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of the

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33rd Annual General Meeting of the Society of Mining Professors (SOMP)

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Preface

Univ.-Prof. Dr.-Ing.
Oliver Langefeld

Dear friends and colleagues,

I am very proud to welcome you all at Clausthal University of Technology for our annual conference.

30 years ago – in 1993 – my colleague Werner Vogt welcomed the society in Clausthal. So, it is the second time that the members of the Society of Mining Professors come to Clausthal for an Annual General Meeting.

But the Society has much older roots in our small Mining and University town: The Society of Mining Professors / Societät der Bergbaukunde was re-established in 1990 based on the much older Societät der Bergbaukunde. Its original foundation was in 1783 with 154 members from 21 countries under the presidency of Ignaz von Born. At the end of the 18th Century, the scientific exchange was already vibrant and documented at the Societät's headquarters in Clausthal-Zellerfeld. The Societät was the first technical-scientific society in the world. Honorary members of this Societät have been amongst others Johann Wolfgang von Goethe, James Watt, and Antoine Lavoisier.

When the new society was refounded in 1990, the Professors Günther Fettweis, Ludwig Wilke, and Walter Knissel were founding member amongst others. Wilke and Knissel have also been rectors of Clausthal University of Technology. Since then, SOMP plays a crucial role through its support in the field of mining science and its contributions to research, education, and transfer. It is the leading international society for mining science professionals and recognized for effective networking, supporting collaboration and innovation in research, teaching, and training, and for its influence on the global mining industry. While the Society initially had a primarily European dominance, it has since evolved into a global community, with approximately 300 members who represent 110 mining institutes across 45 countries.

Nowadays, we are facing global changes in terms of economy and environment. Wars are shaking the world and completely disrupting old trade routes. Last winter, Europe was facing a major energy shortage, while electricity and gas is hardly affordable for poorer families. This development shows the importance of raw materials – not only energy raw materials but also mineral ones. Raw materials for all planned electric vehicles have yet to be found, extracted, and, above all, paid for. These two examples already clearly show how important our work as miners is. And it shows that the education of creative young people who can master future challenges is even more important.

What can SOMP contribute to this?

We are a globally established and active community. So we can answer the question with my slogan for my year as SOMP president: "SOMP connects the world". That is exactly what we are doing on all levels. In our committees, we develop ideas in smaller groups that will then be implemented in our Society. During the several meetings between our Annual Conferences, the concepts are evolved mainly on a digital base. Special sessions at the conferences are used to share and discuss those with the delegates. In this way, ideas and concepts can grow over several years. SOMP's contributions are:

- Share and learn education approaches
- Initiate and promote student mobility
- Build networks for joint research
- Enhance an alliance in academia
- Enable global faculty mobility

Another important way to strengthen our society is the realization of Regional Meetings. We have to foster these meetings to share our ideas in all countries and recruit new members.

During this Annual General Meeting, we share and discuss advances in more sustainable mining, trust for those activities, innovative and creative ways of education and its challenges, the emerging workforce, and ways of collaboration and interactions between our members. I hope that these will be fruitful and help us on our mission. At this point, special thanks go to those SOMP members who helped us set up the program with its elements and who peer-reviewed selected articles. The committees and my team in Clausthal prepared all these and I wish all of us an interesting and good conference.

My team, which I proudly present, consists of Angela Binder, Sandra Nowosad, Mareike Bothe-Fiekert, and Florence Apollo. Without their support and organizing nothing would have been realized.

Best regards and enjoy the conference

Glückauf

Univ.-Prof. Dr.-Ing. Oliver Langefeld

Building Trust in Mining

Current status and future perspectives of the global mining industry concerning the net zero emissions goal: An academic point of view

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Abstract

As the demand for renewable energy continues to grow, the global mining industry is reaching a historical turning point to transforming from a polluting business to a recognised contributor to the broader clean energy transition. The supply of critical minerals essential for clean energy technologies must pick up sharply over the coming decades to meet the world's climate goals. However, data shows a looming mismatch between the availability of critical commodities and the realisation of the world's ambitions to pursue net-zero carbon emissions and energy generation from renewable sources. In addition, declining reserves and ore grades, environmental issues, and social arguments remain bottlenecks that challenge global mining operations' sustainability. The diversity of conditions, policy-making and public perception of mining in different parts of the world is investigated in this work. Furthermore, the different points of view of academics, researchers, government officials, and mining industry stakeholders are being considered. A significant number of mining experts worldwide are participating in a survey comparing the industry's current status and future perspectives in different countries and continents, focusing on the increasing demand for critical minerals and metals toward the transition to renewable energy sources. This work discusses the apprehension of academics on the subject matter, and the survey outcomes support comparing their opinions with other stakeholders. Additionally, this research identifies all struggling issues of local sectors, proposing the following steps and indicating the future perspectives of mining operations as well as the role of academia worldwide. The authors aim to map the diverse conditions and challenges that both the mining industry and academic sectors are facing in different parts of the world, provide a clear academics point of view as to if and when the world will fully transition to renewable sources for energy production, and serve as a guide to how the academia can contribute further toward a sustainable supply of critical raw materials.

Sustainability in Mining: a vision of the mines of the future, its challenges and opportunities

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Abstract

Mining is currently undergoing a transformation since the stakeholders of the mining industry pursue more and more sustainable practices as core value of their activities, specially since the achievement of the sustainability development goals has become a key point in their strategies.

This transformation is currently impulsing a structural change at every level within mining companies and operations. This, mostly related to the implementation of technological developments and trends such as automation, digitalisation and interoperability.

However, considering the effects of climate change, the actions that industries are undertaking to reduce emissions, the social perspective of mining in the broader society, and the conciouseness developed in the latest years, the vision of the mines of the future should be centered in sustainability.

This is shared by the vision Epiroc has of the future of mining as one of the leading machinery manufacturers and engineering solutions providers of the mining industry. This presentation centers in the technological, enviromental, safety and social challenges and opportunities that come along with the mines of the future. It showcases examples such as the new abilities required from the workforce and innitiatives from the private sector to create sustainable knowledge, opportunities for inclusion brought by the new working places (for example dispatch centers for automated machinery), from the experience Epiroc has made through the implementation of new technologies worldwide.

Additionally, this presentation addresses the role of the academia as the center element for educating the workforce of the future.

Critical Minerals: Importance, Risks, and Future Prospects in Australia and Beyond

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Abstract

Critical minerals are crucial for modern technologies, economies, and national security due to their essential properties. These minerals are used in various industries, most notably in low-emission technologies, including electric vehicles, wind turbines, solar panels, and rechargeable batteries, as well as in defence, aerospace, medical applications, communication, fibre-optic cables, semi-conductors, banknotes and in many others. The demand for critical minerals will increase exponentially and likely stay at the same levels for a carbon-free future. Therefore, a constant supply of critical minerals is imperative. The future of critical minerals depends on developing sustainable mining practices, diversification of supply sources, and advancements in recycling technologies. Optimising the extraction and processing of critical minerals requires advanced technologies such as artificial intelligence, automation, and big data analytics to ensure efficient and cost-effective production while minimising environmental impacts. Governments, industry, and research institutions are working towards addressing the challenges related to critical minerals. This paper aims to discuss critical minerals-related challenges and opportunities in Australia and globally, including their geopolitical definitions, use, supply chain risks, recycling, future outlook, and technologies required to optimise mining and processing. Further, the roles of universities and research organisations in promoting the mining of sustainable critical minerals and developing new technologies are highlighted.

Sustainable Green Mining Engineering based on Efficient Power Generation and Utilisation: Towards Low Carbon Footprint

Peer Reviwed

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Abstract

Mining is currently responsible for between 4 - 7 % of greenhouse-gas emissions globally, consisting of 1 % from mining operations and power consumption, while the other 6 % is attributed to the fugitive-methane emissions from coal mining. Faced with the rising pressure on climate change, and given that some forecasts indicate that climate hazards such as heavy precipitation, drought, and heat will become more frequent and intense, green mining engineering is becoming imperative. It is proposed that green mining be prioritised in mining and this involves integrating sustainable and environmentally friendly practices in the design, operation, and closure of mining operations. Firstly, the basic concepts of green mining engineering are presented in this study, and the green obligations that mining engineers may confront are then discussed. A case study was undertaken to analyse green mine engineering, and four aspects namely efficient power generation, usage, skills training and low carbon footprint production were explored in depth. Several solutions were proffered, including using renewable energy sources such as solar, wind, or pumped-storage hydropower (PSH) (which utilise re-purposed open pits and underground mines/shafts) to provide electricity to mining and processing operations. This could be done by installing solar panels, wind turbines, or pumped-storage hydroelectric generators on site, or by connecting to a nearby grid that is powered by renewable sources. Another approach is to use energy-efficient technologies and practices to reduce energy consumption and greenhouse gas emissions. This could include using energy-efficient lighting and heating systems, optimizing mine ventilation systems, and using advanced sensors and control systems to monitor and optimize energy use. It is also proposed that the green mining engineering concept be equipped to future engineers as essential guiding principles to minimize carbon footprint, which is normally exacerbated by poor decision-making during the life of mine. In addition, mining companies could adopt low-carbon production processes to reduce their carbon footprint. For example, they could use recycled materials and water, reduce waste generation, and adopt more sustainable mining practices. Adopting green mining engineering practices can help mining companies reduce their environmental impacts, lower operating costs, and enhance their reputation as responsible corporate citizens.

1 Introduction

The mining industry plays a pivotal role in global economic development, providing essential resources for various sectors. However, it is also known for its significant environmental impact, particularly in terms of energy consumption and carbon emissions. To mitigate these effects, the concept of green mining engineering has emerged, focusing on adopting sustainable practices to minimize the industry's ecological footprint. This paper explores the importance of efficient power generation and utilization techniques in green mining engineering to achieve low carbon footprint mining. Mining activities consume vast amounts of energy, predominantly sourced from fossil fuels which contribute about 25 % to the overall world energy matrix (Shia, 2012). This energy reliance results in substantial carbon emissions, contributing to climate change and environmental degradation. It is crucial to address this issue by implementing energy-efficient practices.

Mining is currently responsible for between 4 - 7% of greenhouse-gas emissions globally, consisting of 1 % from mining operations and power consumption, while the other 6 % is attributed to the fugitive-methane emissions from coal mining. One of the greenhouse gases is Carbon dioxide, which is measured by amount of CO_2 emissions released into the atmosphere which continue to increase, causing glaciers to melt and increase sea level, reduce water resources, thus causing global warming (Akyol, & Uçar. (2021)). In support of Paris Climate Agreement and Kyoto Protocol to reduce the carbon footprint, the mining industry is under immense scrutiny to reduce its carbon footprint. To address this issue, green mining engineering emphasizes the reduction of carbon emissions through efficient power generation and utilization. In some cases use of High Pressure grinding and tower mills technology has been advocated to reduce power demand in comminution (Botshiwe, 2022).

The objective of the research was to ascertain the readiness of Southern African mines to reducing the carbon footprint in the mining operations. This was undertaken by estimating the proportion of the renewable power generation to the total power demand and assessment of any other forms of efficient utilization of power. Lastly ranking of the renewable power generation proportion was done in order to assess the preparedness of the Green Mining aspect.

2 Literature Review

The world is transitioning towards green technology. Green technology is the technology that limits or reverses the impacts of human activity on the planet. Business and individuals are embracing the benefits of sustainability, conservation, environmentally friendly lifestyles and the benefits of going green. Green Mining technology refers to technology that will reduce carbon emissions in operations and mitigate adverse environmental impacts. This has made the mining industry to join the rest of the world by embarking on a number of initiatives in the green technology which include methane capturing techniques, carbon capturing and storage, zero discharge water programs, energy efficiency, reclamation and green products and dust control (mining.com, 2016). Two main ways used in green mining reform are governmental regulation and innovative technology. A number of researchers have developed frameworks to embrace green mining and have discussed a number of aspects starting with Environmental policy, resources utilization, environmental protection and mining efficiency enhancement as key (Li et al., 2022).

2.1 Environmental Policy

Mining organisations should develop and abide by their safety and environmental policies in order to limit work-related injuries and ecological effects. A polluted environment results in resource wastage and unsafe workplaces. More often, three parameters of work-related injuries are assessed and should be minimised, namely the annual number of slight injuries, annual number of serious injuries, and deaths per million working hours, (Wang et al., (2020); Zhou et al. (2020). Safety management is a key concern for the organization and implementation of enterprise safety management planning, guidance, inspection, and decision making (Han et al. 2017) is enhanced through training.

2.2 Resources Utilization

Utilization of resources covers two phases namely to improve the utilization rate of the resources, and to complete the comprehensive utilization of solid waste. In the case of mines, the resources are mainly the product or metal or other associated mineral. In this case the improvement of the utilization of the resources will include improving the mining recovery rate (Chen et al.2022), and mineral processing recovery rate (Chen et al., 2020). In this particular case efficient power generation and utilization is key to reducing the carbon footprint.

The other view is to utilize the waste especially the solid waste from the mines. The solid waste includes waste rock from mining and tailings from processing, which will occupy industrial land and pollute the environment. Actually, the waste produced in gold mines is also a valuable resource, which is worth developing and utilizing (Liang et al. 2020).

2.3 Environmental Protection

On the other hand, ten environmental indicators have been grouped into the natural resources, namely energy, materials, water, emissions, effluents and wastes, Land use, restoration and biodiversity, transport and logistics, suppliers and contractors, products and compliance and voluntary activities (Azapagic, 2003). Of great concern is the waste rock piles and tailing dams filling up land, which damages the natural landscape, causing environmental pollution. Land reclamation is the activity of restoring damaged land to a usable state, the strength can be demonstrated by land reclamation rate (Wang et al. 2020). The main focus of mine greening is to restore vegetation by greening and planting barren areas to increase the vegetation coverage rate of mining area (Liang et al., 2019) and fulfill the goal of optimizing the landscape. In addition to land pollution, emission pollution is also important and its control is vital for environmental protection (Liang et al., 2019). One other aspect to consider before and during the mining operation is the environmental investment ratio which measures the relationship between economic development and environmental protection (Zhao et al. 2021).

2.4 Mining Efficiency

Mining efficiency is measured by a number of parameters namely power consumption per ton of ore, mining ore dilution, mining productivity, and minimization of mining losses. During the mining process, one big objective is to increase efficiency in power utilization. Hence, reflection on the energy consumption level of mining (Chen et al., 2020). Efficiency improvement plan and decreasing environmental effects of mining can be facilitated by closing illegal and unregulated mines, re-evaluating cut off grades and implementing recently discovered green technologies (mit.edu).

Insitu leaching – another aspect for improving efficiency would be to look into the general mining and beneficiation processes. Open pit mining contributes about 85 % of all mineral mining, but is the most environmentally burdening. More than 73 % of extracted rock goes to waste depending on the mineral. On the other hand, underground mining produces only 7 % of the extracted rock but nevertheless is more costly (Hartmann & Mutmansky, 2002). Meanwhile, in situ mining is generally more environmentally friendly than either surface or underground mining in terms of the carbon footprint, and is cheaper (Ulmer-Scholle, 2008). Unfortunately, in situ mining cannot be implemented in all cases where the ore above the water table and the host rock needs to be porous enough to let the leaching solution percolate (Topf, 2011).

3 Green Mining Strategies

A number of green technology strategies have been undertaken which include methane capturing techniques, carbon capturing and storage (sequestration) (Fox et al. 2020), zero discharge water programs, energy efficiency, reclamation and green products and dust control (mining.com, 2016). A fundamental strategy for achieving efficient power generation in mining operations is the transition from fossil fuel-based energy sources to renewable alternatives. Green mining engineering involves integrating sustainable principles into mining operations. Incorporating solar, wind, hydroelectric, or geothermal power can significantly reduce carbon emissions. Installing renewable energy infrastructure at mine sites not only reduces environmental impact but also offers long-term cost savings, as renewable energy prices continue to decline. This includes reducing energy consumption, optimizing resource utilization, minimizing waste generation, and mitigating environmental impacts as depicted in Figure 1. By adopting these principles, the mining industry can make significant progress toward achieving a low carbon footprint and the extent to which the mining companies focused on in this study had adopted these initiatives was assessed.

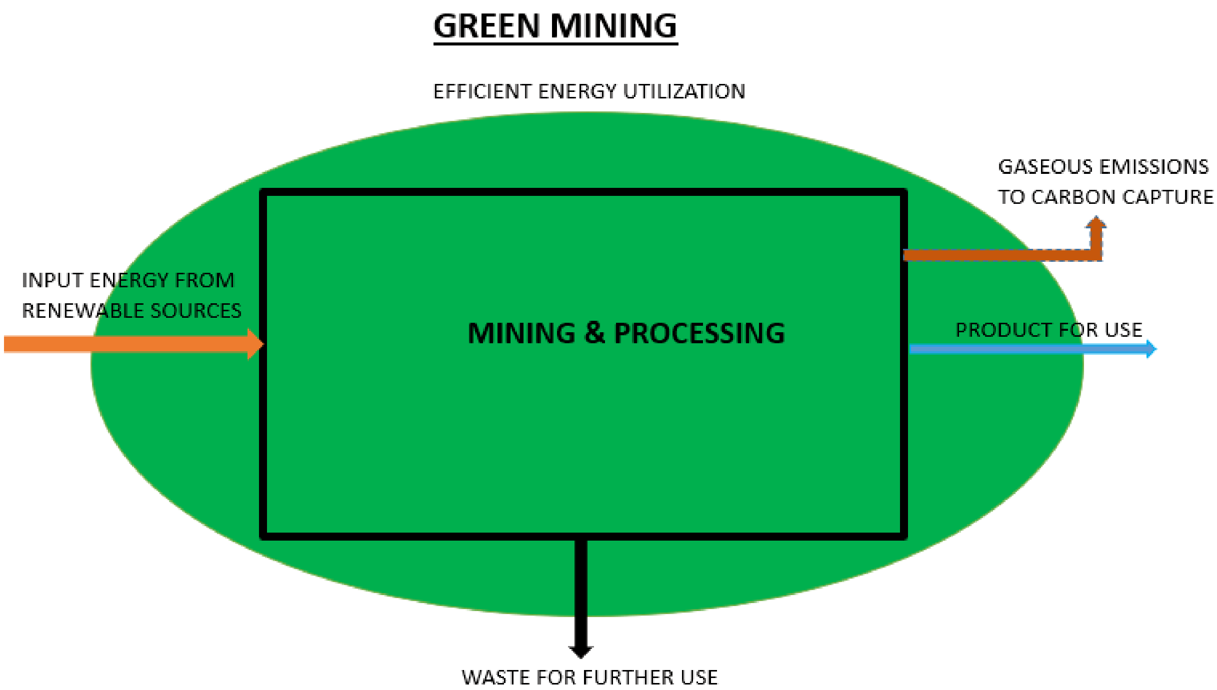

Figure 1: The Green Mining concept showing input, process and output

3.1 Power Generation

Efficient power generation in mining operations: transitioning to renewable energy sources is a key strategy in green mining engineering. Solar power, for instance, can be harnessed through the installation of photovoltaic panels in and around mining facilities, reducing dependence on fossil fuels and lowering carbon emissions. Similarly, wind energy, hydropower and green hydrogen can be integrated into mining operations, providing clean and sustainable power.

3.2 Energy Utilization and Management Techniques

Apart from generating clean energy, efficient utilization and management of power are crucial for reducing carbon footprint. Implementing energy-efficient processes in mining operations, such as optimizing equipment and machinery, reducing idle time, and employing advanced technologies, can significantly improve overall energy efficiency. Furthermore, integrating mine power grids with the regional electrical grid enables the sharing of renewable energy resources, further reducing reliance on non-renewable sources. Smart grid technologies and energy storage solutions further enhance energy utilization by optimizing power distribution and reducing energy wastage.

3.3 Energy Storage and Grid Integration

Energy storage systems, such as batteries or compressed air, can optimize energy use, allowing mines to store excess renewable energy for later use during peak demand periods. This may be achieved through pumped-storage hydropower systems. There is potential for converting or re-purposing mined opencast pits at one of the Gold mines in Namibia.

3.4 Smart Grid and Energy Management Systems

Implementing smart grid technologies and advanced energy management systems can optimize power generation and utilization in mining operations. By employing real-time monitoring, data analytics, and automation, mines can match energy supply with demand more effectively, reducing wastage and improving overall energy efficiency. Additionally, intelligent load management systems can prioritize energy usage, directing power to critical processes and minimizing energy waste.

3.5 Technological Innovations and Best Practices

Continued research and development in green mining engineering are essential for driving further advancements in efficient power generation and utilization. Technologies such as energy-efficient equipment, process optimization, and waste heat recovery systems can significantly enhance energy performance in mining operations. Sharing best practices and collaborating with industry stakeholders can accelerate the adoption of these innovations.

3.6 Inclusion of Green Mining Principles in Mining Curricula

To ensure that future generations understand and continue to implement green mining techniques, it is imperative that the principles should be incorporated into higher mineral education curricula.

4 Case Studies:

A questionnaire was sent out to the mines in Namibia in addition to physical meetings. The questionnaire, however, generated a low feedback because of time constraints. The response of the Namibia mines was compared to what is taking place in South Africa on NuGen project as it is considered to be a leader in terms of Green Mining Strategy. The questionnaire looked at assessing the different strategies used in mines to combat greenhouse gases. In light of the strategies discussed in Section 3, an assessment of these strategies on different mines was undertaken. The ranking of the assessment was based on the overall use of renewable power in the power mix or the overall reduction of power demand using other alternatives. The case studies were used to assess the readiness of mines in Southern Africa for Green Mining. During the research the aspects that were assessed are shown in Table 1 and include the following:

- Amount of renewable energy in the power input
- What factor of efficiency in power consumption was achieved measured by the power consumption per ton of ore
- What is the environmental investment ratio

Successful Green Mining initiatives: several mining companies have successfully implemented green mining engineering principles to achieve efficient power generation and utilization. For example, *B2Gold* transitioned from heavy fuel oil (fossil) fired power generation to renewable energy sources, installing solar panels and wind turbines, leading to a substantial reduction in carbon emissions. *Rossing and Swakop Uranium* implemented energy-efficient mining processes, optimizing the use of equipment and machinery using the trolley assist, resulting in significant energy savings.

South Africa NuGen project at the Mogalakwena mine owned by Anglo America Platinum Limited will use power from a 140-megawatt solar plant to supply hydrogen electrolyzers to split water and provide the trucks, which can carry up to 315 tons of ore each, with hydrogen fuel. This is against a background that about 80 % of diesel consumption at large mines is consumed by large trucks thus eliminating the use of diesel in trucks and transitioning to carbon neutral in the early future (mybroadband, 2022).

Navachab Gold: Reduction in energy consumed by comminution processes is one way to reduce the carbon footprint from mining. A review of a number of prominent/popular published sources indicates that the Mining Industry may be responsible for 8 - 11 % of global energy consumption and that comminution is responsible for a significant proportion of this (Morrell, 2023). This points to comminution being a major contributor to global greenhouse gas emissions. The adoption of High Pressure Grinding Rolls (HPGR) technology is shown to be able to reduce it significantly. Navachab Gold mine in Namibia installed the HPGR technology as well as comparably efficient tower mill technology and realised significant savings in comminution energy consumption (Botshiwe, 2022).

