The Role of Environmental Pollutants and Nutritional Components In Modulating Carcinogenesis in Aquatic Life Using Carcinogenmodnet. Vascular and Endovascular Review. 2025 Sep 20;8(1s):23-6. https://doi.org/10.70102/IJARES/V5S1/5-S1-21

[5] Flores-Castañeda RO, Olaya-Cotera S, López-Porras M, Tarmeño-Juscamaita E, Iparraguirre-Villanueva O. Technological advances and trends in the mining industry: a systematic review. Mineral Economics. 2025 Jun;38(2):221-36.
[6] Bhanot D, Jadhav Y, Tiwari G, Walia A. Environmental Implications of Heavy Metal Deposition and Particulate Matter in Coal Mining Ecosystems. Natural and Engineering Sciences. 2025 Mar 1;10(1):325-39. https://doi.org/10.28978/nesciences.1648723
[7] Zhironkin S, Ezdina N. Review of transition from mining 4.0 to mining 5.0 innovative technologies. Applied Sciences. 2023 Apr 14;13(8):4917. https://doi.org/10.3390/app13084917
[8] Venkatesh S, Raj I. Innovations in mechanical engineering: bridging safety, efficiency, and sustainability. International Academic Journal of Innovative Research. 2022;9(3):38–43. https://doi.org/10.71086/IAJIR/V9I3/IAJIR0924
[9] Codoceo-Contreras L, Rybak N, Hassall M. Exploring the impacts of automation in the mining industry: A systematic review using natural language processing. Mining Technology. 2024 Sep;133(3):191-213. https://doi.org/10.1177/25726668241270486
[10] Kumar P, Tiwari R. AI-based predictive maintenance for industrial IoT applications. International Academic Journal of Science and Engineering. 2024;11(4):10–15. https://doi.org/10.71086/IAJSE/V11I4/IAJSE1164
[11] Zhironkina O, Zhironkin S. Technological and intellectual transition to mining 4.0: A review. Energies. 2023 Feb 1;16(3):1427. https://doi.org/10.3390/en16031427
[12] Borhan MN. Exploring smart technologies towards applications across industries. Innovative Reviews in Engineering and Science. 2025;2(2):9-16.
[13] Patil Y, Tatiya M, Dharmadhikari DD, Shahakar M, Patil SK, Mahajan RG, Kurhade AS. The Role of AI in Reducing Environmental Impact in the Mining Sector. Journal of Mines, Metals & Fuels. 2025 May 1;73(5). https://doi.org/10.18311/jmmf/2025/48521
[14] Rachmad YE. Green Technologies for a Sustainable Mining Industry. The United Nations and The Education Training Centre; 2015 Jul 4.
[15] Jenkins H, Yakovleva N. Corporate social responsibility in the mining industry: Exploring trends in social and environmental disclosure. Journal of cleaner production. 2006 Jan 1;14(3-4):271-84. https://doi.org/10.1016/j.jclepro.2004.10.004
[16] Puronaho LA. Strategic integration of a new technology for advancing sustainable mining. 2024.
[17] Djanetey GE, Yakin Z. Ground control systems for deep underground mining: Advancing safety and resource recovery in high-stress mining environments. World Journal of Advanced Research and Reviews. 2025;27(1):2134-42. https://doi.org/10.30574/wjarr.2025.27.1.2751
[18] Rojas L, Hernandez B, Garcia J. A Systematic Review of Intelligent Agents, Language Models, and Recurrent Neural Networks in Industrial Maintenance: Driving Value Creation for the Mining Sector. International Journal of Intelligent Systems. 2025;2025(1):9953223. https://doi.org/10.1155/int/9953223
[19] Ali MA, Ali MI, Osman AA. AI-driven Mining 4.0: A Systematic Review of Smart, Sustainable, and Autonomous Technologies across the Mining Lifecycle. Current Journal of Applied Science and Technology. 2025 Jun 30;44(6):125-39. https://doi.org/10.9734/cjast/2025/v44i64564
[20] Jackson S, Poelzer G, Poelzer G, Noble B. Mining and sustainability in the circumpolar North: the role of government in advancing corporate social responsibility. Environmental Management. 2023 Jul;72(1):37-52.
[21] Li Y, Li L, Wu Z, Bing Z, Ai Y, Tian B, Xuanyuan Z, Knoll AC, Chen L. MiningLLM: Towards mining 5.0 via large language models in autonomous driving and smart mining. IEEE Transactions on Intelligent Vehicles. 2024 Mar 26. https://doi.org/10.1109/TIV.2024.3382048
[22] Zhironkin S, Szurgacz D. Mining technologies innovative development: Economic and sustainable outlook. Energies. 2021 Dec 20;14(24):8590. https://doi.org/10.3390/en14248590
[23] Oluokun OA, Akinsooto O, Ogundipe OB, Ikemba S. Energy efficiency in mining operations: Policy and technological innovations. Journal Name Missing. 2024 Jan. https://doi.org/10.54660/.IJMRGE.2024.5.1.994-1008
[24] Rachmad YE. Innovation and Technological Advancements in Mining. The United Nations and The Education Training Centre; 2015 Jul 8.
[25] Cacciuttolo C, Guzmán V, Catriñir P, Atencio E, Komarizadehasl S, Lozano-Galant JA. Low-cost sensors technologies for monitoring sustainability and safety issues in mining activities: advances, gaps, and future directions in the digitalization for smart mining. Sensors. 2023 Aug 1;23(15):6846. https://doi.org/10.3390/s23156846