Table 1: Showing different mines that use different strategies to reduce carbon foot print

Catergory	Mine 1	Mine 2	Mine 3	Mine 4
Environmental investment ratio	1 %	2 %	1 %	1 %
Power consumption	16 MW	140 MW	24 MW	4.5 MW
Renewable Energy Power proportion	43.75 %	80 %	0 %	0 %
Energy Storage and Grid	Nil	Nil	Nil	Nil
Technological innovation	Nil	Nil	Nil	Nil
Smart Grid and Energy management	Nil	Nil	Nil	Nil

Other	Nil	Use Hydrogen trucks and elimantess carbon emission significantly	Use trolley assist and reduce carbon emissions by about 20 % and use acid plant which generates thermal energy and reduce power demand from the national grid	Use trolley assist and reduce carbon emissions by about 23 % and use acid plant which generates thermal energy and reduce power demand from the national grid
Ranking *	2	1	4	3
Overal Rating	Good transition	Very good	Planning to install 50 % solar plant	Good transition

*Ranking was done by considering the proportion of the renewable component to the overall power mix or how much power saving has been integrated into the mining system

5 Discussion

Table 1 shows the different strategies that are employed by the mines under review to reduce the carbon foot print. Overall, the mines are employing good strategies such as generating power from renewable energy, and thermal power utilisation to reduce power demand and efficient utilisation of power through trolley assist for heavy trucks. Similarly, the environmental investments were fairly standard ranging between one and two percent. However, none have as yet implemented any latest energy storage techniques, smart grid and energy management systems, integrated smart grid technologies, allowing for better energy management and reducing overall power consumption. Evaluation of the latest strategies is underway at the mines, which will lead a long way in the direction of green mining. As in the Table 1, the multi variable problem was reduced to a two variable model which made the ranking easier.

The postgraduate curricula offered by NUST in both Mining and Metallurgical Engineering, however, do incorporate these concepts. It is expected that the graduates from these programmes will drive and promote implementation of Green Mining within the country and the region.

6 Conclusion

The significance of the study was to ascertain the readiness of Southern African mines to reducing the carbon footprint in the mining operations. Green Mining engineering, with its focus on efficient power generation and utilization with a low carbon footprint, is crucial for the sustainable development of the mining industry. By transitioning to renewable energy sources, optimizing energy utilization, and adopting sustainable practices, mining operations can significantly reduce their environmental impact. The implementation of these strategies not only benefits the environment but also promotes long-term economic viability. It is imperative for mining companies to embrace green mining engineering principles and contribute to a more sustainable future for the industry and the planet as a whole. The inclusion of these principles in mining engineering curricula will ensure sustainability of green mining into the future.

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Building trust through Citizen Science in Mining

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Abstract

Growing global population results in an increase in demand for raw materials hence the need to be more innovative in measures regarding sustainability in mining. Sustainable mining requires monitoring of parameters that affect the environment and human health. Citizen science which is the participation of the public or non-scientists in collecting scientific data and other aspects of the scientific process (Grace-McCaskey, Iatarola, Manda, & Etheridge, 2019), has the potential of providing a solution through parameter monitoring. Citizen science in mining could mean training the public and giving them basic skills in parameter monitoring which can aid in bridging the knowledge gap between local knowledge and scientific research (Fraser 2006) resulting in a better-informed decision-making process that will ensure accountability, acceptability, and transparency. Environmental and health variables, including water quality and quantity, air quality, soil, and sediment monitoring, make up the majority of the parameters that can be monitored through citizen science. Some of the advantages of citizen science are its capability of increasing data collection and analysis at minimal costs, citizen science can argument project scope across temporal and spatial scales (McKinley et al., 2017), hence facilitating the observation of otherwise difficult to quantify phenomena. Other advantages of citizen science include education through improving scientific literacy and engaging with the public. A mining project does not exist alone, the community around it needs to be involved since the mere existence of the project in the region results in changes both positive and negative. To deal with the negative changes, mitigation measures must be implemented. For the successful implementation of these measures, society must be involved. This is where citizen science has the potential to provide community involvement in mitigation or monitoring and result in acceptance, transparency and accountability. The presentation will show examples of mining projects where citizen science has been incorporated, present the parameters monitored through citizen science, the strengths and weaknesses, and suggest significant improvements to promote greater integration of citizen science in mining projects.

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Valorization of mining heritage in the process of Post Mining

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Abstract

The mining industry has had great importance in the socio-economic/cultural development of many cities, districts, regions, and countries around the world. Society must know the important role that mining has had on the history and development of mankind and this is an important strategy in achieving a positive image of mining from the society. Mining will have a great future if we are able to achieve that society and new generations have a real and positive understanding of what the mining industry has been and represent now for the future. This is a transcendental role that using the mining heritage in post mining projects can accomplish. There are thousands ideas for using the mining heritage to develop the future and economy of the mining towns. In this paper we present an international vision on the synergies that can emerge from using mining heritage as a tool in the post mining process in the mining sector worldwide.

Proposal of Support for the Process of Formalization and Consolidation of Mining Activities in the Community of Santa Rita – Andes, Antioquia – Colombia

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Abstract

This paper seeks to develop a support the process of formalization and consolidation of mining activities in the community of Santa Rita – Andes, Antioquia, which requires the approach of different lines of approach from the legal, technical, and economic aspect for the coexistence of the economic sectors involved. Some of the lines that are initially proposed are:

- Education
- Mining formalization
- Geological study
- Mining concept
- Processing concept
- Circular economy
- Inclusive economies

As intervening actors in the sector, the Universidad Nacional de Colombia – Medellín (UNAL), from the academy are called to initiate the application of these strategies, which seek to meet the objective of supporting the mining communities, particularly this community in Santa Rita, Antioquia, Colombia in the process of consolidation of its mining economic activities present in this area, for the development of circular and inclusive economy that contribute to the coexistence of these productive sector in the territory.

In addition, the Universidad Nacional de Colombia as the entity of education, research and extension, which supports the development of policies to the Colombian State and the support to entities in the social, environmental and economic work in the regions of the country, has extensive experience in the mining sector, in addition to a high coverage in the national territory, which has the privilege and capacity to make presence in territories with indigenous communities, afro descendent and peasants.

This work contributes to the training of students of the Mining and Metallurgy Engineering program and future engineers, giving them a socio-technical training in order to have a more inclusive and sustainable mining sector in the different scales of work. Sustainability is the central axis that governs this research and allows the integral formation of young students in training.

1 Introduction

The topic of small-scale gold mining has been addressed by Universidad Nacional de Colombia in the context of research and technical cooperation with different research centers since the 1990s in order to support the rational exploitation of geologically rich gold zones suitable for artisanal and small-scale mining.

Although some of these approaches have been very successful and have provided important learning experiences, they have remained very focused and mono-causal in nature. Most often, the topics of support are related to geological aspects, such as ore characterization and deposit delineation for small-scale mining, and to technical aspects, such as alternatives for amalgamation. Other aspects, such as economic alternatives to gold mining, the regional planning of land use or creating a scenario for the use of mining waste streams were only touched upon in passing.

However, for the sustainable development of a municipality or community that is largely based on mining and agriculture, a holistic view is needed in terms of an optimal use of the natural resources of a region without unduly affecting the other resource (Pareto-optimum).

The task of the study work announced here is to bring together all the aspects of ASM mining zones management; that are ore extraction and processing, environment protection, mine closure, post mining planning, circular economy and education in such a way that the standard of living of the broadest possible population strata in the community of St. Rita can be increased in a sustainable way and finally inclusive economic growth for the community is possible.

To this end, UNAL Campus Medellin, Colombia, decided to work with the population and stakeholders of the municipality of St. Rita in the province of Antioquia to draw up a participatory development concept for the mining zones of the municipalities and to apply this concept as an example in pilot measures. This includes support for the formalization process of an artisanal small-scale mining zone (ASM-Zone) in St. Rita. The UNAL of Medellin has a long and successful tradition of supporting small scale mining activities.

The experiences gained in this context will be documented in a report and made available to other gold mining communities as a guide to action.

2 Scope of work and methodology of this study

2.1 Definitions

For the purposes of these presentation, the terms referred to in this document are defined as follows:

- Special Reserve Area (SPA): a mining zone set aside by the National Mining Agency specifically for artisanal mining (ASM-zone) for the exploration of the mineral resources and for gold mining. The ASM-zone can be created at the request of the municipality in order to better control illegal mining as well as traditional mining.
- Extraction concept: is a schematic mining strategy that includes environmental, mining safety and mining efficiency aspects.
- Processing concept: the processing of gold ore should, as a minimum requirement, comply with the Minamata Convention, preferably avoiding amalgamation and the use of mercury altogether.
- Circular economy: In traditional gold ore processing, there is no use for the remaining processing residues or wastes. Therefore, it is necessary to find a use for the residues that minimizes the amount of waste that has to be dumped and thus reduce the environmental risk.
- Inclusive economy and resource management: is an economy that considers four factors; that are the environment, human equality, quality of life and economic progress, and seeks to optimize all factors together.
- Environmental protection: environmental protection considers all-natural resources and also human beings (water, air, biodiversity, soil, people et cetera).
- Closure of operations and post mining management of the ASM-zone: proper closure of ASM-zone should minimize the risks and maximize the benefits of post mining for the community.
- Key stakeholders: national and regional authorities involved in mineral resource utilization in Colombia, the municipality and citizenry of St. Rita, the mining cooperative COOPAMINES, the administration of the Farallones de Citará forest protection zone, mining companies involved in the gold production chain, representatives of coffee growers and farmers.

2.2 Methodological approach and requirements for the study

UNAL is to work in a participatory manner with key stakeholders in St. Rita in order to design concepts and strategies for the mining gold deposits in St. Rita, and in particular for the ASM-zone, which, when put together, will constitute a blue print for the sustainable development of the community that considers the interests of all stakeholders and that is endorsed by the vast majority of the population.

For this purpose, the following sub-studies and concepts are to be elaborated by UNAL.

2.2.1 Geological Study for the Planning of an ASM-zone in St. Rita

In addition to using relevant existing geological information, such as information derived from the "Plan Estratégico del Conocimiento Geológico del Territorio Colombiano", the characterization of the ores in the ASM-zone in St. Rita shall be supplemented by a representative sampling program. In doing so, an assessment of the extractability of ore, processability of ore and economic viability of the ASM-zone for use by artisanal mining will be made. The geological study will thus serve to guide and support mining activities in the ASM-zone.

2.2.2 Mining concept

The mining concept shall consider the following sub-issues and serves as a blueprint for safe extraction of gold the resources in the ASM-zone.

- Mining safety and OHS
- Blasting technology
- Ventilation
- Ground control and support
- Efficient mining methods
- Construction of waste dumps
- Prevention and treatment of acid mine drainage
- Extraction costs

2.2.3 Processing concept

For the processing concept, the proposals from the "Guía Metodológica para el Mejoramiento Productivo del Beneficio de Oro sin el Uso de Mercurio" shall be taken up and used for the planning of a concrete, artisanal production chain. For this purpose, metallurgical tests with sample material are to be carried out for the design of the process scheme if UNAL consider this as necessary. For an exemplary case of an ASM mine a complete material and value flow balance (ore, water, processing partial streams, gold enrichments and gold losses in the different process steps) as well as the consumption of input materials, consumables and electricity should be presented. The indicator values derived from these flow sheets and balances are to be input variables for the feasibility evaluation that will be carried out in the concept for the "inclusive economy".

2.2.4 Circular economy

This concept should consider all streams of mining wastes and other wastes generated during extraction and processing and examine the possibilities for economic use of these streams, also considering positive effects from improved environmental protection or increased social acceptance. If the economic use is not given at present, at least a safe landfill and disposal shall be ensured, which does not stand in the way of a future use. The concept should include proposals for reasonable alternative uses of the waste streams from mining. Possibly, the proposals for alternative uses are to be supplemented by practical experience and experiments.

2.2.5 Inclusive management of the ASM-zone

Inclusive management of the ASM-zone means that, in addition to looking at the benefits and profits of the operation both the operating and investment costs, as well as all external costs and direct and indirect losses due to diminishing benefits or damage of goods elsewhere are considered and evaluated in the course of the economic evaluation of gold extraction in the ASM-zone. This also includes answering the question of whether mining really increases the standard of living of as broad a section of the population in the community as possible in the long term.

For this purpose, UNAL has to develop a management proposal that maximizes the benefits for the community of St. Rita and minimizes risks and potential harms. In this context also, the impact of the ASM-zone on the social situation and on the local "governance" in St. Rita shall be assessed and evaluated.

The concept should include an inventory of the current situation (environment, social aspects and economy without the use of the ASM-zone) as well as an outlook and estimation of the situation with the use of the ASM-zone. For the estimation of the economic situation, the exemplarily determined parameters from the extraction and processing concept are to be extrapolated for the entire ASM-zone. Also, alternative uses for the management of the ASM-zone shall be examined. In particular, recommendations for the management of the ASM-zone shall be made and risks for the inclusive economy are to be worked out.

2.2.6 Environmental protection

The use of the ASM-zone for mining requires an integrative approach to environmental protection that considers all assets worth protecting in the environment of the ASM-zone (water, air, soil, geo-resources, biodiversity, people and animals, culture et cetera). In this regard, the period covered by environmental protection extends from the time when the ASM-zone is used for mining purposes for the first time to the time when a post mining utilization of the ASM-zone is established. The issue of environmental protection in mining should not only be considered individually for each mine, but also generically for the management of mining in the entire ASM-zone.

2.2.7 Closure and post mining use of the ASM-zone

The concepts for closure and post mining use of the ASM-zones are closely related to the issues of environmental protection and inclusive management of the ASM-zones. Since the exact timing of closure is unpredictable, flexible concepts must be developed that include partial closure of mined-out areas within the ASM-zone. The concept shall include at least two alternative closure and post mining models. The elaboration shall include map sections of the ASM-zone illustrating the closure and post-closure models in spatial and temporal terms. In addition, existing mining legacies in the ASM-zone should be identified, the risks of the legacies assessed, and, if applicable, remediation proposals made that are compatible with the proposed closure and post-closure concepts.

2.2.8 Inclusive economies

Inclusive economies promote the participation of informal sector workers, corporations, regional and community leaders in value chains, in such a way that businesses, markets and economies are developed promoting equity, ingenuity and resilience.

Creative Capacity Building (CCB) and co-design are two key approaches that are leveraged to catalyze inclusive market systems. CCB workshops invite people to use their creativity and local knowledge to develop solutions to challenges they identify as relevant to improving their quality of life and that of their communities. Within the Inclusive Economies program, the co-design workshops bring together diverse interdisciplinary teams to collaboratively frame problems and prototype solutions to stimulate the development of market systems that offer income generation opportunities for people living in situations of vulnerability and poverty. Both approaches are used to identify pathways for the creation of inclusive and resilient enterprises, markets, and economies.

2.3 Discussion and testing of the acceptance of the concepts in the municipality

In order to secure the support of the stakeholders, UNAL shall inform the stakeholders about the objectives of this study assignment in individual discussions or in a common workshop. In doing so, the acceptance shall be checked and recommendations as well as reservations shall be considered in the planning and elaboration of the different concepts and the geological study.

After completion of the assignment, the results as well as the concepts shall be presented to the stakeholders on site in St. Rita in a half-day workshop.

2.4 Pilot implementation of the concepts for two artisanal mining operations within the ASM-zone

If the concepts are accepted by the stakeholders, the results of the geological study and the concepts will be used for the exemplary planning and development of two artisanal mining operations. This will require the following steps:

- Selection of the two artisanal operations
- Participative planning of the concrete measures for the operations
- Providing consultancy and advice for the implementation of the proposed measures
- Monitoring of the effects of the measures
- Written compilation of the results and experiences during implementation of the measures

3 Conclusions

We were able to bring together all the mining leaders of the town of Santa Rita, establishing a good relationship of willingness and collaboration between the miners themselves, the National University of Colombia and the mayor's office of Andes.

A change in the miner's mentality was noted in terms of working as a team to avoid the use of mercury in gold extraction.

- The general area delimited for the development of the mining activity is not specified as a total area, therefore, the total use of the same is not recommended, since in this study the aspects to be considered are merely technical and do not necessarily represent the social, cultural and economic reality of the region.
- For the exercise of public, technical and social control, the ZIM (mining industrial zone) is a good alternative for all those municipalities opting for a secondary use of soils, where mining and its primary production are protected by the different legal mechanisms in the use of local political power.
- The delimitation of the mining production area was based on the data obtained from the different studies carried out by governmental and public entities.
- The care of the environment as the main axis of this study and the ways to ensure its sustainability over time.
- The use of digital tools such as geographic information systems (GIS) are essential for the proper delimitation and georeferencing of the important points within the study.
- The layers generated for the delimitation of the mining production area were chosen generically considering the Colombian mining legislation.
- Future studies on transport methods are recommended to take advantage of gravity for communication between mines and mills.
- The studies carried out zoned the two IMZs of interest (Yarumal 1 and 2), and these could be united under the premise that in a larger area the impact generated is much greater and control over it is more difficult.
- In the studies carried out in the different townships of the municipality of Andes, the remoteness of Tapartó and its close relationship with local tourism was evident.
- Due to the distance that must be traveled for the ZIM, a special area is proposed in which to develop beneficiation activities.

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Mining in Kazakhstan with adopted international standards and globally educated specialists

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Abstract

In 2018 a new Mineral Resource estimation code (KAZRC) in Kazakhstan was adopted based on Western Australia's standards (JORC Code). The KAZRC code introduced a number of improvements in the regulatory environment and introduction of a more flexible licensing process by introducing a "first-come – first-served" model which is quite convenient for investors seeking exploration opportunities. This can also guarantee for exploration license holders to obtain extraction licenses. For all these, mining education should be represented in compliance with international standards and local needs. School of Mining and Geosciences (SMG) at Nazarbayev University missioned to be a model for higher education reform and modern research in Kazakhstan and aimed to educate mining industry leaders for Kazakhstan and the world. SMG is building trust in mining in Kazakhstan by expanding knowledge and technology through teaching and research by employing sustainability approaches and application of digitalization, automation, and virtual reality. Moreover SMG vast industrial collaborations associated with the transfer of knowledge and technology is a crucial part of the education system that helps our students meet current industrial needs. Consequently, their skills and knowledge help companies become more competitive and provide trust for sustainable mining. SMG will be in charge with developing sustainability assessment methodologies suitable for mine life cycle which allows defining hazardous influences on environment, society and economic dimensions, and helps quickly, conveniently and qualitatively solve, operate, find optimum options for existing problems and provide a better image for mining.

Mining as an Expression of Sustainability

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Abstract

Mining and sustainability seem to be contrary. But it is a necessary combination. Because there is a need for raw materials on the base of all three elements of sustainability:

- Economical growth depends on raw materials. This growth shall be independent from the need of primary resources (Green Deal and EU-Climate-Package). But the use of secondary resources cannot substitute the use of primary resources completely. The secondary resources can reduce the need for primary resources. If it is evidently sure that exist enough secondary resources there can result an obstacle for the permission of mining projects. But this is to discuss.
- The economical growth shall be based on climate protection: there is only growth in favour of climate protection, even if raw materials remain necessary for climate protection (lithium).
- Therefore the need of raw materials is also based on the ecological component of sustainability. Raw materials are essential in the different fields of climate protection, for example to build wind power plants or to improve the energy efficiency of buildings. Conversely, mining is also essential for the ecological component of sustainability.
- The social component of sustainability forces also to gain raw materials. Otherwise the prices of products will get higher and higher. Above all this poor people will suffer if there is inflation. Therefore the state has to maintain a sufficient supply with raw materials which have adequate prices.

Result: In the times of climate change it is sustainable to mine raw materials if the enviroment is protected. An intensive exchange between states with raw materials and without raw materials is necessary.

- This international component is also an expression of the climate decision of the Constitutional Court in Germany, which requires an international view of climate protection. This view must include raw materials. Therefore the sustainability of mining is international.
- A mining project is primarily sustainable under the following conditions: It respects the environment which has to be protected in favour of future generations. It contributes to the components of sustainability.


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The Sustainable Mine

Technological innovation as a tool for sustainable development in clay mining in La Guajira, Colombia

Peer Reviwed

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Abstract

Worldwide, there are routes of technological innovation transferred from one country to another, in which environmental regulations are rigorous and force the improvement of conventional technologies; With this, it seeks to globalize productive management strategies, contributing to the challenges of sustainable development. For its part, La Guajira is a department of Colombia characterized by implementing rudimentary methods that have an impact on the low production capacity of clay mines; For this reason, this study aimed to identify technological innovation processes that can promote sustainable development in clay mining in La Guajira, Colombia.

The methodology employed in this study is descriptive and uses a nonexperimental approach; that is, the behaviour of the technological innovation nominal variable was studied within the proposed context to define its significance in sustainable mining and minimizing environmental impacts. The collection techniques were based on secondary information and direct sources, represented by a bibliographic documentary review, structured observations in the field, and the implementation of the Leopold matrix to identify environmental impacts, susceptibility to environmental impacts (ASPI), and environmental factor receptors of impacts (FARI).

To develop the study, a sampling frame that included the entire population was consolidated. The mines studied in total were five named thus: Camarones, San Pedrito, El Confuso, Loma Fresca and La Junta; which are located in the jurisdiction of the La Guajira department and have clay as a raw material in their production chain.

The studied clay mines lacked a sustainable approach because they generated 19 impacts affecting environmental components and failed to comply with Colombian regulations for the use of resources.

Technological innovation is a key tool for sustainable mining in the future; however, the clay mines of La Guajira develop deficient production cycles in radical or incremental innovations owing to the use of conventional technology. In the productive phases, there are three FARI: anthropogenic, biotic, and abiotic systems, and 13 ASPI: prospecting, stripping, construction of kilns, construction of operating areas, clay extraction, mixing and kneading, brick moulding, drying, loading of bricks into the kiln, firing, unloading from the kiln, dispatch of bricks, and finally closing. These do not include environmental management measures to mitigate impacts.

The ability to articulate production with care for the environment is what allows mines to be sustainable; therefore, companies are recommended to carry out an environmental management plan (PMA), articulate sustainable production regulations, include clean technologies to reduce emissions of particulate matter and greenhouse gases (GHG) and implement the use of the MK-3 Furnace, soft, and hard technologies, as they symbolize an alternative of greater efficiency.

1 Introduction

Currently, the development of countries and regions depends on the promotion of a culture of innovation in the production sector, which leads to the creation, dissemination, and application of technologies that guarantee economic growth and the well-being of society and the environment [1]. However, while global technological transformation in the mining sector advances, some barriers limit the adaptation of hese innovations; some are related to industry-specific problems in the contextualization and implementation of innovation [2].

In this order of ideas, technological innovation is positioned as one of the most viable routes to promote sustainable development, which, hand in hand with the Sustainable Development Goals (SDGs), promotes the rational use of natural resources worldwide, and minimizes environmental impacts in strategic areas and ecological marketing; indeed, there are a variety of countries that allocate more than 2 % of their Gross Domestic Product for research and development from environmental management, such as Switzerland, Italy, and Germany [3].

Likewise, sustainable development is framed within economic, social, and environmental aspects, which means that it encompasses the need to maintain a balance between well-being, production, and resource minimization. Mining is one of the oldest activities categorized as generating significant economic benefits. Its beginning is related to the execution of simple and rudimentary activities in daily life, such as carving rocks to hunt and making simple tools. With time, more complex technologies have begun to be implemented hand-in-hand with industrialization; however, it was identified that this activity has negative consequences in environments where it is carried out and even in surrounding areas [4].

Latin America is classified as one of the richest territories in minerals, and its geographical position makes it possible to have a range of reserves and deposits of valuable resources including iron, lead, silver, and construction materials such as stone aggregates and clay; which allow mining to be recognized as one of the most representative activities in the economic sector, influence the quality of life in Caribbean countries, but also trigger environmental problems because there is no special focus on socio-environmental aspects [5]. Therefore, it is important to consider technological innovation as a tool that offers the possibility of minimizing environmental impact and aligning strategic plans focused on sustainability.

In general, technological innovation processes in the environmental field are oriented towards ideas that solve problems caused by anthropological activities (domestic and industrial sources) and natural. In the particular case of Colombia, there are a series of problems due to illegal mining, 66 % of which are developed in strategic protected areas, natural parks, and forest reserves, which leads the country to assume challenges in terms of environmental management [6]. The Republic of Colombia is the second most biodiverse country in the world [7], which makes it vulnerable to the effects of climate change. For this reason, it is necessary to implement sustainability actions aligned with the integral management of water resources, a reverberation of the soil, protection of endangered species, and others that help potentiate ecosystem care.

Similarly, La Guajira is a department of Colombia where industrial minerals are exploited, and its importance is reflected in the variability of products it generates to meet the productive needs of the country [8]. Technological innovation within the Guajiro territory is deficient, which is attributed to the implementation of rudimentary methods and productive informality that intervene in the low production of the mining sectors. It is important to identify technological innovation processes that promote sustainable development in La Guajira [9].

In the same way, La Guajira is a department of Colombia where industrial minerals are exploited, its importance is reflected in the variability of products that it generates to meet the productive needs of the country [8]. Technological innovation within the Guajiro territory is deficient, this is attributed to the implementation of rudimentary methods and productive informality, these two factors intervene in the low production of the mining sectors, for this reason, it is important to identify technological innovation processes to promote sustainable development in La Guajira [9].

Clay mining is not highly appreciated nationally and internationally; However, in La Guajira, it is an activity of great importance because clay is used as a raw material for the manufacture of bricks and ceramics, which makes it a very important asset at the local level due to its production processes that are usually low-tech [10]. This mineral is obtained through a series of phases aimed at open-pit mining in an artisanal and rudimentary way, for its exploitation environmental management plans are not taken into account; which causes concern since no compensation actions are executed for the damage caused to the environment, nor are environmental management measures associated with each of the pertinent affectations implemented, which can have repercussions in the short, medium and long term.

Technological innovation processes aligned with environmental management represent a fundamental axis in the different productive sectors, which points towards an economic, social, and environmental balance that guarantees the rational use and preservation of natural resources for future generations, in other words sustainable development [11]. Because of the above, this type of innovation is called to facilitate productive work sustainably, aiming at the achievement of Sustainable Development Goals (SDGs), which are of great importance and represent the possibility of strengthening the formulation of environmental standards of each country.

However, clay mining has consequences for the environment in its wake, [12] highlighting that some of the damage is associated with ecological imbalances, erosion, and deforestation processes. Therefore, it is essential to envision a mining environment focused on environmental responsibility, where innovative technology is articulated to promote the proper use of natural resources through productive exploitation processes where negative impacts are minimized. To align clay mining with sustainable development, it must be innovated, taking into account the alternatives of clean technologies, which are adapted according to environmental needs, and operate as management tools [13].

In La Guajira, brickmakers traditionally use rudimentary technology consisting of hand tools (shovels, picks, hoes, axes, machetes, wooden moulds, plastic buckets, and asphalt or plastic cloth) that increase the physical effort required for the execution of the tasks, these elements are distributed by each owner according to the activity to be carried out and their economic capacity. It is evident that the damage caused to the environment by the extraction and processing of clay is considerable, and it is important to inject capital to diversify the supply of products derived from clay, incorporating the use of environmental machinery to carry out operations works, the improvement of access roads, and the legalization of the mine through the design of a medium-term project, which allows the adaptation of clean technologies for the activities with the support of the government and the search for private stakeholders [14].

In short, technological innovation in mining promotes sustainable production thanks to the fact that they do not require large amounts of natural resources for their operation and are mostly self-sustaining except for the maintenance phase. Although the modernization and implementation of mining processes require an economically significant initial investment, it should also be mentioned that this strategy allows companies to improve their image in the market, which in turn translates into new customers. and higher profits, in addition to minimizing the environmental repercussions of this activity, complying with some of the parameters established in the environmental regulations [15].

Finally, Colombian Guajira, being a clay producer, should focus its efforts on the implementation of clean technologies; therefore, knowing the environmental problems and production processes is beneficial for identifying the actions that, together with technological innovations, help build environmental efficiency in the exploitation of this mineral. It is of great importance to go hand in hand with the norms, plans, and national programs [16] that can be articulated to environmental management measures as a key tool to achieve the closing of the technological gap, strengthening commitment to the environment.

2 Methodology

For the development of this study, it was determined that the type of research is descriptive with an explanatory approach because it is based on information from primary and secondary sources, which serves as input for the development of the research objective for the study of technological innovation in mining companies dedicated to clay extraction in La Guajira [17]. In addition, documentary analysis was implemented based on the search, recovery, analysis, and interpretation of secondary data, that is, those obtained and recorded by other researchers in documentary sources.

This study is associated with the non-experimental frame of reference because it seeks to observe the behaviour of the technological innovation variable without any manipulation within the proposed context to define its significance. It is based on the observation of phenomena or problems in the natural way in which they occur, and finally, an analysis is carried out [18].

Regarding the population, it should be clarified that we did not work with samples but with a finite universe, as shown in Table 1. For this, mining companies were identified within the department dedicated to the extraction, production, and commercialization of clay, in total within the territory the activity is represented in five mines listed below: Camarones S. A, San Pedrito S. A, El Confuso S. A, Loma Fresca S. A, and La Junta S. A.

Table 1: Total study Population

Municipality	Mining companies	Number of workers
Barrancas	San pedrito S.A	20
Fonseca	El confuso S.A	25
San Juan del Cesar	Loma Fresca S.A and La Junta S.A	30
Riohacha	Camarones S.A	25
	Total	100

The sources of information were structured through documented field visits and detailed observations, as well as a review of secondary sources focused on bibliographic references (books, magazines, and scientific articles). Technological innovation is a nominal variable that goes hand in hand with specific actions. For a specific case of clay mining, the environmental impacts generated by the activity were evaluated and the Leopold matrix categorized as a qualitative evaluation of impact method was used [19].

Following the above, the implementation of the Leopold matrix was applied taking into account two important factors: the first is related to the susceptibility to environmental impacts (ASPI) and the second focuses on the environmental factors that receive impacts (FARI). We generated a rating of the magnitude and importance of the negative environmental impact and prioritization ranges using FARI and ASPI in clay mining in La Guajira.

Thus, Table 2 shows the judgment criteria that were considered for the environmental impact assessment (EIA) in mining companies dedicated to the exploitation of clay. The matrix helped to categorize environmental externalities according to their magnitude and importance, in which the magnitude was measured in a range of (-10 - +10) and the range of importance was measured from (+1 - +10), which was evaluated according to the criteria of the authors [20].

Table 2: Matrix used for Categorization of environmental externalities for evaluation of environmental impacts in the clay mines of La Guajira

Magnitude				Importance		
Alteration	Degree of destruction	Qualification (-)	(+)	Persistence	Extension	Rating (+)
Low	Minimum	1	1	Fleeting	Punctual	1
Medium	Minimum	2	2	Temporary	Punctual	2
High	Minimum	3	3	Permanent	Punctual	3
Low	Medium	4	4	Fleeting	Partial	4
Medium	Medium	5	5	Temporary	Partial	5
High	Medium	6	6	Permanent	Partial	6
Low	High	7	7	Fleeting	Extreme	7
Medium	High	8	8	Temporary	Extreme	8
High	High	9	9	Permanent	Extreme	9
High	Very High	10	10	Permanent	Total	10

Concerning the above, the observation visits carried out in the field were a key instrument to identify environmental impacts, and once the repercussions of the activity in the environment were analysed, technological innovation strategies were proposed in the productive phase of clay mining in the department of La Guajira. For methodological development, the review of regulations with an environmental approach from the mining field was of interest, which allowed us to reach a conclusion about which aspects are essential for the development of activities within Colombian law, emphasizing sustainable development.

Therefore, to establish the validity of this research, the criteria for technical consultation with experts in the areas of research methodology, environmental sciences, and mining in La Guajira were taken into account, evaluating that the applied instruments were pertinent to the scope of the study, considering content, effectiveness, coherence, and writing, among other aspects related to the central objective. Based on these considerations, the reliability of this research is subject to the researchers' criteria, both in field observations and for the selection of documentary material.

3 Results

Within the productive phases necessary for the exploitation of clay in the Department of La Guajira, some effects are not beneficial to the natural environment, which generate damage to the environment, some of which are related to the use of rudimentary machinery and unsophisticated techniques for the development of the activity. Therefore, it is necessary to view production as a technological innovation because this tool goes hand in hand with sustainable development.

Clay, for its part, is a sedimentary rock composed of aggregates of hydrated aluminium silicates, its origin is related to the decomposition of rock material, to carry out its exploitation, productive phases are developed within mining as described [21]; In the first place, the prospecting of the area to be intervened is carried out to ensure that the chosen area has the raw material (clay), after that, the top is removed and the clayey material is extracted.

In the same way, a mixing phase is developed that consists of homogenizing the material to provide malleability, since it is easier to continue with the packaging, which is carried out with the implementation of moulds that have the objective to provide the final shape to the product, it was found that the five mines studied used a rectangular geometric shape to mould the product. Continuing with the productive cycle, a rest period is necessary, which is carried out over a period of twelve hours, a very important agent is the sun since this factor is needed to eliminate excess moisture from the material during processing, once the time and humidity requirements have been met, the drying stage continues, which consists of dehydrating the material in conventional ovens that supply its energy with plant material (firewood). The basic production methodology is shown in Figure 1. However, this does not stop representing damage to human health and the environment.

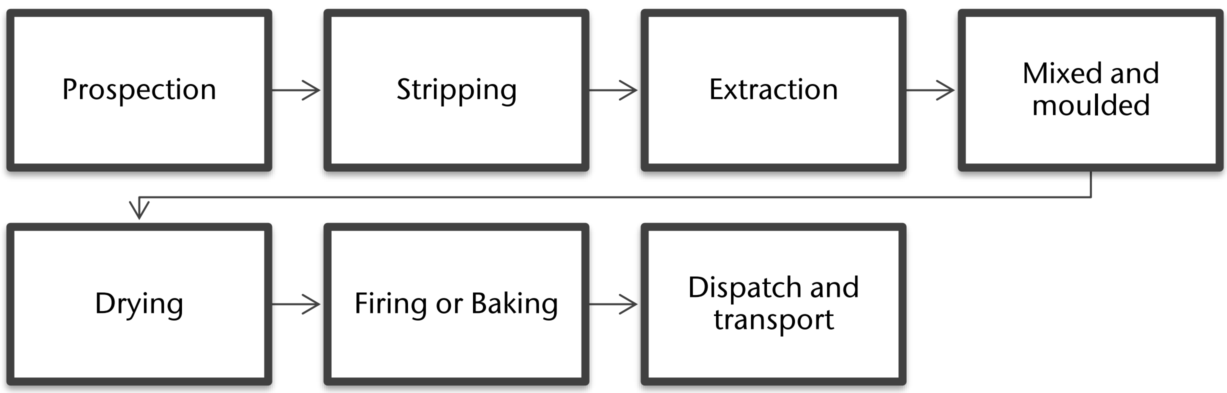

Figure 1: Brick production processes in the clay mines studied in La Guajira

In particular, in the department of La Guajira, technologies consistent with mining processes are not implemented because companies do not take environmental legislation into account or simply dissociate themselves from the socio-environmental component because they represent high costs, which distorts them from the possibility of contributing to sustainable development.

This is how it was currently identified that the technologies used in the exploitation of the clay of the mining companies under study in La Guajira are artisanal and/or rudimentary, as shown in Table 3, because they fully implement manual tools, which even in the short term increase the physical effort of the workers in the execution of the different activities.

Table 3: Matrix used for Categorization of environmental externalities for evaluation of environmental impacts in the clay mines of La Guajira

Production phase	Technology implemented	Use
Prospection	shovels and hoe	Preliminary work, to carry out small excavations to see if the clayey material can be exploited
Stripping	Shovels, machetes and chainsaw	For the removal of the vegetal layer that covers the clayey material
Clay extraction	Hoe and shovels	For extraction of subsoil material
Mixed	Hoe, shovels, buckets and manual kneading (with hands)	Mix and homogenize the clayey material
Moulded	wooden or iron moulds	Mould the clay mixture into a rectangular shape for the bricks
Bricks drying	Solar radiation	The bricks are left exposed to sunlight in the open air, so that the bricks lose moisture
Bricks Firing or Baking	bricks and firewood	Artisanal cooking and idealizing humidity
Dispatch and transfer of bricks	Wheelbarrows and trucks	Transfer the bricks inside the mine, cover with plastics, stored bricks after being burned and having recovered an ambient temperature. They are loaded onto trucks for sale.

Within this framework, it is important to open a field for innovative technology transfer that works as a tool to promote sustainable development in mining companies, increasing their productivity and maintaining added value in the current market, and adapting to the innovative technology following the needs of mining activities without affecting production.

To identify the environmental conditions within the investigation, the environmental problems of mining companies dedicated to the exploitation of clay in La Guajira were studied using a methodology to identify the activities, as shown in Figure 2. These disrupt the environment and have negative impacts on the environment, the economy, and society.

In this way, and concerning the Environmental Impact Assessment (EIA), three moments were established to evaluate the externalities or environmental impacts in mining companies dedicated to the exploitation of clay in La Guajira.

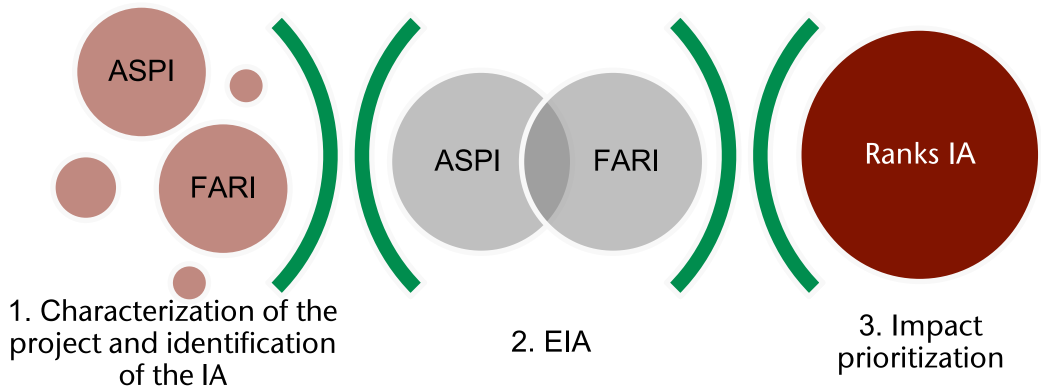

Figure 2: Moments of environmental evaluation in the mines that exploit clay in La Guajira.

In the first evaluation, 13 ASPI were identified: prospecting, stripping, construction of kilns, construction of operating areas, clay extraction, clay mixing and kneading, brick moulding, brick drying, and brick loading. kiln, brick firing, kiln unloading, dispatch and transfer of bricks, and finally, closure and abandonment of the mines, integrated into five phases: exploration, construction, exploitation, operation, and dismantling, and three FARI: abiotic, biotic, and anthropogenic systems, identifying 19 impacts and considering environmental components such as water resources, soil, air, flora, fauna, and social and economic environment of the mining companies under study.

Table 4 shows a summary of the EIA results for mining companies dedicated to the exploitation of clay in La Guajira obtained through the Leopold Matrix.

Table 4: Synthesis matrix of the EIA results in the mining companies that exploit clay in La Guajira
Source: Own elaboration based on (Viloria Villegas et al., 2018)

	Exploration	Impact	Construction	Impact	Exploitation	Impact	Operation	Impact	Dismantling	Impact	Total FARI value
natural environment	Abiotic system										
	Water	-50	Water	-16	Water	-120	Water	-3	Water	42	-147
	Soil	-145	Soil	-141	Soil	-270	Soil	-14	Soil	56	-514
	Air	-28	Air	-21	Air	-64	Air	-94	Air	51	-156
	Biotic system										
	Flora	10	Flora	-124	Flora	-108	Flora	-60	Flora	-161	-443
	Fauna	-12	Fauna	-98	Fauna	-120	Fauna	-60	Fauna	-71	-361
	Anthropic system										
Human environment	Economic	-74	Economic	37	Economic	90	Economic	144	Economic	-90	107
	Social	-102	Social	-39	Social	-30	Social	-123	Social	-30	-324
ASPI value	Exploration	-401	Construction	-402	Exploitation	-622	Operation	-210	Dismantling	-203	-1838

As can be seen in Table 4, the environmental impact generated by clay mines is -1838 units, which represents 7.4 % of negative environmental externalities, placing this mining activity in a low impact range, compared to the maximum results that can be obtained by applying the Leopold matrix, owing to the number of FARI and ASPI (19 FARI and 13 ASPI), and with a maximum impact value of 100 units, a total impact value of -24700 was obtained. units (100 %), which is the greatest possible grade of impact on environmental quality by mining companies engaged in the extraction of clay in La Guajira.

Concerning the score obtained by the project (-1838 units), the medium with the greatest affectation was the natural with -1621 units, thus corresponding to 88.2 % affectation; in contrast, the human environment presented a negative effect with -217 units (11.8 %) (see Table 4). On the other hand, the mining process with the greatest impact was the exploitation of clay minerals with -622 units, with a percentage of 33.8 %.

In this sense, and following the proposed methodology, where each evaluation attribute has a maximum value of ten and a minimum of one after applying the EIA Leopold matrix, it was determined that the environmental impact values (AI) of the total ASPIs range between -630 and 229 units and the FARI range between -248 and 287 units; therefore, to prioritize the AI that cause mining activities (ASPI) and the environmental factors that receive impacts (FARI), three ranges were established, as presented in Table 5 and Table 6, respectively.

For this, a classification from highest to lowest is established, where the values obtained and those that are lower, that is, with a negative impact, result in the highest priority activities.

Table 5: Ranks for prioritization by ASPI of environmental impact in clay mining in La Guajira

IA Rank	Priority by ASPI
-630 to -343	High priority activity: urgent priority measures are required for the prevention, mitigation, control, restoration and/or compensation of the environmental impact generated and a red colour is assigned.
-342 to -57	Medium priority activity: impact management measures are required; however, these are not prioritized and an orange colour is assigned.
-56 to 229	Low Priority Activity: Actions are not a priority and are assigned a green colour.

Table 6: Ranks for prioritization by FARI of environmental impact in clay mining in La Guajira

AI Rank	Priority by FARI
-248 to -70	High priority impact: urgent priority measures are required for the prevention, mitigation, control, restoration and/or compensation of the environmental impact generated and a red colour is assigned.
-69 to 109	Medium priority impact: impact management measures are required; however, these are not prioritized and an orange colour is assigned.
110 to 287	Low Priority Impact: Actions are not a priority and a green colour is assigned.

In this order, the ASPI and FARI of the mining companies dedicated to the extraction of clay in La Guajira were classified, generating a list based on a hierarchy of categories, environmental components, and mining activities (Leopold Matrix), which indicates that clay mining activity generates highly relevant effects on the environment.

Table 7: Ranking by impact of ASPI in clay mining in La Guajira

No.	Impact and ranking of ASPIs	Impact
High Priority Impact		
1	Stripping and/or removal of topsoil	-630
2	Clay extraction	-622
Medium priority impact		
3	Brick firing	-329
4	Construction of artisan kilns	-277
5	Closure and abandonment (dismantling / demolition)	-210
6	Construction and adaptation of operational areas	-125
Low Priority Impact		
7	Dispatch and transfer of bricks	7
8	Bricks drying	11
9	unload bricks from kiln	17
10	Load of bricks in the traditional kiln	23
11	Mixing and kneading of clay mineral	32
12	bricks moulding	36
13	Prospecting and/or preliminary works	229

Table 8: Ranking by impact of the FARI in clay mining in La Guajira

No.	Impact and hierarchy of the FARI	Impact
High Priority Impact		
1	Alteration and/or loss of biological corridors, habitat and vegetation matrix	-248
2	Soil quality deterioration	-235
3	Affectation in land tenure due to increased erosion processes, scour and loss of soil	-180
4	Loss of abundance and/or diversity of terrestrial and aquatic animal species	-178
5	Loss of aesthetic quality of the landscape	-177
6	Damage to the physical environment	-145
7	Impact on the quality of life of communities	-135
8	capacity of use and/or increase in the occurrence of soil removal	-134
9	Loss of abundance and/or diversity of plant species	-124
10	Increase/decrease in birds	-112
11	Depletion of air quality	-94
12	Loss of protected and/or endangered animal species	-71
13	Loss of protected and/or endangered plant species	-71
Medium priority impact		
14	Increased levels of vibrations or ambient noise	-62
15	Groundwater quality degradation	-59
16	Deterioration of surface water quality	-56
17	Decrease in water resources	-32
18	Increase/decrease in demographic index	-12
Low Priority Impact		
19	Employment generation	287

Table 9: Kiln evaluation and analysis matrix as a technological innovation in clay mining processes

Criteria	Hoffman kilns	Trunk kilns	Hive kilns	sleeping fire kilns	MK-3 kilns	Multiple cameras kilns
Kilns capacity	Hight	Hight	Low	Regular	Regular	Regular
Type of kilns	continuous	intermittent	intermittent	intermittent	continuous	continuous
Allows the use of another fuel	Yes	Yes	Yes	Yes	Yes	Yes
temperature homogeneity	Good	Regular	Medium	Regular	Good	Good
Energy required per Kg/ of brick	Low	Hight	Medium	Hight	Low	Low
It allows to recover the heat for drying	Yes	No	No	No	Yes	Yes
It can be used to produce other building material	Yes	Yes	Yes	Yes	Yes	Yes
Emissions to the atmosphere	Low	Medium	Medium	Hight	Low	Low
Ability to meet emission standards	Medium	Low	Medium	Low	Hight	Hight
Product quality	Optimal	Regular	Good	Regular	Good	Good
Investment	Hight	Medium	Medium	Low	Medium	Medium

Qualitative ranges are assigned based on the capacity of these ovens, the temperature distribution inside them, the energy demand required for the cooking process, the investment cost they represent, the quality of the product, and the probabilities to comply with the provisions of the environmental regulations on emissions, the results of the matrix show three different pieces of equipment that could be implemented in clay mining; however, the multi-chamber kiln and Hoffman type were ruled out owing to land requirements that must be operated.

Although the capacity of the MK-3 kiln is not the most grandiose according to the decision matrix, it is capable of covering the production of bricks continuously in the clay mines of the department, for its operation it will be used as a power source of solar energy, the selection criteria was the matrix of alternative fuels. The implementation of this technology will allow brick factories to carry out a more sustainable mining process aligned with sustainable development.

The processes that are currently carried out in the clay mines of the Department of La Guajira obey a basic model of operation in which the economy is prioritized over all impacts; however, this economy does not represent companies' development internally. After analysing the characteristics of the MK-3 kiln, it is concluded that solar energy as the installation to feed the MK-3 kiln is the one that best suits the conditions presented by the Department of La Guajira. However, other types of energy are not ruled out because the chosen energy (solar energy) is exposed to trial periods if the study is implemented.

With the implementation of the suggested hard and soft technologies, it will be possible to optimize some mining processes, such as the drying and combustion of bricks, and improve the conditions of the work environment. Where the brick combustion and drying processes would be made up of an MK-3 type kiln which will be powered by fuel or renewable energy; Likewise, with the implementation of soft technologies, it is sought that companies guarantee an adequate work environment, where the safety of workers is prioritized within the brick kilns, for this, a design of the MK-3 kiln is made in connection with the clean energy to be used for its feeding as shown in Figure 4.

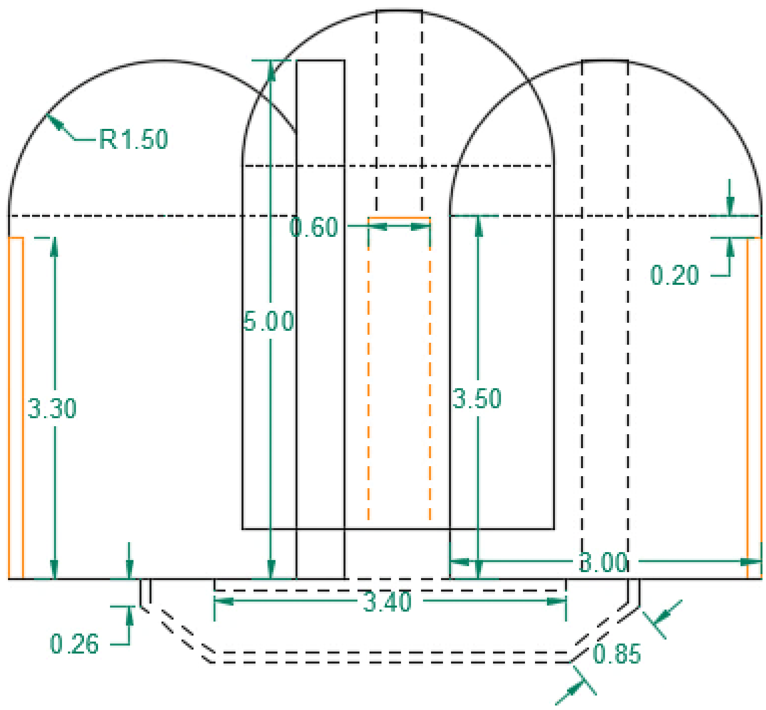

Figure 3: Scheme of the MK-3 kiln from a front view

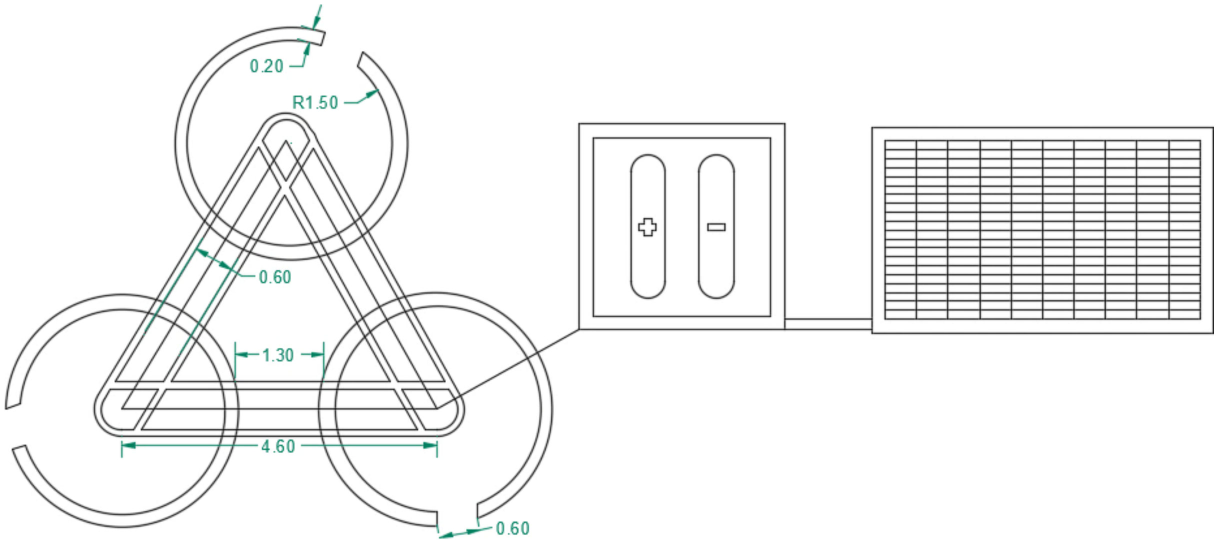

Figure 4: Diagram of the MK-3 kiln, aerial view, connected to the solar system for its operation

The main objective of implementing clean processes in clay extraction miners is to encourage companies (brick factories) to seek, through the modification and implementation of control systems or technological reconversion using clean energy, the reduction of their pollutant emission levels. Consequently, it is important to create programs within brickyards based on compliance with Colombian environmental regulations to improve the planning of companies by identifying the impacts that it causes or may cause when using conventional energy.

Finally, in general, the clay mines in La Guajira do not contemplate a marked sustainable production that integrates social, economic, and environmental aspects, causing an inappropriate use of natural resources, where economic growth does not reflect the development of the surrounding communities. and their impact on the environment.

Thus, it is important to reduce the ecological footprint through a change in the methods of production and consumption of goods and resources, guaranteeing the balance between economic growth, care for the environment, and social well-being. For this reason, it is important to include clean technologies in clay mining to reduce the impacts caused by emissions of particulate matter and greenhouse gases (GHG) derived from the mining processes carried out in this type of mining, which undoubtedly contributes much to global warming and its effect on climate change (CC).

4 Conclusions

It is concluded that environmental innovations were based on the purpose of implementing clean technologies to reduce the negative effects on the environment and human health from the exploitation of clay minerals in La Guajira, in addition to encouraging brick factories to manage and implement sustainable development in the mines through the modification and implementation of control systems or through the reconversion of hard and soft technologies that help to achieve a reduction in environmental impacts, which is one of the pillars of sustainable development.

Likewise, it should be noted that for soft technological innovation, companies guarantee an adequate work environment, where the safety of workers within the brick kilns is prioritized without neglecting social benefits and others. In addition, some strategies have been suggested to mitigate environmental impacts and create a culture of innovation in workers to modernize all mining processes.

The production processes in clay mining must be oriented to the appearance of the environment and the environmental management of natural resources, integrating clean technologies for the recovery of contaminated areas, or covering, in a broader sense, issues such as the supervision of mining processes that include the production of bricks and their improvement, as well as an adequate administration of environmental systems that promote research and development (R&D) through machines that are implemented concerning the principle of sustainable development.

Finally, in the department of La Guajira, there is a deficiency in the integration of environmental regulations through strategic plans and programs that, hand-in-hand with the Regional Autonomous Corporation, require mining companies to work internally in the organization, according to experience, context, and learning appearing throughout the activity. New technologies are capable of providing added value, in which an excellent operation with distinctive characteristics of clean production is promoted, which serves as an example for other operations and generates sustainable development.

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Battery Electric Vehicles (BEVs) in underground mines – The major requirement for sustainable underground mining

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Abstract

Replacing diesel machines with electric vehicles in underground mines has been widely acknowledged by the mining industry as a critical step to improve working conditions by reducing diesel exhaust contaminants, whilst also lowering mine ventilation electrical power cost by reducing mine airflow requirement and reducing greenhouse gas emissions. All of these are major requirements to achieve sustainable future underground mining practices, including a target of zero carbon emissions and a very low concentration of atmospheric contaminants in workplaces. Among all types of electric vehicles, Battery Electric Vehicles (BEVs) are the most suitable for underground mining application due to its flexibility. With the recent developments in battery technology, reliable BEVs have been manufactured since 2016. However, an investigation must be carried out to ensure their smooth introduction. Therefore, the European Union (EU) has funded two projects namely SIMS and NEXGEN SIMS where several BEVs were trialled at several EU mines. This paper outlines some results of these trials which include, among others, improvement of working conditions, power consumption, perception of the mineworkers, and perception of the mine management. Moreover, perception of the management of mines that are not part of the project consortium but have trialled BEVs is also outlined in this paper. This paper also outlines challenges in introducing BEVs to underground mines that have been found in these two projects.

Employability of mining tailings of polymetallic origin in the production of shotcrete for underground support

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Abstract

The mineral concentration processes not only generate the recovery of the mineral extracted from the mine; but also the formation of mining tailings, which generate great economic and environmental impacts in a mining operation, since they must be deposited in large tailings dams, or in more efficient cases in dry stacks, which must ensure the physical and chemical stability of these residues. Due to this problem, the possibility of making use of these residues and employing them within the mining cycle in the support stage is identified. Therefore, this article has as its main objective the experimental study of the employability of polymetallic mining tailings in the production of shotcrete as a support element in underground excavations. Putting this residue to use in the production of shotcrete will reduce the generation of environmental liabilities and reduce the maintenance costs of dry stacks as well as tailings dams. For the development of the investigation, a granulometric analysis and the physical and chemical properties of the tailings under study will be based on, then the different mixture designs will be carried out, which will later be tested to obtain their resistance to compression and identify the most optimal design that meet safety standards.

Keywords: polymetallic, tailings, shotcrete

Application of LiDAR data for numerical ana lysis of airflow in mine excavations: A case study from a real mine

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Abstract

Mine ventilation is a vital aspect of overall mining operations, responsible for a significant proportion of operating costs, usually ranging between 30 to 40 %. The strategic importance of mine ventilation calls for conducting calculations and simulations to determine the airflow in ventilation networks, both those in existence and those planned for future mining operations. Technological developments have provided new opportunities to optimize the design and performance of ventilation networks, thereby reducing costs and increasing efficiency. One such technology that has revolutionized the industry is LiDAR (Light Detection and Ranging). LiDAR has become an indispensable tool in the mining industry because of its ability to create high-resolution 3D models of underground mines. It can capture the shape and details of a mine's surface with high accuracy, creating detailed point clouds. These point clouds can be used to generate accurate 3D models of underground mines, which can then be applied to simulate air flow in ventilation networks. Numerical Fluid Mechanics (NFM) is another technology that is useful for simulating airflow in underground mines. NFM is a branch of fluid mechanics that deals with the analysis of fluid flow through numerical simulation. NFM simulations can be used to determine the velocity, pressure, and temperature of fluid flows in mines, which can help to optimize the design of ventilation networks. The aim of this paper is to investigate the potential of LiDAR and NFM technologies for simulating air flow in mine workings. Simulations are performed on geometric models created from point clouds acquired during laser scanning in an underground mine. The study suggests that these advanced technologies could helped mining companies optimize the design and performance of ventilation networks, reducing costs and improving productivity. The development and use of advanced technologies such as LiDAR and NFM are fundamental to the future of mining operations, ensuring that mining companies can operate safely and efficiently.

MK-A35
GHH

Project ECHO – a new solution for grinding oversize lumps in copper ore mining.

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Abstract

The ECHO project, funded by EIT Raw Materials under Horizon Europe, aims to bring to market an all-electric, programmable impact hammer (LEH) as an alternative to standard hydraulic breaker hammers (HBH). Standard hydraulic hammers are used to crush blasted oversize material in the mining industry. HBHs are installed on machines operating on the surface or stationary manipulators at the loading points of underground conveyor belts. Compared to hydraulic breakers, the patented technological solution from Lekatech (Finland) brings many advantages, such as elimination of CO_2 emissions, energy savings of up to 60 %, prevention of leakage and excessive consumption of hydraulic oil, increased safety, reduction of noise and shock levels, and significant reduction of life cycle costs. The advantage of the presented solution is the ability to adjust operating parameters on a case-by-case basis. Project ECHO supports the initiative to transform the mining industry by developing technologies related to electrical transformation and digitization of industrial processes. The project also enables the introduction of innovative data-driven business solutions, which contributes to increasing the efficiency and competitiveness of companies operating in the mining sector. The research work in this project is related to the measurement and collection of process data on operations during LEH testing at several mining companies in Poland, Finland and Spain. The purpose of the study is to evaluate the reliability of the LEH hammer and identify optimal vibration control parameters for different materials and operating conditions in the mining industry.

Advanced predictive maintenance in mining industry – diagnosis and machine health forecasting in presence of non-Gaussian disturbances

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Abstract

Predictive maintenance has been recognized by Mining Magazine as one of ten technologies that will revolutionize the mining sector. It may be profitable, indeed, however, the raw materials sector is specific and implementation of predictive maintenance is not so rapid as expected.

In recent years, it has been found that some classical methods are not as effective as expected due to the presence of non-Gaussian disturbances (called later noise). Non-Gaussian noise affects damage detection procedures, as well as RUL prognosis methods. In order to deal with these issues we developed advanced algorithms to identify character of the noise. We proposed novel methodologies for damage detections as well as fault development forecasting – all under assumption that disturbances have non-Gaussian distributed.

In this paper, we introduce the most popular non-Gaussian models that are used in predictive maintenance. We will show that the existence of variance of the noise is critical, next we will propose a method for testing the existence of variance.

We also present recently developed procedures that are based on matrix and tensor factorization (applied to time-frequency maps) and methods of detecting cyclostationary signals in noisy (non-Gaussian noise) observation.

Finally, we discuss our results on modeling, segmentation (detection of location change points, that are detection of standard/warning/alarm class boundaries) and forecasting of long-term data obtained from machine monitoring systems. To achieve our goals we used among others advanced methods such as statistical modeling, Hidden Markov Models and neural networks.

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Study on dynamic subsidence prediction of abandoned open-pit mine affected by multi-layer goaf

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Abstract

Correctly predicting the dynamic surface subsidence of abandoned open-pit mine affected by goaf is crucial to protection against post-mining damage and developing and utilizing residual resources. The distribution of goafs was surveyed and the dynamic surface subsidence values were analyzed in Haizhou open-pit mine, the results show that the cumulative dynamic surface subsidence value is greater than the thickness of the mining coal seam. Considering the influence of slope angle and multi-layer goaf on the dynamic surface subsidence, a modified prediction model is proposed based on a double-parameter time function model. The proposed predicted model modifies the maximum value of the double-parameter Knothe time function model, which is suitable for the dynamic subsidence prediction of open-pit mine affected by multi-layer goaf. In order to analyze the evolution law of surface and slope displacement fields in different periods during combined open-pit and underground mining, a three-dimensional numerical calculation model based on the built-in Burgers-Mohr model of FLAC3D was established. Numerical calculation results show that: Using the combination of open-pit and underground mining, the vertical displacement of the surface and slope of the open-pit mine affected by the goaf is greater than the cumulative mining thickness of the coal seam, and the time for the surface subsidence to reach a stable state is longer than that of single mining method. The vertical displacement average acceleration of slopes and steps is greater than that of the surface, and the time required for the surface to reach a stable state is longer than that of slopes and steps. The proposed modified model can accurately predict the dynamic surface subsidence for different mining methods, periods and goaf spatial distribution. The research provides a new method for the prediction of dynamic surface subsidence in combined open-pit and underground mining, and provide a reference for the feasibility evaluation of the redevelopment and utilization of the residual resources of abandoned open-pit mine.

1 Introduction

According to the predicted results, the total number of abandoned mines in China will reach 15000 by 2030 [1]. The management and utilization of abandoned mines has always been a worldwide technical challenge, which not only causes a huge waste of resources, but also may induce subsequent safety, environmental and social problems. Therefore, it is of great scientific and social significance to carry out overall strategy formulation, basic theoretical research and key technology research on the development and utilization of residual energy from abandoned mines [2][3][4][5]. At the same time, the reuse of abandoned mines is an important way to realize green mining [6].

The dynamic surface subsidence affected by the goaf is one of the main problems faced by the reuse of abandoned open-pit mines. Dynamic surface subsidence prediction is a very complex problem related to spatial and temporal [7][8]. In order to accurately and scientifically assess the impact of goaf on the surface and buildings (structures), it is necessary to establish a scientific dynamic surface subsidence prediction model and analyze the dynamic subsidence in the study area at any time [9].

The Polish scholar Knothe [10] established the time function model for the prediction of dynamic surface subsidence in 1952. Based on the observed values, many scholars have studied the difference between the surface subsidence law and the subsidence velocity and acceleration of the Knothe time function, and the law of taking values of parameters is analyzed [11][12][13]. Aiming at the limitation of Knothe time function in engineering application, many modified Knothe time function models are proposed to be suitable for specific engineering conditions. For example: Sroka-Schober [15][16], generalized [17], segmented [18][19] power exponential-Knothe [20], double-parameter [21], piecewise Knothe [22], Gompertz [23][24], backfill mining Knothe [25][26], Knothe-Budryk [27], 3DGIS-based dynamic model [28], IPIM-G dynamic prediction model [29], et cetera. Meanwhile, many scholars have improved the Knothe time function while exploring the meaning of the parameters in the model [30][31]. The calculation of time influence coefficient and correction parameters is analyzed comprehensively [32].

Through literature analysis, it can be seen that the Knothe time function plays an important role in the research of dynamic prediction and is widely used. Most of the existing dynamic surface subsidence prediction models focus on the flat surface. There is a lack of research on the dynamic surface subsidence prediction under the interaction of open pit mining and multi-layer mining. There are large errors when using existing models to study dynamic surface subsidence in open-pit mine affected by multi-layer goaf. The long-term dynamic subsidence prediction of open-pit mine affected by goaf is of great significance for the prevention and control of geological disasters and the effective use of abandoned mine pit. Therefore, it is necessary to establish a accurately dynamic surface subsidence prediction model for open-pit mine affected by goaf.

In this study, the distribution of goaf in spatial and temporal was surveyed and counted. Combined with the observed subsidence data, the subsidence characteristics of the open-pit mine surface and slope affected by the multi-layer goaf are analyzed; Considering the influence of slope angle and multi-layer goaf on the dynamic surface subsidence, a modified prediction model is proposed based on a double-parameter time function model, which is suitable for the dynamic subsidence of open-pit mine affected by multi-layer goaf; Based on the Burgers-Mohr model creep model built in FLAC3D, the subsidence law of the surface and slope of Haizhou open-pit mine in different periods was studied.

The research results provide a new method for the dynamic surface subsidence prediction in combined open-pit and underground mining, and provide a reference for the feasibility evaluation of the reuse of abandoned open-pit.

2 Engineering background analysis

Fuxin Haizhou open-pit mine is located in Fuxin City, Liaoning Province, China. At the end of large-scale mining in 2005, the world's largest artificial abandoned mine pit was formed, with a length of 3.9 km from east to west, width of 1.8 km from north to south, and depth of about 350 m. The area of surface subsidence affected by goafs is more than 20 km^2 and the surface is currently subsiding all the time. The distribution of goafs around the Haizhou open-pit mine ware investigated and analyzed, and it was found that there are multi-layer goafs, the mining time is from 1964 to the present, the depth is 70 - 600 m, the total area of goafs in the study area is 2526 km^2. The distribution of goafs is shown in Figure 1.

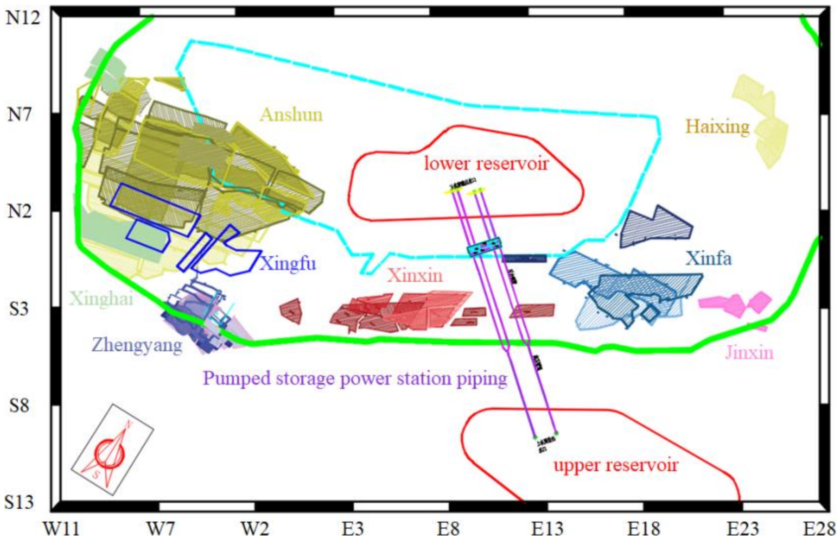

Figure 1: Plane diagram of goaf distribution

3 Dynamic Prediction Model of Surface Subsidence in Open Pit Mine

3.1 Dynamic Prediction Model of Surface Subsidence

In order to studied the dynamic process of surface subsidence over time after underground mining, the Polish scholar KNOTHE [10][33], established the Knothe time function model in 1952. Its expression is:

$$W(t) < W_m\varphi(t) = W_m(1 - e^{-ct}) \tag{1}$$

Where ΊT is the subsidence velocity, m/s; Ό΄Τ(is the subsidence value, m; Γis the influence coefficient of time factors related to the physical and mechanical properties of the overlying strata, Ⱥ; T is the arbitrary moment of dynamic surface subsidence; ΌM is the final subsidence value, and its value is related to the mining thickness (M), surface subsidence coefficient (ΓȚ, and coal seam dip (α), ΌM < MΓΤΞΣ⁄, m.

The first and second derivatives of the Knothe time function represents the surface subsidence velocity and acceleration respectively. The expressions are formula (2) and (3) respectively.

$$W'(t) = W_m c(1 - e^{-ct})e^{-ct} \tag{2}$$

$$W''(t) = W_m[-c^2 e^{-ct}(1 - e^{-ct})^2] \tag{3}$$

The Knothe time function and its first and second derivative curves are shown in Figure 2. Their curves shape has the following characteristics: When the time T is from 0→+∞, the surface subsidence amount gradually increases from 0 to the maximum value, the subsidence velocity gradually decreases from the initial acceleration Γ to 0, and the subsidence acceleration gradually decreases from the initial acceleration Γ[illegible] to 0.

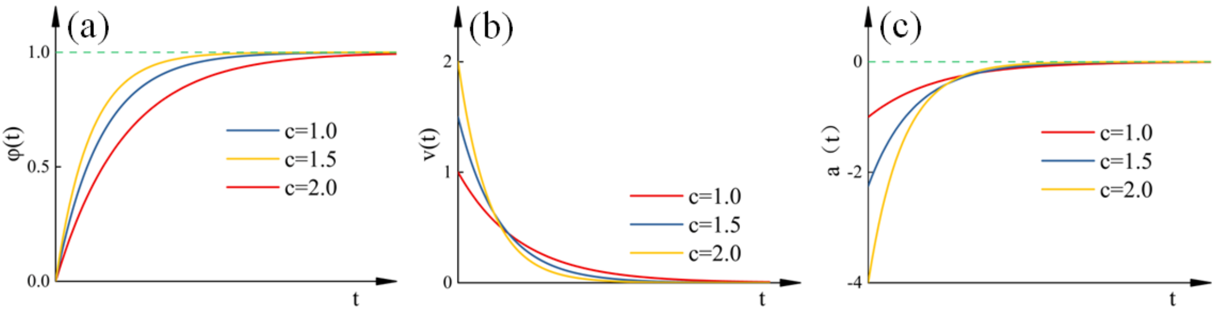

Figure 2: Shape characteristics of the Knothe time function and its first and second derivatives. (a) Knothe time function, (b) first derivative, (c) second derivative

A large number of observed values show that the actual process of surface subsidence caused by mining is: When T< / , the subsidence value, velocity and acceleration of the surface are 0 respectively. The variation law of the subsidence value, velocity and acceleration with time is: the surface subsidence amount gradually increases from 0 to the maximum value; The surface subsidence velocity is 0 from the start of the working face advance to before subsidence occurs on the surface. After that, the surface subsidence velocity changes from 0→+max→0 with time. The surface subsidence acceleration is 0 from the start of the working face advance to before subsidence occurs on the surface. After that, the surface subsidence acceleration changes from 0→+max→0→-max→0 with time.

Combining the results of the first and second derivatives of the Knothe time function, it can be seen that when the Knothe time function is used to predict the dynamic surface subsidence affected by the goaf, the evolution law of the subsidence velocity and acceleration is not consistent with the actual engineering.

In order to break through the limitation of Knothe time function in predicting subsidence velocity and acceleration, and improve its applicability and prediction accuracy. A double-parameter Knothe time function is proposed [21]. The expression is:

$$W(t) < W_m(1 - e^{-ct})^k \tag{4}$$

Where k is the parameter to be fitted.

The double-parameter Knothe time function and its first and second derivative curves are shown in Figure 3. It can be seen that the double-parameter Knothe time function model conforms to the changing characteristics of dynamic surface subsidence, and it is more consistent with the whole process of the actual surface subsidence affected by the goaf.

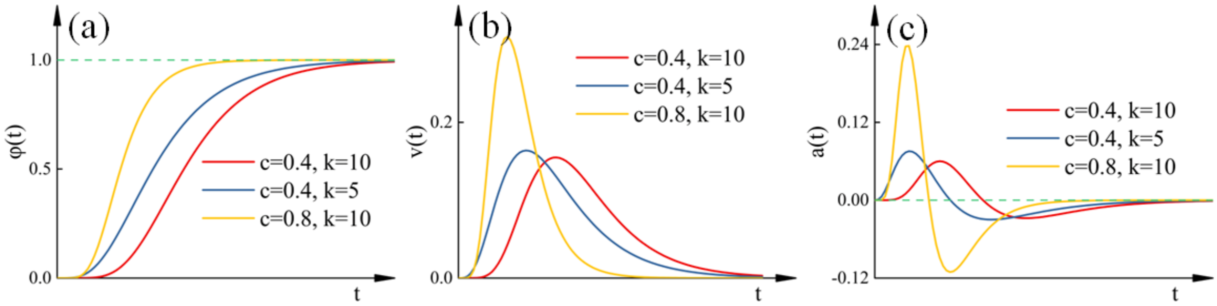

Figure 3: Shape characteristics of the double-parameter Knothe time function and its first and second derivatives. (a) double-parameter Knothe time function, (b) first derivative, (c) second derivative

3.2 Dynamic subsidence prediction model of open-pit mine affected by multi-layer goaf

The surface and slope subsidence of open-pit mines affected by multi-layer goaf is more complicated than the general situation, and the influence of multi-layer goaf and open-pit mining is not considered when establishing the double-parameter Knothe time function model. Therefore, the double-parameter Knothe time function model has limitations when used to predict the dynamic subsidence of surface and slope of open pit mines affected by multi-layer goaf. Aiming at the insufficiency, the influence factor ΓΞ⊬ t ◁ of the slope angle, and the ° .Ⅎ(′⁸t N⟜• of buried depth, cumulative min ing thickness and number of mining layers are introduced to modified the double-parameter Knothe time function model.

The modified prediction model is as follows:

$$W(t) < W_m(1 - e^{-ct})^k \, cos\alpha^{-\eta}(\frac{H}{h})^{(1-n)\lambda} \tag{5}$$

Where ⊬ is the slope angle of the open pit mine, °; ◁ is a parameter related to slope angle;° is the average buried depth of the goaf, m; Ⅎ is the cumulative mining thickness of the goaf, m; Nis the layer number of the goaf; ⟜• is a parameter related to the spatial distribution of goaf.

The modified double-parameter Knothe time function and its first and second derivative curves are shown in Figure 3. According to the control effect of various parameters in the model on the curve shape or quantity value, the proposed predicted model modifies the maximum value of the double-parameter Knothe time function model. At the same time, the variation law of the velocity and acceleration of the revised model is also consistent with the characteristics of dynamic surface subsidence. It can be seen that the proposed modified model can more accurately predict the dynamic subsidence of open-pit mine affected by multi-layer goaf.

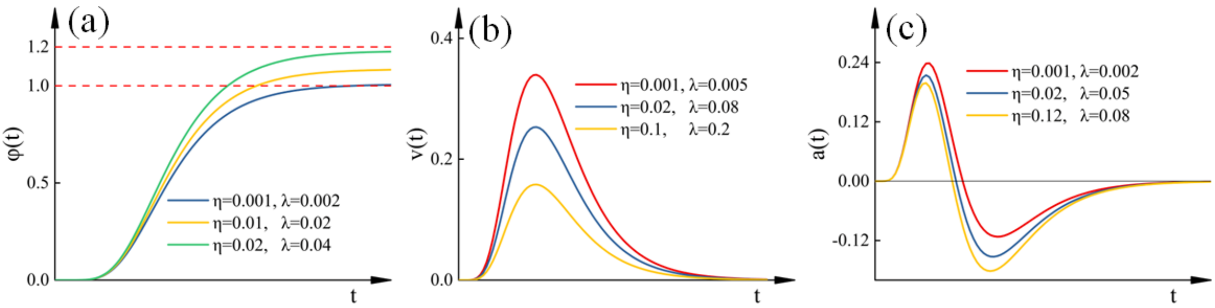

Figure 4: Shape characteristics of the modified double-parameter Knothe time function and its first and second derivatives. (a) modified double-parameter Knothe time function, (b) first derivative, (c) second derivative

3.3 Modified dynamic predictive model verification

In order to verify the applicability and correctness of the proposed modified model. Obtain the InSAR satellite monitoring data from March 2, 2019 to December 16, 2021 in the Fuxin open-pit mining area. The ENVI software was used to post-process the data, and subsidence values for the surface and slopes of the Fuxin open-pit mining area were obtained. According to monitoring data, the cumulative value of dynamic surface subsidence is greater than the thickness of the mining coal seam.

The Anshun Coal Mine in the west of the open-pit mine has been mined since 2014, the average thickness, dip angle and buried depth of the middle coal seam of Anshun coal mine are 2 m, 16° and 291 m, respectively. The slope angle and the cumulative thickness of the goaf at the 1# observation point are 58° and 5 m respectively, and the goaf is divided into two layers; And the 2# observation point are 30° and 27.3 m respectively, the goaf is divided into four layers. According to the Fitting results of observed values of different prediction models in Figure 4. For observation point 1#, the R2 of the fitting curves of the modified model, double-parameter and Knothe time function model are 0.921, 0.715 and 0.698, respectively. The R2 of observation point 2# are 0.944, 0.151 and 0.117, respectively. It can be seen that the proposed modified model can accurately predict the dynamic surface subsidence in different mining methods, periods and spatial distribution of goaf.

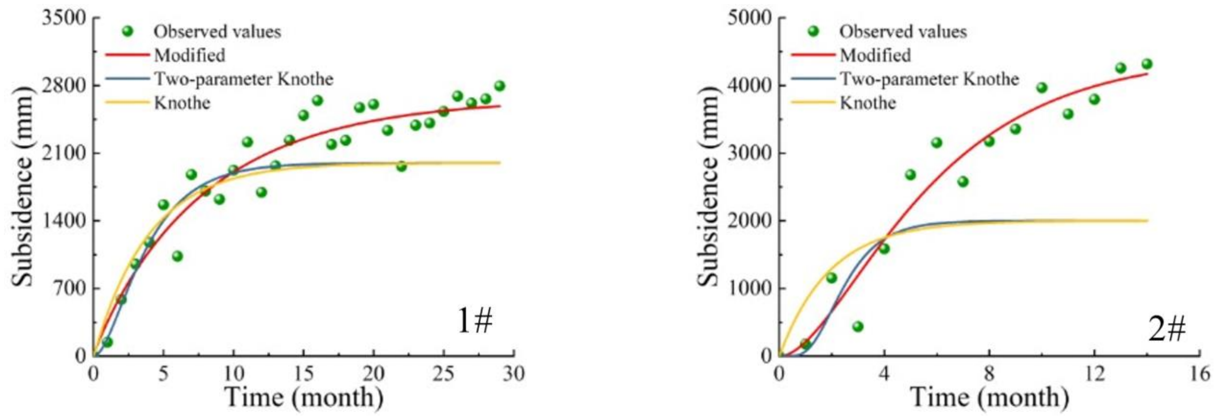

Figure 5: Fitting results of observed values of different prediction models

4 Numerical simulation research on dynamic surface subsidence of open-pit mine

4.1 Creep model of rock and soil mass

The improved Burgers creep model is based on the Burgers model, and a plastic element based on the Mohr-Coulomb criterion is connected in series. This model can simulate the elastic-plastic deviation characteristic and volume behavior of materials, and can describe the creep characteristics of rock more accurately. The model structure is shown in Figure 5, and the creep equation of the Burgers-Mohr model is expressed as:

$$\varepsilon = \frac{\sigma}{G_M} + \frac{\sigma}{\eta_M} t + \frac{\sigma}{G_K}\left(1 - \exp\left(-\frac{G_K}{\eta_K} t\right)\right) \quad (6)$$

Where G_M is the Maxwell shear modulus, MPa; η_M is the Maxwell viscosity, MPa·s; G_K is the Kelvin shear modulus, MPa; η_K is the Kelvin viscosity, MPa·s.

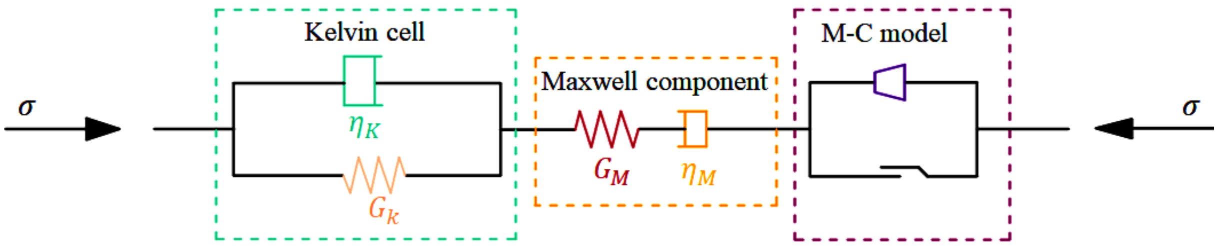

Figure 6: Schematic diagram of the Burgers-Mohr model

4.2 Analysis of the numerical results

Based on the built-in Burgers-Mohr model of FLAC3D, a three-dimensional numerical calculation model combining open-pit and underground mining is established [34]. Open-pit mines and underground mines are excavated separately according to different mining periods. The evolution law of the surface and slope displacement fields in different periods of open-pit and underground mining and from 2010 to 2050 after the end of mining is analysed [35][36][37].

According to the vertical displacement distribution in the four time periods in Figure 6, the vertical displacement of the surface and slope is divided into two parts after the mining of the open-pit and Xinxin coal mine: The surface and slope located in the upper part of the goaf are greatly affected by the goaf, and the vertical displacement gradually increases with time. The maximum vertical displacements of the surface and slope in 2010, 2020, 2030, 2040 and 2050 are 2005 m, 2552 m, 2869 m, 3138 m and 3343 m respectively; Due to the shallow buried depth of the goaf, the vertical displacement of the lower part of the slope is less affected by the goaf, and the vertical displacement does not change significantly with time. The cumulative thickness of the goaf is 2.98 m, due to the common influence of underground and open-pit mining, the vertical displacement of the surface and slope of open-pit mines is greater than the cumulative mining thickness of the coal seam. The surface and slope of open-pit mine affected by goaf experience a greater time to reach a stable state than a single mining method. In addition, the influence range of the goaf gradually increases with time.

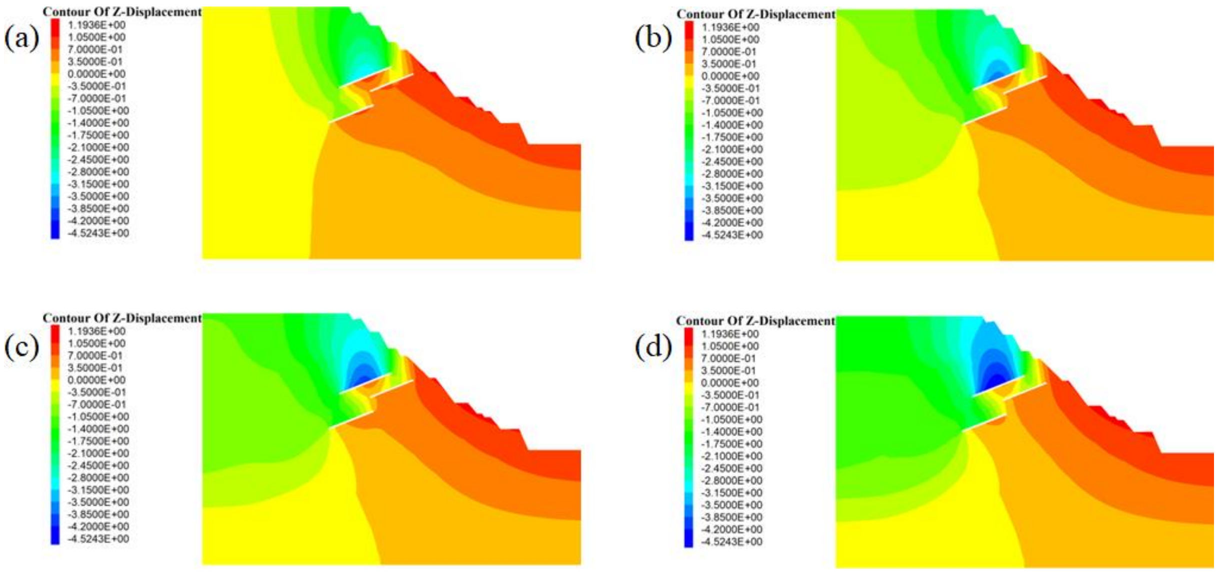

Figure 7: Vertical displacement distribution in different periods (unit: m). (a), (b), (c) and (d) are 2010, 2020, 2030 and 2050 respectively

According to the results of vertical displacement monitoring of the ground surface, slope and step in Figure 7. The vertical displacement of the surface increases as the horizontal distance (between the surface measurement point and the slope) decreases in Figure 7 (a). Due to the impact of underground mining, the upper slope and steps of the open-pit mine are obviously larger than the lower part. When slope and step were only affected by open-pit mining, their vertical displacements did not change significantly with time in Figure 7 (b and c). According to the average annual vertical displacement increase rate curve in Figure 7 (d), it can be seen that the vertical displacement increases and the rate of increase decreases gradually with time, the vertical displacement increases rate of the slope and steps is greater than that of the surface in the early stage, and the increase rate of the surface is greater than that of the open slope and step after a period of time. It can be concluded that the vertical displacement acceleration of the slope and step is greater than that of the surface, and the time required for the surface to reach a stable state is longer than that of the slope and step. Therefore, when developing and utilizing abandoned open-pit mines affected by goaf, the impacts of goaf on buildings in different periods should be considered.

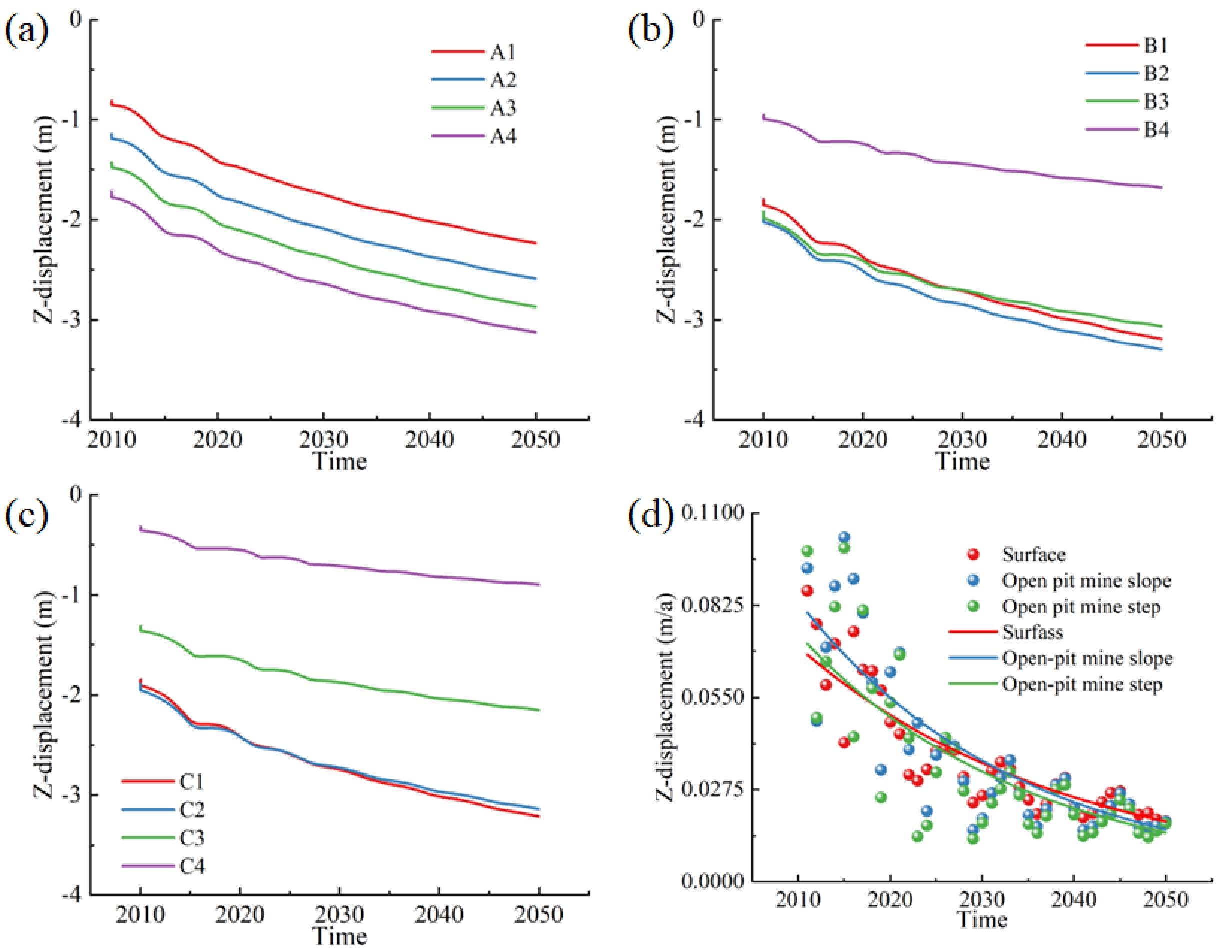

Figure 8: Vertical displacement changes of surface and slope in different periods. (a), (b) and (c) are the vertical displacements of the surface, slope and step respectively; (d) average annual increase rate of vertical displacement

5 Conclusion

In order to effectively prevent secondary geological disasters, and provide theoretical basis and technical support for the feasibility assessment of the development and utilization of abandoned open-pit mine affected by goaf. The distribution of goaf around the Haizhou open-pit was surveyed, and the method of combining field measurement, theoretical analysis and numerical simulation was adopted. The subsidence characteristics and laws of open-pit mine affected by multi-layer goafs are studied. The main conclusions are as follows:

(1) There are 13 coal mining goafs distributed around the Haizhou open-pit. The mining time is from 1964 to the present, the mining depth is 70 to 600 m, the maximum number of goafs is six layers, and the total area is 2526 km^2.

(2) The observed subsidence data in the field show that the surface subsidence value is greater than the thickness of underground coal seam mining, which is affected by the interaction between open-pit and underground mining. Considering the influence of slope angle and multi-layer goaf on the dynamic surface subsidence, a modified prediction model is proposed based on a double-parameter time function model. which is suitable for the dynamic subsidence of open-pit mine affected by multi-layer goaf.

(3) Based on the built-in Burgers-Mohr model of FLAC3D, a three-dimensional numerical calculation model combining open-pit and underground mining is established. The evolution law of the surface and slope displacement fields in different periods of open-pit and underground mining is analyzed. Due to the common influence of underground and open-pit mining, the vertical displacement of the surface and slope of open-pit mines is greater than the cumulative mining thickness of the coal seam. The surface and slope of open-pit mine affected by goaf experience a greater time to reach a stable state than a single mining method. The vertical displacement acceleration of the slope and step is greater than that of the surface, and the time required for the surface to reach a stable state is longer than that of the slope and step.

(4) Therefore, when developing and utilizing abandoned open-pit mine affected by goaf, the impacts of goaf on buildings in different periods should be considered. The proposed modified model can accurately predict the dynamic surface subsidence in different mining methods, periods and spatial distribution of goaf. The research results provide a new method for the prediction of dynamic surface subsidence in combined open-pit and underground mining, and provide a reference for the feasibility evaluation of the reuse of abandoned open-pit pits.

6 Funding

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An innovative two-step site selection concept for pumped hydroelectric energy storage and potential estimation of mines in Yunnan Province of China

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Abstract

In the context of carbon neutrality, numerous old mines could be suitable for underground pumped hydroelectric energy storage (UPHES). Site selection and potential estimation are critical for planning and implementing UPHES in old mines. This paper introduces an innovative two-step site selection concept for UPHES, comprising a screening assessment followed by a comprehensive assessment. The screening assessment incorporates geological features, mine water disasters, and minimum installed capacity as indicators, while the analytic hierarchy process (AHP) is used in the comprehensive assessment.

Based on an actual mine, Dahongshan, a case study is carried out to validate the proposed two-step site selection concept. Electricity consumption and generation for the designed UPHES plant are calculated. Additionally, this study conducts a preliminary assessment of old mines in Yunnan Province and estimates their potential for UPHES. The following results can be drawn:

1) The power generation of the Dahongshan UPHES plant could reach 1.72×10^{8} kWh per year. The total efficiency of the plant is 71 %.
2) The accumulated excavation space in numerous mines in Yunnan Province exceeds 1.5×10^{9} m3, with a usable volume of approximately 1.2×10^{8} m3, providing excellent conditions for UPHES construction. UPHES in old mines of Yunnan Province has the potential to generate 3.29×10^{10} kWh of electricity per year.
3) This study offers preliminary guidance for policy-makers in developing UPHES in old mines.

1 Introduction

Due to resource exhaustion, increasingly complex extraction conditions that compromise safety and economic feasibility, or policy adjustments driven by environmental protection and societal development considerations, mines inevitably face the prospect of closure or abandonment. There are millions of closed and abandoned underground and open-pit mines globally, mainly in regions such as North America, Europe, South Africa, Australia and East Asia[1,2]. In Germany, hard coal mining lasted for about 200 years, with approximately 20000 mines located solely in the Ruhr region[3]. Over the past 20 years, China has continuously intensified mining regulations and phased out outdated production capacity. Currently, the number of mines has decreased by 80 %, with at least 20000 abandoned mines[4].

Closed or abandoned mines and mine lands will transition into a long post-mining phase. Nevertheless, these abandoned mines still offer a variety of exploitable resources, such as underground space, mine water, and geothermal energy[5,6]. Simple and direct mine closure will lead to resource wastage and may induce new environmental pollution and geological disasters in abandoned mine lands. Against the global backdrop of carbon neutrality, low-carbon green sustainable development, and the circular economy, the strategic and sustainable development of abandoned mine resources, alongside the promotion of transformation in resource-exhaustion mine lands, has become an important agenda in the fields of mining and energy.

To promote the energy structure transition and optimise the electricity supply market, renewable energy sources, including wind and solar, have been continuously developed over the past decade in both Germany and China[7,8]. This development, however, also raises problems in terms of maintaining grid stability, as wind and solar power are intermittent and subject to seasonal and weather-dependent variation. Grid-scale deployment of energy storage is indispensable to handle the fluctuation and uncertainty problem[9]. Among various energy storage technologies, pumped hydroelectric energy storage (PHES) is widely utilised due to its technical, economic, and sustainability advantages. These include technical maturity, high efficiency, large achievable capacity, and a prolonged lifetime[10]. A significant challenge for PHES is the requirements for necessary topographic features, because of its technical need for large reservoirs and sufficient vertical height to store substantial amounts of water and energy. Furthermore, the implementation of PHES projects may face obstacles in terms of environmental and social impacts, given it typically requires massive alterations to the existing landscape[11]. As a consequence, the number of potential locations is limited.

A possible alternative is utilising abandoned mines for underground PHES (UPHES), which works on the same principles as a conventional PHES system, with the main difference being the type of lower reservoir employed[12,13]. The mining process naturally forms large quantities of underground spaces, which can function as ready-made reservoirs with significant elevation differences, making them well-suited for pumped storage. Redeveloping abandoned mines for underground energy storage not only offers a second life to otherwise unused assets but also can support the promotion of local renewable energy projects[14]. At present, there are some studies on UPHES, primarily revolving around technical feasibility, environmental impact, and economic analysis[3,15-20]. Nevertheless, limited attention has been paid to site selection, which is vital to the development of UPHES using abandoned mines. Unlike conventional PHES, site selection for UPHES requires additional consideration of the geological and hydrogeological conditions of the mining lands, which may even be decisive or restrictive.

The establishment of a reliable and effective site selection model is necessary for the implementation of UPHES in abandoned mines. Therefore, this study proposes an innovative two-step site selection concept, including a screening assessment followed by a comprehensive assessment. Based on the site selection model, the suitability of Dahongshan Mine for UPHES is evaluated. Moreover, the annual electricity consumption and generation capacity of the designed UPHES plant are estimated. Subsequently, a preliminary assessment of abandoned mines in Yunnan Province is conducted to estimate the potential for UPHES.

2 UPHES and two-step site selection concept

2.1 UPHES using old mines

Many abandoned or closed mines are still in the closure process and await post-mining management. Meanwhile, these inactive old mines provide a large amount of accessible underground space, including shafts, drifts, chambers, and goaf, which can be effectively repurposed as underground reservoirs and the power house for UPHES. According to the spatial locations of the upper and lower reservoirs, UPHES can be categorised into semi-underground and full-underground models.

In the case of underground mining, the initial stress equilibrium state of the overlying strata above the goaf is disrupted after the extraction of mineral resources, leading to a sequence of movement and deformation occurring, such as caving, fracturing, and bending. Eventually, these processes extend their impact to the surface, giving rise to an extensive mining subsidence area[7]. For the semi-underground model, mining subsidence areas can be utilised as upper reservoirs after appropriate renovations. Besides, natural lakes, rivers, or artificial reservoirs near the mining lands are optional alternatives. Drifts in old mines can be utilised as lower reservoirs, while the main shaft or auxiliary shaft can function as the penstock. Furthermore, other underground spaces like shaft stations can be transformed into the power house, as shown in Figure 1.

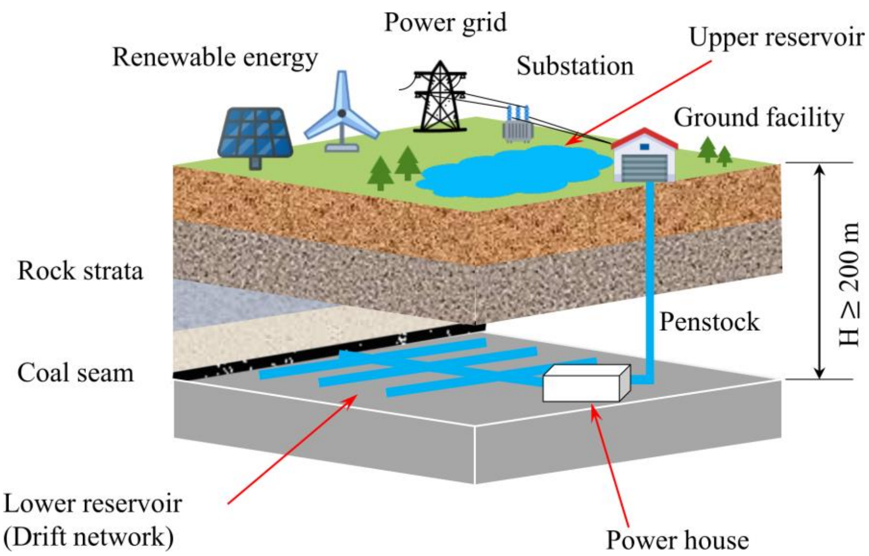

Figure 1: Schematic diagram of semi-underground model[21]

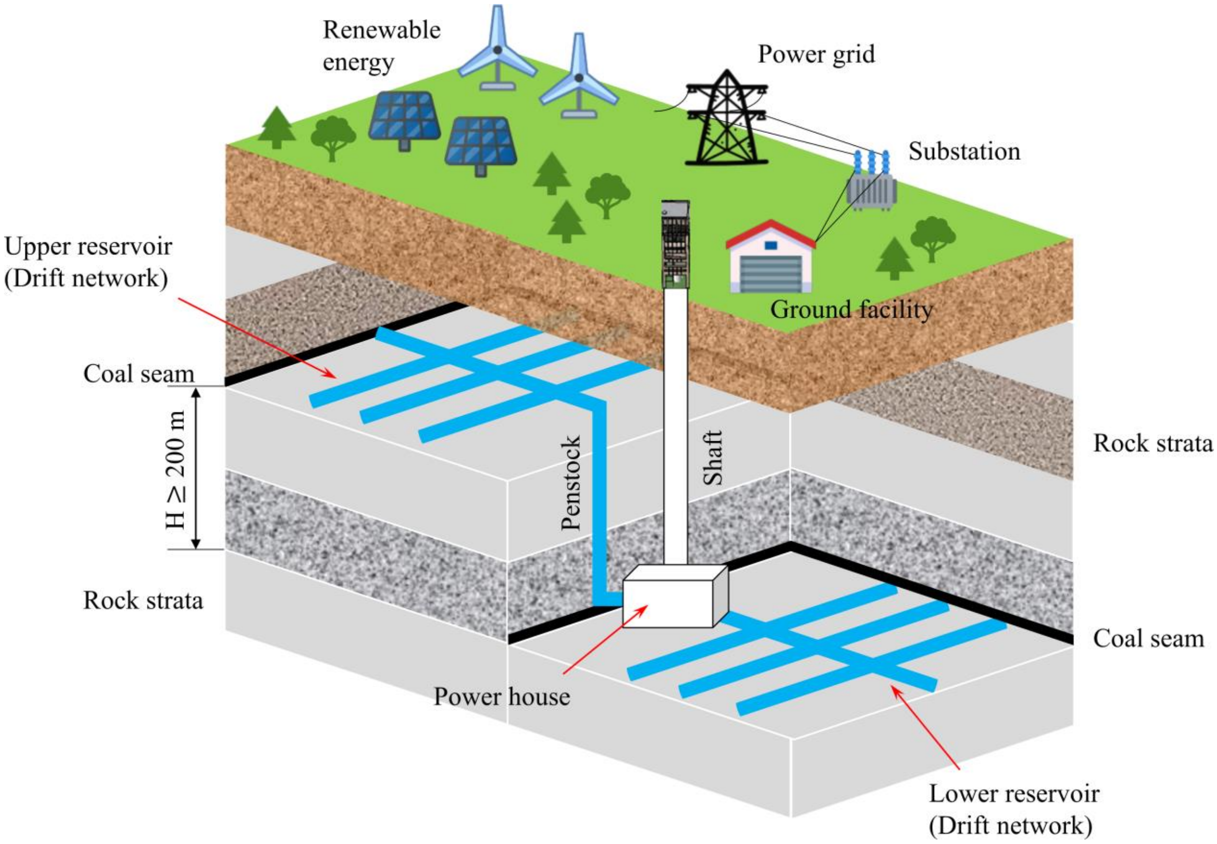

Figure 2: Schematic diagram of full-underground model[21]

In the case of multi-level underground mining, a full-underground model is feasible. In this model, shallow underground drifts can become upper reservoirs, while deeper drifts are suitable for lower reservoirs. Apart from these reservoirs, the other configurations are similar to the semi-underground model, as illustrated in Figure 2.

In both models, implementing UPHES in old mines necessitates the utilization of underground space resources. Renovating old mines introduces numerous uncertainties, including the safety of drifts, the stability of surrounding rock, and underground geological and hydrogeological conditions. Additionally, since UPHES is a construction project, the issue of site selection is essential for identifying suitable mines.

2.2 Two-step site selection concept

Typically, site selection for conventional PHES projects involves techno-economic, social and environmental factors. For UPHES projects in old mines, the geological and hydrogeological conditions of mines must also be considered. Furthermore, wind and solar energy are the primary power sources for UPHES plants. To facilitate the construction of wind-PV-UPHES hybrid systems, it is essential to consider the distribution of solar and wind energy resources around the candidate mine. Among these factors, some indicators play a decisive role in site selection and demand particular consideration. For instance, adverse geological conditions in old mines can imperil the stability of underground reservoirs. The common one-step site selection method will diminish the significance of these restrictive indicators, resulting in unrealistic decision-making results. Consequently, to effectively and reliably address the issue of site selection for UPHES in old mines, this study introduces a two-step site selection concept.

The two-step site selection concept consists of a screening assessment followed by a comprehensive assessment. During the screening assessment, three critical indicators are designated as screening criteria. Mines that satisfy the specified conditions are immediately eliminated from the list of candidate sites. Implementing the screening assessment not only enhances the efficiency of site selection but also improves the significance of those restrictive indicators. Mines that pass the screening assessment then proceed to a comprehensive assessment. An evaluation indicator system is established for the assessment, with the AHP employed to determine indicator weights. Ultimately, mines with the highest scores receive priority for UPHES implementation. The overall process of the proposed two-step site selection concept is shown in Figure 3.

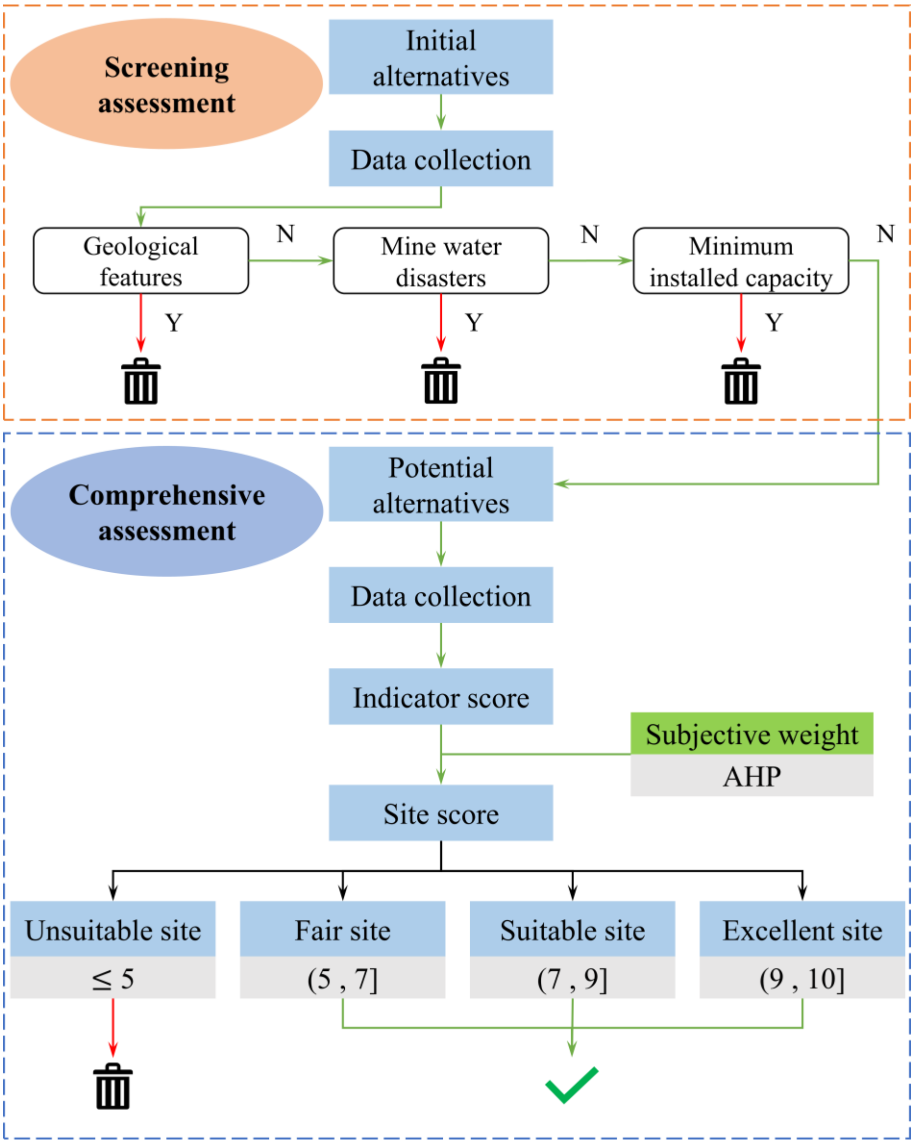

Figure 3: Flow diagram of the two-step site selection concept

2.2.1 Step I: screening assessment

In the case of conventional PHES projects, the screening indicators frequently involve gross head, head-distance ratio, and water source. In this study, these indicators are combined with the geological and hydrogeological conditions of old mines to determine the restrictive indicators for UPHES projects. Finally, geological features, mine water disasters, and minimum installed capacity have been identified as the three screening indicators.

Geological features: The old mine is located in karst topography or areas with underground rivers nearby. Karst topography is susceptible to water dissolution and erosion, which can damage the integrity of underground reservoirs and the stability of surrounding rocks, ultimately posing a risk of underground reservoir collapse.

Mine water disasters: The old mine has experienced repeated water inrush incidents throughout its mining history or has a large mine water inflow, for example exceeding 600 m^3/h. Repeated water inrush accidents indicate that the mine is under complex hydrogeological conditions, threatening the safety and stability of underground reservoirs. Additionally, a substantial mine water inflow during the storage phase would occupy the lower reservoir, reducing actual power generation capacity and resulting in pumping costs surpassing revenue over the long term.

Minimum installed capacity: The designed installed capacity of the UPHES plant is below 20 MW. For a candidate mine, the potential installed capacity of the UPHES plant can be evaluated by

$$P = \rho \cdot g \cdot Q \cdot H \cdot \eta \tag{1}$$

where ς is the density of water; g is the acceleration of gravity; Q is the planned water discharge through the turbine; H is the planned elevation difference between the upper and lower reservoirs, that is head height; η is the overall mechanical efficiency of the generation system, which is usually around 90 %. The Nassfeld plant, featuring a nominal flow rate of 11.6 m^3/s and a head height of 317 m, has an installed capacity of 31.5 MW and an annual power generation of 50 GWh, which can supply around 14 000 households with clean electricity. Based on these specifications, a minimum installed capacity of 20 MW is determined for UPHES plants in old mines.

2.2.2 Step II: comprehensive assessment

An evaluation indicator system is formulated in this study to comprehensively assess the remaining candidate sites, with evaluation indicators identified through consultation with five experts who possess expertise in UPHES and redeveloping old mines.

UPHES plants effectively provide "peak shaving and trough filling" and surplus energy consumption services to support solar and wind power. Conversely, solar and wind power provide electricity for pumping. Therefore, it is necessary to consider local distribution and utilisation conditions of renewable energy sources to be evaluation indicators. Furthermore, this system introduces a local peak-to-valley tariff differential as an economic evaluation indicator. For UPHES plants, grid peak regulation is a primary objective in daily operations and a key revenue generation method. A higher peak-to-valley tariff differential enhances the economic viability of UPHES plants.

2.2.2.1 Evaluation indicator system

The expert committee reached a consensus on the evaluation indicator system, including eighteen indicators that cover four aspects: geological and natural condition (C1), society (C2), resource (C3) and economy (C4). These indicators possess a tree-like structure in Figure 4.

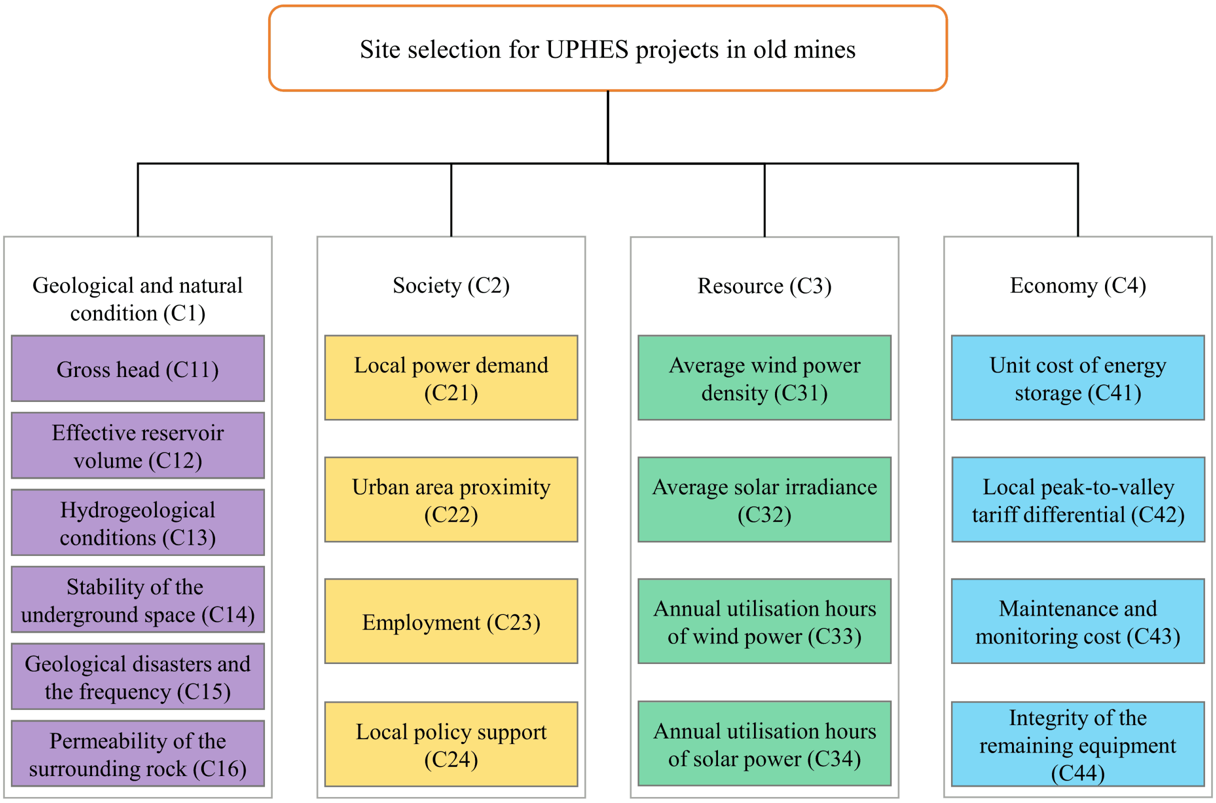

Figure 4: Tree-structure of the evaluation indicator system for UPHES site selection in old mines[21]

2.2.2.2 Weight determination

For weight determination, the AHP is a widely acknowledged subjective evaluation method, possessing good applicability for both qualitative and quantitative indicators. Given the presence of qualitative indicators within the evaluation indicator system, this study adopted the AHP for weight determination. The AHP typically involves the following steps:

Create a hierarchy: Construct a hierarchical structure by organizing the goal, criteria, sub-criteria, and alternatives in a tree-like diagram, as depicted in Figure 4.

Construct comparison matrixes: Evaluate the relative importance of indicators by pairwise comparisons. It involves comparing each indicator within a hierarchy level with all others at the same level and assigning numerical values representing their relative importance. The five experts evaluated the relative importance of each indicator using Saaty's nine-point scale.

Calculate priority: Pairwise comparison generates a matrix of the relative rankings for each level of the hierarchy. After all matrices have been created, the vector of relative weight and maximum eigenvalue (λ_{max}) for each matrix is calculated.

Check for consistency: Verify the consistency of pairwise comparisons to ensure their reliability and eliminate potential logical contradictions. Inconsistencies require revisiting and refining the pairwise comparison. To validate consistency, the consistency index (CI) and consistency ratio (CR) are successively calculated according to the maximum eigenvalue (λ_{max}). If the value CR is less than the acceptable threshold, which depends on the dimension of the matrix, it indicates sufficient consistency. Conversely, the value CR exceeding this threshold indicates inadequate consistency.

According to comparison matrixes provided by five experts, the final weight of each evaluation indicator is presented in Figure 5.

By weight determination, indicators that have significant influences over site selection are identified, including gross head (C11), effective reservoir volume (C12), local peak-to-valley tariff differential (C42), unit cost of energy storage (C41), stability of the underground space (C14), and local power demand (C21).

These indicators play crucial roles in determining the technical feasibility, safety, and economic viability of UPHES projects in old mines.

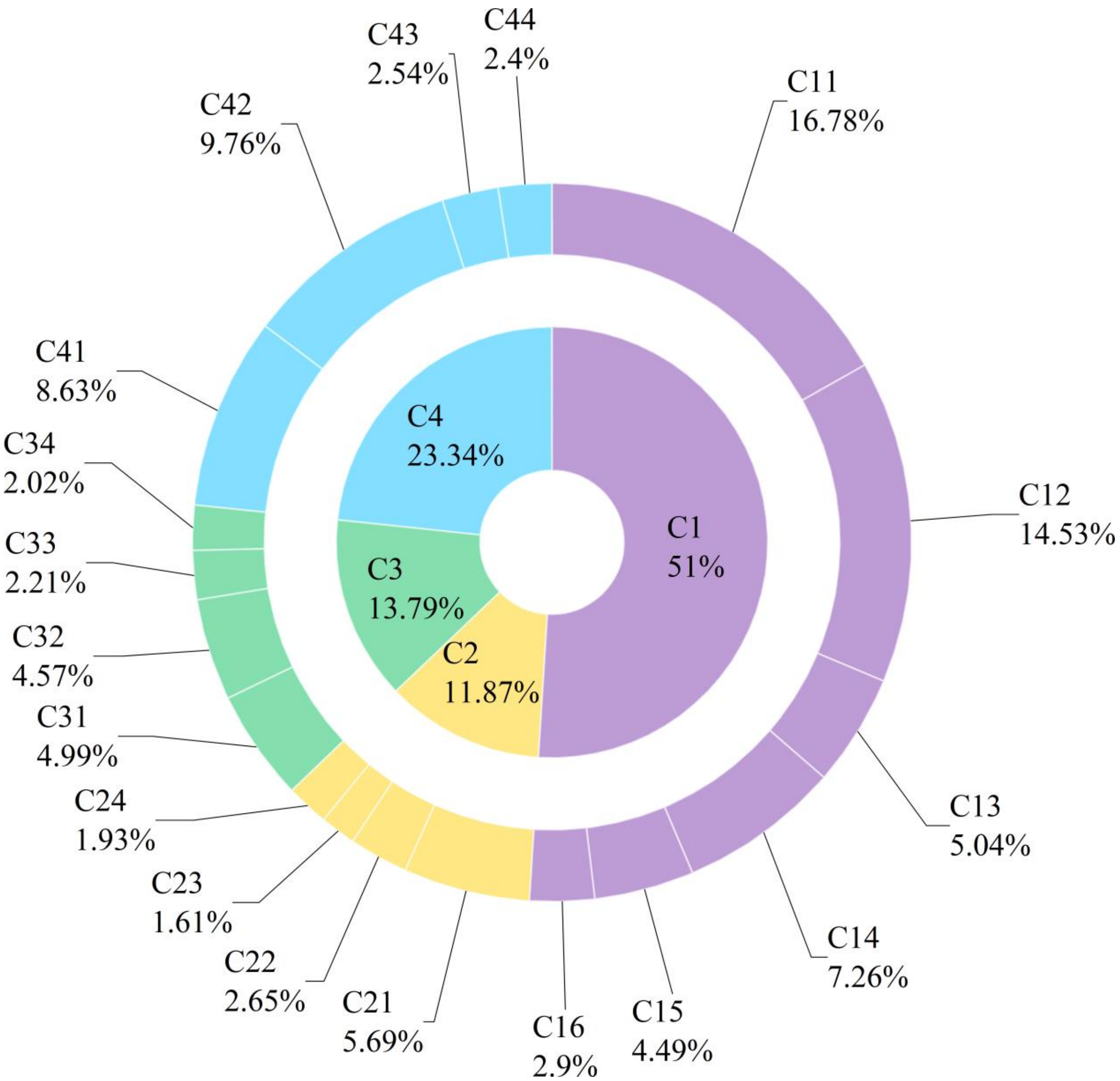

Figure 5: Weight results of evaluation indicators for the comprehensive assessment[21]

3 Case study: UPHES plant in Dahongshan Mine

Dahongshan iron-copper mining area is located in Xinping County, Yunnan Province, China, with coordinates ranging from 101°73′52″ E to 101°39′51″ E and 24°04′58″ N to 24°06′49″ N[22]. It is situated 37 km west of Xinping County, with a distance of approximately 150 km from Yuxi City. The mine covers an area of 15.2 km^2. The altitude of the whole mining area is ranging from 500 - 1850 m, generally high in the northeast and low in the southwest. The mountain ranges and rivers follow an east-west orientation, controlled by east-west folded fractures, as shown in Figure 6. There are three rivers in the mining area, including Mangang River, Feiwei River, and Laochang River.

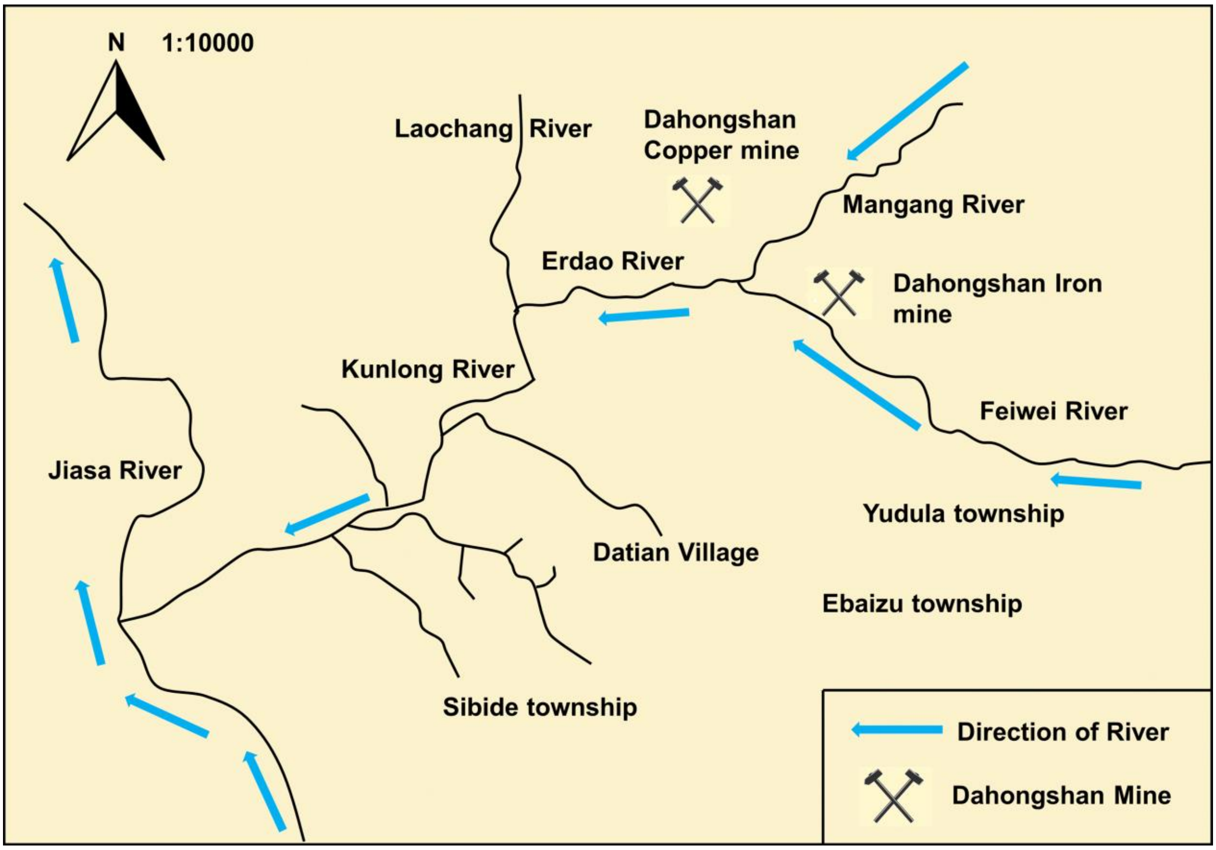

Figure 6: Location of Dahongshan Mine and its nearby rivers

Due to the terrain restrictions, the deposit development of Dahongshan Mine is complex. Various adits, inclined shafts and vertical shafts are employed. The current deepest mining level is at an elevation of 0 m in the third-phase project. The main mining method of Dahongshan Mine is the open stope mining method. Since no backfill is integrated into the ground pressure management, the mining space always keeps open and large amounts of goafs are left. Just for the room and pillar method, an accumulated volume of the goaf is 951900 m^3, of which the largest single one is 215000 m^3. Most goafs in Dahongshan Mine are in good stability without obvious collapse and spalling. These surrounding rocks are mostly hard or semi-hard rocks and the compressive strength of surrounding rocks are relatively high. These conditions provide a possibility of reusing the available goafs as reservoirs for UPHES plants.

3.1 Site selection

The proposed site selection model is utilised to determine the suitability of Dahongshan Mine for UPHES. The basic data of the mine are collected and presented in Table 1.

Table 1: The basic information of Dahongshan Mine

Parameter	Value
Planned head height/m	334
Effective reservoir volume/(10^4 m^3)	61.9
Urban areas proximity/km	150
Average wind power density/(W/m^2)	150
Average solar irradiance/(kWh/m^2)	1500
Uniaxial compressive strength of drift surrounding rock/(MPa)	77.28 ~ 93.37

The mine is located in non-karst terrain without nearby underground rivers. The roof, floor, and interlayers of the ore body comprise iron-copper-bearing rocks, exhibiting notable compressive strength and stability. Moreover, a favourable section within Dahongshan Mine is selected for UPHES construction, which has simple hydrogeological conditions and minimal mine water inflow. Given the planned head height and water discharge, the estimated installed capacity could reach 50 MW. As a result, therefore, Dahongshan Mine successfully passed the screening assessment.

Five experts are invited to assign scores to each indicator for the mine. The weighted arithmetic mean of all indicator scores is calculated and deemed the final score. The average scores for all indicators are provided in Table 2, alongside the final score for the mine. Consequently, Dahongshan Mine obtains a score above seven, indicating that it is a suitable site for UPHES project.

Table 2: Average score for each indicator and the final score for Dahongshan Mine

	C11	C12	C13	C14	C15	C16	C21	C22	C23	Final score
Average Score	6.0	10.0	8.6	8.4	6.0	6.8	6.0	4.8	7.2	
	C24	C31	C32	C33	C34	C41	C42	C43	C44	
Average Score	8.0	7.2	7.6	5.6	6.0	7.8	7.4	5.6	6.6	7.4

3.2 Electricity Consumption and Generation

Taking Dahongshan Mine as an example, the section of underground space characterized by favourable geological conditions, simple drift arrangement, and stable surrounding rock is selected as the construction site for UPHES. Table 3 lists the relevant parameters of the mine for its transformation into an UPHES plant[23].

Table 3: Parameters of the mine for transformation into an UPHES plant[23]

Parameter	Value	Parameter	Value
High horizontal elevation, upper reservoir/m	+1158	Low horizontal elevation, upper reservoir/m	+1058
Average horizontal elevation, upper reservoir/m	+1108	Total volume of the upper reservoir/m^3	619700
Low horizontal elevation, lower reservoir/m	+745	Water stage depth, lower reservoir/m	58
Elevation of normal water stage, lower reservoir/m	+803	Average horizontal elevation, lower reservoir/m	+774
Total volume of the lower reservoir/m^3	982500	Volume ratio of upper/lower reservoirs	1.0:1.5
Length of the water path/m	1956	Discharge duration/h	5
Pump duration/h	5		

3.2.1 Electricity consumption

The pump flowrate, Q (m^3/s), is

$$Q = \frac{V}{T} \tag{2}$$

where V is the effective reservoir volume (619700 m3); T is the pump duration (5 h or 18 000 s); and hence, Q is calculated as 34.43 m^3/s.

The head loss along the water path, H_f (m), is calculated by

$$H_f = \mu \frac{lv^2}{2dg} \tag{3}$$

where l is the pipe length (1956 m); μ is the roughness (0.02); g is the gravity (9.8 m/s^2); v is the cross-sectional flow velocity (2.4 m/s); d is the pipe diameter (0.5 m); and hence, H_f is calculated as 22.99 m.

The partial head loss of water flow through the filter screen, H_j (m) is calculated by

$$H_j = \xi \frac{v^2}{2g} \tag{4}$$

where ÷ is the partial head loss coefficient (1.0); v is the flow velocity (1.75 m/s); and hence, H_j is calculated as 0.15 m.

The total head loss during the pump mode, H_p is calculated as 23.14 m. The average head during the pump mode is calculated by

$$H_1 = Z_u - Z_l + H_p \tag{5}$$

where Z_u is the average horizontal elevation of the upper reservoir (1108 m); Z_l is the average horizontal elevation of the lower reservoir (774 m); and hence, H_1 is calculated as 357.14 m.

The electricity consumption of the water pump, W_p is

$$W_p = \frac{H_1 V g \rho}{\eta_1} \tag{6}$$

where η_1 is the overall mechanical efficiency of the pump system (90 %), ρ is the water density (1.0×10^3 kg/m^3), and hence, the W_p is 6.69×10^5 kWh.

3.2.2 Electricity generation

The average head during the discharge mode is calculated by

$$H_2 = Z_u - Z_l - H_p \tag{7}$$

and H_2 is calculated as 310.86 m.

The maximal electricity generation during the discharge mode, W_d is

$$W_d = \eta_2 H_2 V g \rho \tag{8}$$

where η_2 is the overall mechanical efficiency of the generation system (90 %); hence, the W_d is 4.72×10^5 kWh. In a discharge mode of 5 h, the average generator power is 94400 kW, and a generator with nameplate power of 1.0×10^5 kW can be selected.

The plant total efficiency η is calculated as 71 % by the following equation:

$$\eta = \frac{W_d}{W_p} \times 100\ \% \tag{9}$$

Based on the above calculations, it can be determined that the transformation of this mine into an UPHES plant could accommodate an installed capacity of 100 MW. The plant generates electricity through 365 annual cycles, with annual utilization hours amounting to 1825 hours, resulting in an annual power generation of up to 1.72×10^8 kW·h.

4 Potential estimation of UPHES in Yunnan Province

4.1 Overview of mines in Yunnan Province

Yunnan Province possesses complex geological structures, favourable mineralization conditions, and abundant mineral resources, particularly in non-ferrous metals. The province boasts a wide variety of minerals, with 148 out of the 162 recognized mineral types in China found within its boundaries. Among these, 86 mineral types have confirmed reserves. Yunnan Province is home to 286 state-owned mines and 10578 township and individual mines. Many of these mines exhibit symbiotic and associated mineral deposits of high utilization value, accounting for approximately 31 % of the total mineral deposits. Furthermore, mineral resources are widely distributed across Yunnan, with metal deposits present in 108 counties (cities) and coal mines in 16 counties (cities). The province hosts numerous mines, leading to an accumulated abandoned goaf space exceeding 1.5×10^9 m^3. Due to topographical constraints, mining in Yunnan Province predominantly employs vertical shafts, inclined shafts, and their combinations, resulting in significant height differences in mining engineering. The prevalent mining method in the province is the open stope mining method, leading to the creation of substantial old goafs underground. The common features of significant height differences and numerous goafs provide a favourable foundation for constructing UPHES plants.

4.2 Potential estimation

Yunnan Province has a considerable number of old mining goafs, with a cumulative abandoned volume exceeding 1.5×10^9 m^3. Considering factors such as the convenience of mine location, rock stability, system safety, technical complexity, development potential, and power station site selection, it is estimated that approximately 1.2×10^8 m^3 of goaf space can be utilized for constructing UPHES plants (approximately 8 % of the total). This study utilizes this available space to construct UPHES plants and calculates their energy storage and losses. The basic calculation process is divided into two parts: pumping energy consumption and water transmission energy storage. With an annual utilization hours of 1825 h, a net head of 600 m, and an available goaf space of 1.2×10^8 m^3 (divided equally between upper and lower reservoirs), it is estimated that Yunnan Province could achieve a maximum annual electricity generation of 3.29×10^{10} kWh.

5 Conclusions

To effectively and reliably address the issue of site selection for UPHES in old mines, this study introduces a two-step site selection concept. Based on the proposed concept, the suitability of constructing UPHES in an actual mine, Dahongshan, is evaluated. Furthermore, this study conducts a preliminary assessment of old mines in Yunnan Province and estimates their potential for UPHES. The main conclusions are as follows:

- The two-step site selection concept consists of a screening assessment and a comprehensive assessment. It can be used effectively for selecting suitable mines for UPHES plants.
- According to the evaluation result, Dahongshan Mine is suitable for the construction of the UPHES plant, which has an annual generation capacity of approximately 1.72×10^8 kWh and an overall efficiency of 71 %.
- Approximately 1.2×10^8 m^3 of goaf space can be utilized for constructing UPHES plants in Yunnan Province. Accordingly, the maximum annual electricity generation is estimated to be 3.29×10^{10} kWh.

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Innovative and creative teaching

A success story in Mining Engineering Education that strengthens Africa-Europe links – The Master in Mining of Diamond Deposits, Angola

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Abstract

Diamond mining in Angola is the most prominent mining activity, both nationally and internationally. The development of science and technology depends largely on mineral resources, and mining is considered one of the most important economic activities on the African continent.

The Master's Degree Program in Mining of Diamond Deposits was created in 2021, by the public university – Faculty of Engineering of the University of Agostinho Neto, Luanda, having started in January 2022. The Master's was created by a joint effort between the University Agostinho Neto, the leading diamond companies in Angola, and the National authorities (Ministry of Mineral Resources, Oil and Gas, and the Ministry of Higher Education, Science, Technology, and Innovation). From Europe, the Master's has counted on the collaboration of the Faculty of Engineering of the University of Porto, Portugal, and the support of the European Union under the UNI.AO-Higher education support program.

The program addresses sustainability as the fundamental pillar on which mining processes are developed, which will give a holistic view of the social, environmental, economic, political, and technological dimensions of mining projects.

The Master's program in Mining of Diamond Deposits has three specializations: Mining Planning of Diamondiferous Deposits, Exploitation of Diamondiferous Deposits, and Treatment of Diamondiferous Ores. In its first edition, 28 students successfully concluded their school work and are currently working on their dissertations.

Due to its importance in the context of Angolan higher education and the extractive industry, the Master has been closely monitored since its inception, with emphasis on the provision of mentoring and training (for example in B-learning) to its teaching staff.

Water Management for Future Mining Engineers (Developmental Approach)

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Abstract

Changing climate conditions are affecting the global water cycle, leading to an increase and intensification of devastating extreme weather events such as floods and droughts. The Intergovernmental Panel on Climate Change predicts that a total of 44 million Europeans will be affected by water scarcity by 2070. Around the world, many regions south of the equator are already suffering from the effects of global warming. At the same time, population growth is expected to increase demand not only for freshwater but also for raw materials, including through the increased use of renewable energy technologies. The mining industry is one of the world's largest consumers of water, and it is likely that the conflict between raw materials and water supply will intensify in the future. It is, therefore, necessary for future mining engineers to learn modern and sustainable water management strategies to obtain the social license to operate. In order to provide future mining engineers with the necessary basics for developing a sustainable water management strategy, a new course based on the lifecycle of a mine is currently being developed at the Institute of Mining at the Technical University of Clausthal in cooperation with Harzwasserwerke GmbH. The course structure follows the methodology developed and presented by Binder et al. in 2022. The course content follows a fictitious mining project from the exploration to the post-mining phase in an application-oriented manner. This paper presents the current status of the course development and the chosen teaching method. The course will be offered for the first time in the winter semester of 2023/24 as an elective.

1 Introduction

Water is an essential but limited resource found in Earth's natural cycle. The annual renewal of freshwater greatly exceeds global demand. However, uneven distribution and growing needs in business and industry will lead to regional shortages, worsened by climate change. The mining sector, a significant water consumer, is expected to support the United Nations Sustainable Development Goals (SDGs) to ensure its legitimacy and profitability. Key areas for sustainable mining include securing water supply (SDG 6), enhancing climate resilience (SDG 13), and minimizing negative environmental impacts (SDG 3 and SDG 15). Water usage was identified as the foremost sustainability concern in mining regions. To address challenges like climate-induced water scarcity and unregulated discharge, effective management strategies aligned with SDGs are crucial. (Gao et al., 2017)

The importance of water management in mine planning and operation increases and cannot be handled only by hydrology or hydrogeology specialists. Due to the interdependencies, interdisciplinary teams need to be formed for a holistic approach to planning and management during all phases of the mining operation. Hence, all persons working in the mining industry can be somehow affected and need skills within this framework. The foundation for these skills needs to be set during the studies and water needs to be addressed as a topic. As an overarching topic, different approaches for integration are available. (Bothe-Fiekert et al., 2023)

As one elective of the mining engineering program at Clausthal University of Technology is dedicated to water and its role in mining. Lately, it needed to be redesigned due to lecturer changes, and at that time the course has also been redesigned aiming for more competence development and focusing on the lifecycle of mine water. In terms of curriculum design, this approach focuses on specialization. This paper presents the framework of the course development, the course aims and its thematic structure, the teaching-learning activities, the exam format and gives an outlook on open points and aspects that can be transferred to other contexts.

2 Course Development Approach

Central to the process of course development is the extension of participants' skill sets, harmonized with the skill profiles projected for the future labor market. This gives rise to demands encompassing both pedagogical and discipline-specific domains that are interconnected. In this context, Schaper, 2012 enumerates several requirements for the design of instructional formats, including:

- Consistent competency orientation
- Constructive Alignment with an initial focus on learning objectives
- Instructor action in accordance with the "shift from teaching to learning"
- Student-centered setting with a focus on learning
- Thematic concentration on core elements with exemplarity
- Interdisciplinarity
- Application and practical relevance.

These demands are met through the configuration of course and personnel development, as outlined by (Binder et al., 2022). The main elements are presented in Figure 1. The different stages are realized by workshops that are supported by individual preparation. Herein, the targeting of goals and competencies is ensured through the preceding articulation of learning objectives and continuous adherence to Biggs' Constructive Alignment (Biggs & Tang, 2011) in the design of Teaching, Learning, and Assessment (TLA) concepts. The formulation itself was based on the structure for Intended Learning Outcomes presented by (Reis, 2015) following a “what – wherewith – why” Structure.

Through program guidance and the structure itself, it is ensured that instructors' role perception aligns with the "shift" and emphasizes the students' learning. The brainstorming of topics and their distribution contributes to content exemplarity. The involvement of various stakeholders contributes to interdisciplinarity and practical applicability. In contrast to the original approach, expert input has been adjusted in consideration of the significantly more interdisciplinary nature of the subject matter.

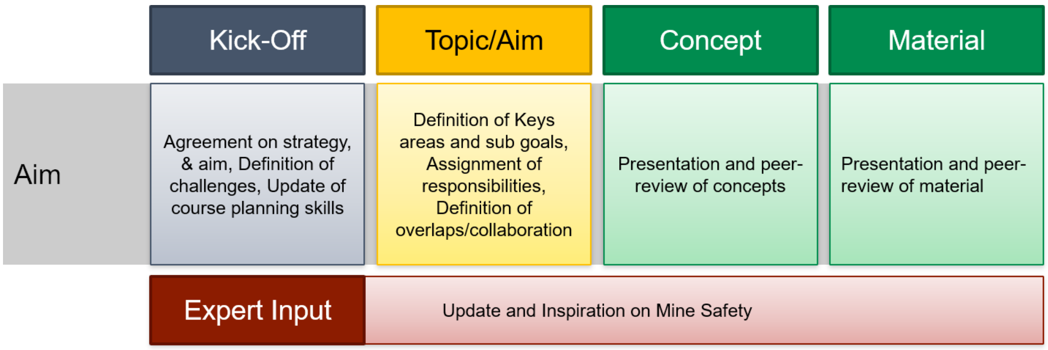

Figure 1: Adapted approach of course development according to (Binder et al., 2022)

Especially favorable for content development and interdisciplinary aspects is the collaborative course development approach, which was also carried out in the original concept. However, since many participants are experts in their respective fields, the "expert input" was consistently integrated into the course development process.

The diverse contributors encompass expertise in areas such as mining engineering, mine water management, historic and post-mining, geology, hydrogeology, water supply, urban water management, and didactics. Moreover, perspectives from both industry and academia are represented. Additionally, subject-specific didactic process guidance is provided through collegial exchange.

One of the developers has a distinctive role in this context. With a background in mining as well as environmental technology and resource management and a foundational didactic education, he is currently employed at Harzwasserwerke GmbH (HWW) coordinating research and development activities. As an external lecturer in the course, he infuses an industrial perspective into the course. Harzwasserwerke GmbH is the largest drinking water provider in Lower Saxony and ranks among the top 10 water suppliers in Germany. Stretching from the Harz region to Bremen, their integrated system serves approximately two million people daily, alongside numerous key industrial enterprises. This supply network relies on five reservoirs in the western Harz region and four groundwater works, that are operated and managed by them. Specific responsibilities of HWW, significantly amplified by the impacts of climate change, are located at two extremes: enhanced flood protection in case of heavy rainfalls and low-water discharge in case of extended dry periods. Furthermore, HWW's initiatives encompass the sustainable generation of electricity through the utilization of hydropower, reflecting their dedication to environmentally conscious energy production. Lastly, the HWW holds a special connection to mining by undertaking the responsibility of conserving the facilities of the Upper Harz Water Management System (Oberharzer Wasserwirtschaft), an integral component of the UNESCO World Cultural Heritage. This highlights their role in safeguarding and promoting a historically significant water-related mine heritage.

This multiplicity of stakeholders ensures a comprehensive and holistic approach to course development, allowing for the integration of diverse perspectives and specialized knowledge. This collaborative effort not only enriches the course content but also fosters an environment that promotes interdisciplinarity and a nuanced understanding of the subject matter. Through the amalgamation of various domains of expertise and the ongoing exchange among participants, the course development benefits from a rich tapestry of insights and experiences, ultimately contributing to a well-rounded and effective educational program.

3 Course Design

The teaching-learning activities and the exam need to be aligned with the intended course learning objectives. Focusing on the aims of the course in all stages of course design as followed by the course design approach enables the focus on an active student learning processes. Hence, the initial focus of the course design is on the definition of an overall learning object and the selection of topics and their connection as a base for the teaching-learning activities as well as the examination. The following sections on the different elements present the results of the design process.

3.1 Learning objective and thematic course structure

Future mining engineers need an in-depth understanding of the different 'types' of water and their qualitative and quantitative evolution throughout the mine's lifecycle to enhance future water management, making it more efficient, responsible, and environmentally conscious.

On this basis, the Intended Learning Outcome is formulated as

> "*The students can*
>
> - *illustrate the importance of water as a raw material in mining and the interdependencies within the lifecycle of a mine with regard to different deposits.*
> - *differentiate measures of water management for different deposit types and climatic conditions based on the specific net water balances.*
> - *select, combine, and adapt water managing strategies for a given simplified example to minimize the negative impacts of mining in terms of the environment and conflicts of stakeholder interests.*"

In the course, students learn that a modern water management plan goes beyond a spreadsheet-based approach and needs to be constantly reviewed and adapted to the life cycle of the mine. An advanced water management plan in mining encompasses a multifaceted approach that integrates several key components to ensure effective resource utilization and environmental responsibility as shown in Figure 2. Monitoring stands as a foundational pillar, involving the continuous assessment of water sources, usage, and quality. This ongoing scrutiny enables the timely detection of deviations from expected patterns and allows for swift corrective actions. Complementing monitoring is the incorporation of predictive methodologies, which leverage historical data and modeling techniques to anticipate potential fluctuations in water availability and quality. This proactive approach empowers mining operations to pre-emptively address water-related challenges, safeguarding against disruptions.

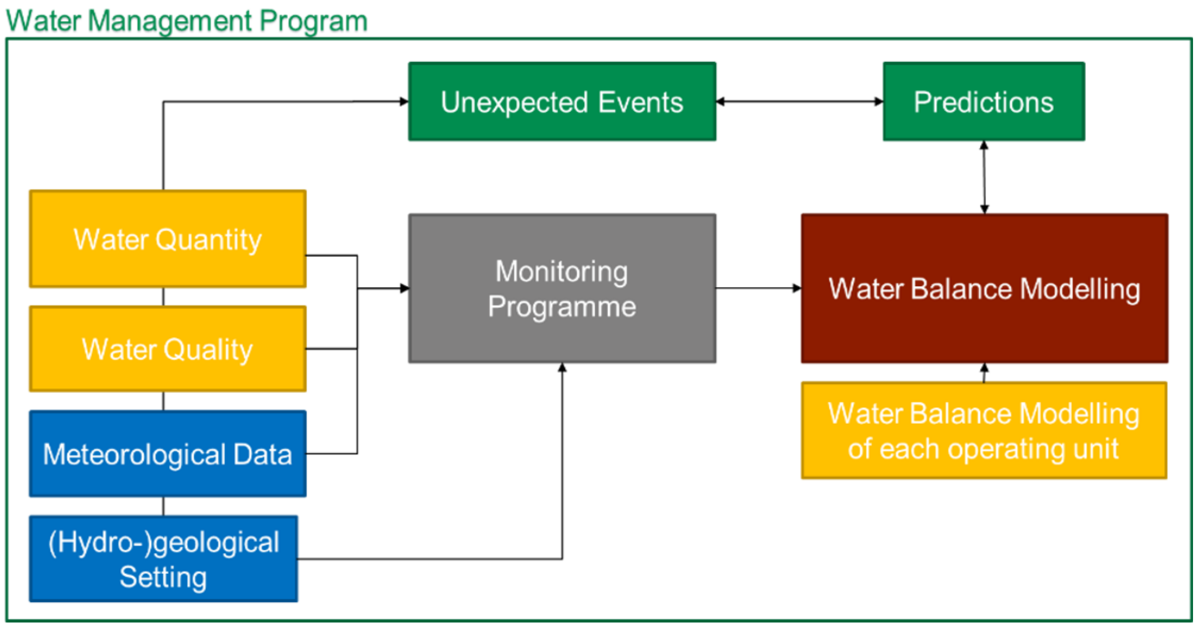

Figure 2: Components and Influences in Water Management Programs

Throughout the lifecycle of a mine, water management becomes a dynamic process that necessitates constant adaptation. The evolving role of water within each phase demands varying approaches to its management. This includes the ongoing need to revise and renew water management programs and associated permits (Punkkinen et al., 2016). As the mine progresses through its lifecycle, the shifting role of water underscores the necessity of addressing diverse aspects in its management. Therefore, the course content follows the structured framework of the five main phases of a mine, and recent and practical examples are used to illustrate the current state of water management as illustrated by the course overview illustration in Figure 3.

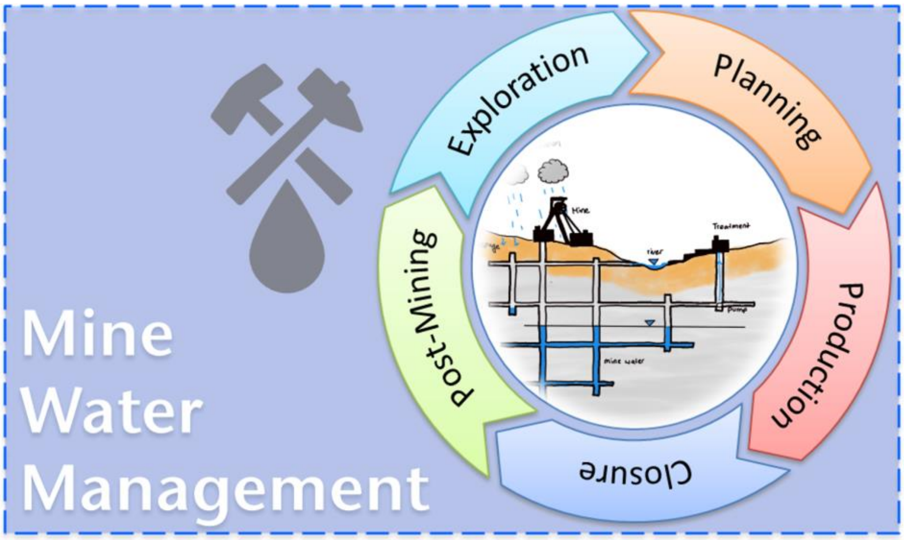

Figure 3: Primary structure of the course

In the exploration phase, the emphasis goes beyond permits to introduce contemporary technologies and methodologies. This involves exploring advanced techniques, such as integrating exploration wells into future monitoring frameworks and considering alternative applications.

Within the framework of the course, the planning phase encompasses a thorough consideration of pertinent aspects. This involves the integration of post-mining water management strategies right from the commencement, coupled with adaptations tailored to mining methods and the overarching mining infrastructure. Moreover, the course delves into discussions surrounding the identification of operational units with the highest water demands and the exploration of potential opportunities for implementing closed-loop processes. This is underpinned by the understanding that water requirements across various sectors within a mining operation differ, thereby necessitating a context-driven approach. Not only focusing on opportunities, the course additionally sets a focus point on water-related hazards, especially for deep mining. Case studies exemplify the theoretical potentials and hazards in operational reality.

During the production phase, a significant focus is directed towards the proactive handling and steadily adapted treatment of wastewater generated. Simultaneously, different potential uses of the water such as the control of blasting emissions and the reduction of dust dispersion are evaluated. As the production is planned in the previous stage, a special focus is set on the optimization of processes.

The chapter "Closure" is dedicated to the comprehensive understanding of mine closure, with a specific focus on inundation procedures. Within this context, a detailed analysis is undertaken concerning various processes associated with mine flooding, which are subsequently examined through illustrative examples.

This chapter constitutes a foundational component for the subsequent post-mining phase, during which an exploration of diverse environmental impacts, post-mining land utilization concepts, and options for passive water treatment are meticulously addressed.

In summary, the course provides mining engineering students with a thorough understanding of water dynamics throughout a mine's lifecycle, enabling them to innovate water management in mining. By grasping water's evolution, students can optimize strategies for various deposits and climates, fostering efficient and eco-conscious practices. Equipped with this expertise, graduates are prepared to pioneer adaptive, sustainable water management that balances mining needs with environmental preservation.

3.2 Teaching Learning Activities

A total of 28 contact hours are allocated for the teaching and learning activities. Various formats were considered for their implementation. Due to the competency-oriented approach, receptive methods with a teacher-centered focus, such as traditional lectures, were excluded. In the final selection process, a seminar-style approach in a workshop format and an inverted classroom approach emerged as potential options. In the inverted classroom approach, students primarily prepare based on videos, allowing the collaborative time to be dedicated to active engagement with the topics.

To ensure uniform learning progress and mitigate differences arising from varying levels of preparation, a seminar-based workshop concept was chosen as the over-arching approach. This approach is supplemented by an excursion to a location relevant to the Harzwasserwerke GmbH, serving as a pivotal element of the course and integrated as a case study. This excursion also effectively illustrates the different phases of mining activities.

The design of the workshops themselves is influenced by the teaching style of the individual instructor(s). Apart from considering the stages of the learning process through a didactic three-step approach, a multitude of activating methods are employed. These methods serve to engage students actively in the learning process, promoting a deeper understanding and application of the subject matter. By utilizing a mix of strategies that align with the learning objectives, the workshops aim to create a dynamic and participatory learning environment that caters to various learning preferences and styles.

3.3 Examination

The student's achievement of the learning objectives is assessed through an examination. To ensure a comprehensive assessment of the relevant competencies, a two-staged examination format has been designed, focusing on a novel, potentially fictional, case study. In this assessment, students are tasked with demonstrating their ability to analyze critical factors using the methods presented throughout the course. They are required to compile a comprehensive report addressing a specific task based on the provided case study. Additionally, during an expert dialogue with the examiner, students are expected to demonstrate their understanding, particularly regarding the intricate interdependencies within the given context.

The assessment process is guided by a segmented rubric. This rubric is constructed in alignment with the overarching learning objective established for the course. The broader learning objective is deconstructed into distinct components corresponding to different aspects of the examination. Criteria specific to each component are meticulously formulated to guide the assessment process. Importantly, this rubric is transparently communicated to the students at the outset of the course, ensuring clarity regarding the expectations and assessment standards.

By employing this rigorous assessment strategy, the evaluation process is closely aligned with the course's educational objectives. The case study-centered approach not only gauges students' theoretical comprehension but also evaluates their ability to apply acquired knowledge to real-world scenarios. Furthermore, the expert dialogue component of the examination not only allows students to showcase their comprehension but also promotes deeper critical thinking and engagement with the subject matter. Through the utilization of a segmented rubric shared with students, the assessment criteria remain explicit and consistent, contributing to a fair and transparent evaluation process.

4 Outlook & Conclusions

The detailed planning of the course is currently in progress, with the implementation scheduled for the winter semester of 2023/24. An accompanying evaluation plan has been devised to assess the attainment of the primary developmental objectives. This involves evaluating individual sessions with integrated approaches. Additionally, the university's systemic evaluation framework, as provided by the Clausthal University of Technology, is employed and augmented with a few specific inquiries. Drawing upon the experiences of instructors, evaluation outcomes, and examination results, a revision of the concept has been undertaken, with a subsequent implementation planned for the winter semester of 2024/25.

The approach presented exhibits several transferable aspects, including:

- The developed course design, along with its components, can be adapted for use at other institutions of higher learning.
- The thematic approach developed can be integrated into other courses with water-related themes, pursuing different avenues for implementing the overarching subject.
- The modified course development model can be employed for the creation of further instructional modules, concurrently equipping developers with qualifications. The reuse by program graduates, as seen in this instance, allows for the benefits of peer instruction to be harnessed.
- The competencies developed among participants are applicable in the development of future courses.

This holistic strategy showcases its potential for dissemination and replication across various educational settings, offering a flexible framework that can be tailored to address diverse academic requirements. The adaptable nature of the curriculum, the thematic methodology, and the developmental model underscores the broader impact and sustainability of this educational initiative.

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MINING REPORT Glückauf

Goslarsche Zeitung

TMR – Tactical Medical Mine Rescue

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Abstract

In mining and remote areas of resource industry, there has been a development towards lacking emergency medical first aid response, that creates a potential disadvantage for patients after work accidents and other medical emergencies compared to standard population. This is due to structural changes in mine rescue brigade coverage caused by transformation from formerly few major resource companies towards many small companies with a broad spectrum of company scopes in resource industry. This raises the question how a professional emergency medical coverage can be provided, taking into account lacking medical professionals in small resource companies combined with long rescue times. Facing this problem, new concepts of emergency medicine are necessary for these particular environments. Aiming on the closure of this gap, a team of the mine rescue brigade from the Research and Training Mine Reiche Zeche (Forschungs- und Lehrbergwerk (FLB) Reiche Zeche) of the TU Bergakademie Freiberg in Freiberg/Germany and its cooperating emergency department of the Freiberg District Hospital developed a totally new rescue concept using elements from tactical medicine and advanced emergency medicine combined with a specifically designed compact equipment and a highly standardized teaching curriculum.

1 Case Example 1

At 10:16 in the morning, a serious accident occurs in a fault zone at a depth of 800 m and 19 km from the shaft: During securing work, a fresh shotcrete shell comes loose from the ridge when the reinforcement mesh is placed on the anchor in the carriage. The shotcrete shell hits the mine worker on the drill rig arm in the head area (Figure 1). The man is pulled to the ground by the falling concrete mass and, in addition to a head laceration, suffers a deep lacerated wound to his thigh that is bleeding profusely. When the mine rescue team arrives, the casualty states severe pain in the area of the head and thigh. The wounds are provisionally covered with compresses and bandages, then the severely injured person is placed on the rescue stretcher. In doing so, vomiting of stomach contents occurs. After that, the injured man, who is now pale and covered with cold sweat, is transferred to the rescue stretcher when he becomes unconscious due to the traumatic brain injury. Furthermore, the already perfused wound dressing slips during the rescue measures causing a renewed increase in the previously unstopped bleeding. In recovery position, the unconscious man is transported in the emergency vehicle of the mine rescue team towards of the shaft. The arrival of the notified public rescue service in the mine is delayed due to safety-related briefings and various uncertainties and concerns on the part of the public emergency service regarding self-protection. At 11:10 a.m., 54 min after the alert, the life-threateningly injured patient is handed over to the public emergency service above ground. The casualty is now in hypovolaemic shock because of blood loss from the thigh and in acute oxygen deprivation by reason of aspiration of stomach contents into the lungs and insufficient spontaneous breathing. After a long course of intensive care therapy, he is finally discharged from hospital, permanently unable to work.

This fictitious scenario, with a seriously injured person in an underground mine, is intended to illustrate the medical challenges that the mine rescue service would face in such an emergency, the logistical problems that the civilian rescue service faces in the event of an accident in the mine and how this gap in medical care can affect the patient's medical outcome. In this context, there is a systemic health care disadvantage for workers insured by the employers mutual insurance association because of their work in remote environments with inadequately adapted emergency medical coverage.

1.1 Can we do better?

Yes, we can. Case example 2 describes how adequate care of the casualty by the mine rescue team might look like after completion of a two-day – now guideline-based – standardized training curriculum based on the fundamentals of tactical medicine and with available specific advanced but compact emergency equipment.

Figure 1: Accident during securing works in the mine (simulated scenario). Photo: A. Fichtner, F. Reuter

2 Case Example 2

After the arrival of the mine rescue team, the heavily bleeding thigh wound is quickly treated with easy-to-use and specific clot-activating dressings until the bleeding stops. To relieve the pain, the miners administer a strong and fast-acting painkiller to the casualty, which is applied through the nose. This enables comfortable positioning on the rescue stretcher with subsequent transport of the patient. After vomiting and loss of consciousness, the vomit is suctioned from the throat, the patient's airway is secured with a specific laryngeal mask and the mask is connected to the Oxylator FR 300 B for ventilator support. Using a cannula inserted into the sternum, the miners apply volume replacement fluid to stabilize the circulation and a drug to stabilize blood clotting. After less than 15 min, the casualty is ready for transport in the mine rescue team's vehicle under continuous pulseoxymetric monitoring. When the patient is handed over to the public emergency medical services, they find a stabilized patient that has been adequately and professionally treated according to the standards of emergency medical first aid and can be transferred to the next hospital without further measures, with a stable circulation, spontaneously breathing with respirator support and with a good oxygen supply (Figure 2).

Figure 2: Treatment according to TMR® concept (scenario with simulated patient). Photo: A. Fichtner, F. Reuter

3 Concept Development

Due to various structural developments in mining as well as organizational and medical peculiarities in underground emergency rescue, it was urgently necessary to develop new concepts to ensure sufficient emergency care and to adapt the corresponding guidelines for the German mine rescue system. The restructuring of the mining industry from large companies to many small operations with an extended spectrum also inevitably entails a reorganization of the mine rescue system. Highly staffed mine rescue units with attached medical rescue personnel, as they are still known from the former large-scale operations, are hardly kept available today.

This problem is aggravated by significantly longer rescue times underground compared to the civilian sector and thus a regular violation of the nationally accepted rescue times, which are 8 to 17 min depending on the respective state rescue service law. In the case of inadequate initial emergency care in the context of lay rescue, the delayed contact of the casualty with the public rescue service represents a serious risk to the patient and increases the risk of medical complications and a poorer medical treatment outcome.

In addition, public emergency rescue is not readily applicable to mining operations. The unsuitable equipment of the rescue service for hazardous areas and long transport distances, the lack of suitable means of communication, the lack of long-term respiratory protective devices as well as regulations of the professional associations for self-protection in hazardous areas enable emergency rescue underground by fire departments and public rescue services only to a very limited extent and on a voluntary basis. These facts are in enormous contradiction to the expected injury severity. Thus, the previously required level of qualification of company first aiders is no longer sufficient to guarantee adequate first aid for injured persons in the context of lay rescue.

Driven by the aim of closing this gap in medical care, a team of the mine rescue brigade from the Research and Training Mine – Reiche Zeche – of the TU Bergakademie Freiberg and the Central Emergency Department of the Freiberg District Hospital have developed a standardized training curriculum for mine rescue teams for emergency rescue underground and in hard-to-reach areas above ground. This course, which is unique for underground hazard conditions as well as for lay rescue, was awarded the Hans Werner Feder Prize at the annual conference of the German Society for Interdisciplinary Emergency and Acute Medicine in 2021. After initial skepticism within the relevant medical societies and also in the field of neighboring aid organizations with similar problems, it now faces major response.

4 Course Organisation, Legal Framework and Certification

After extensive legal examination and appropriate statements, including involvement of the respective administrative bodies of the mining industry, it was finally achieved to firmly implement the validated course concept in the ongoing training of mine rescue teams in Germany. Since 2022, training according to "Tactical-Medical-Mining-Rescue" (TMR®) has been part of the guidelines of the German Committee for Mine Rescue, with the aim of improving the level of competence and qualification of mine rescue teams and ensuring adequate medical emergency care until the arrival of public medical emergency services. Further, the guidelines for the organization, equipment and deployment of mine rescue teams now call for "validated, extended training in first aid designed for underground and mine-specific conditions" if medical care measures cannot be provided immediately by an emergency physician. In this context, the TU Bergakademie Freiberg acts as the training and certification body for TMR® and ensures the ongoing validation of the course and the appropriate didactic teaching of advanced emergency medical skills to medical laypersons, as well as the maintenance of the quality level of the training. In addition to the basic training and TMR® certification through the TU Bergakademie Freiberg, it is optional to be certified as a TMR® instructor after successful completion of a corresponding second level training course containing, for example specific elements of medical didactics. Repeated condensed courses are required every two years to maintain the level of competency. The extended emergency rescue by laymen is carried out on the legal basis of the entrepreneurial duty to ensure first aid in accordance with the General Federal Mining Ordinance (ABBergV) according to § 11 para. no. 4, the duty to provide first aid within the scope of emergency competence pursuant to the Criminal Code (§ 34 StGB) and the lack of underground competence and accessibility by the public rescue service (fire and disaster control laws of the federal states in Germany). Of course, once medical professionals are available, the emergency medical authority of the mine rescue team ends.

5 Course Content, Validation and Emergency Medicine Competencies

For the development of the course concept, the operational spectrum of the past years in mining rescue was evaluated, which predominantly records traumatologic emergencies and thus clearly differs from the operational spectrum of the public emergency services. A large part of those workers involved in accidents are seriously injured, some with life-threatening injury patterns. This caused the necessity to focus the training content on the treatment of severely injured patients as well. A training curriculum, didactically adapted to laypersons, sequentially teaches the practical skills of a specially developed condensed emergency medical treatment algorithm. The modified c-AVPU-ABCDE algorithm is shown in Figure 3. The algorithm includes assessment of an acute life threatening situation, resuscitation, hemostasis, stabilization of cardiovascular and respiratory function, pain management, reduction and splinting of fractures, body temperature preservation, transport positioning with fixed equipment, and options for drag and vertical rescue, including invasive ventilation. Within a maximum treatment time of 15 min, a patient can thus receive complete preclinical emergency care and be ready for transportation within the framework of the skills learned.

During the development of the treatment algorithm together with specific and extremely compact equipment, the demand for a high level of user safety as well as patient safety from the viewpoint of lay rescue was paramount. The aim is to provide a modern and rapid emergency rescue, taking into account the essence of current emergency medical guidelines, with a view to the best possible treatment outcome for the patient. For this purpose, established schemes from emergency rescue and tactical medicine were modified and used to create a separate logical chain of therapy that enables medical laypersons to safely handle and treat the patient without extensive prior medical knowledge on the basis of simple diagnostic results and clearly defined therapeutic measures. Hence, the specific practical skills to be applied in a step-by-step decisional tree, are taught in a realistic operational environment directly in the mine as part of a training course of 16 teaching units and are tested in realistic accident scenarios with simulated patients according to the Peyton scheme.

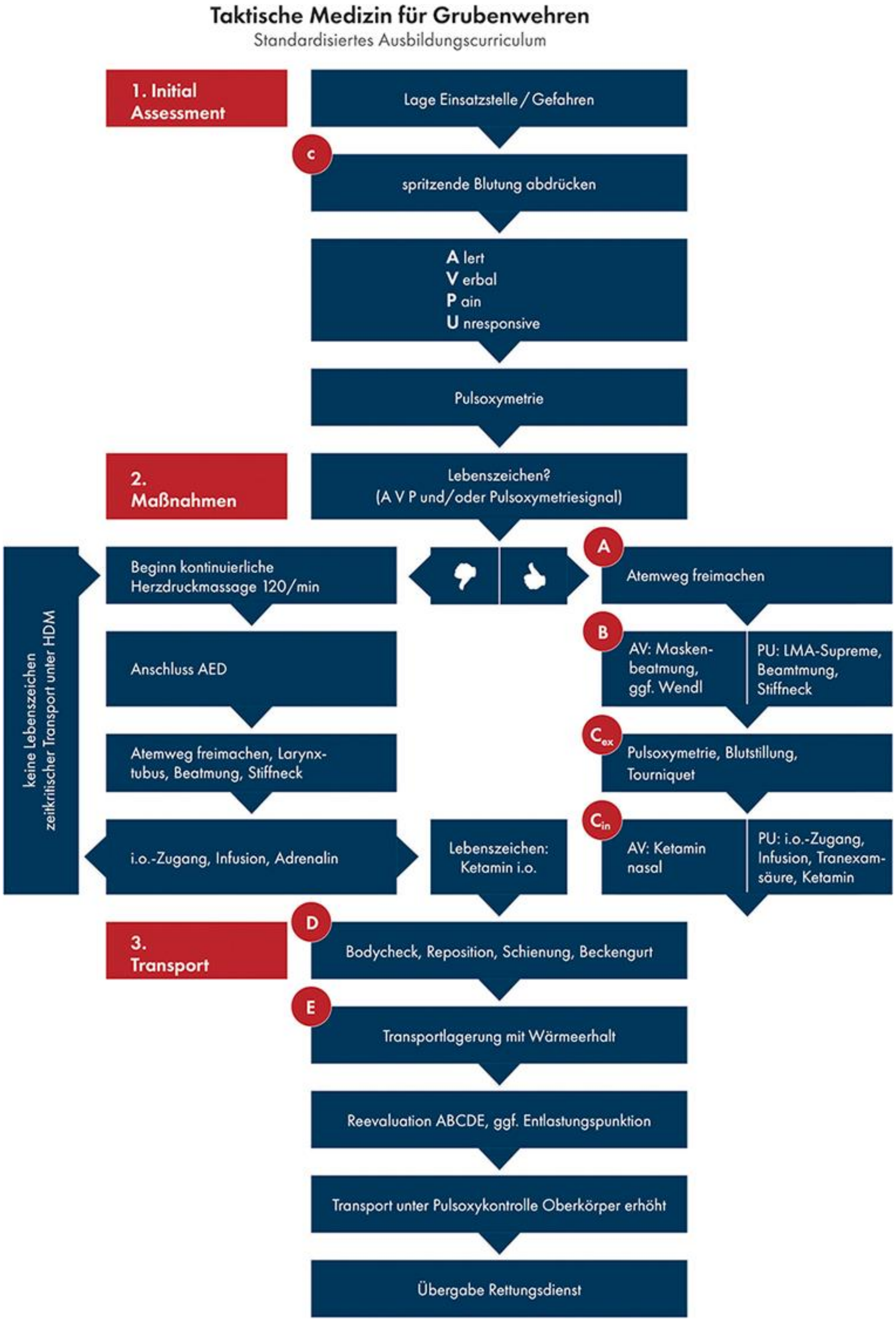

Figure 3: Summary of the TMR® deployment scheme at a glance. This scheme, with additional detailed information, is part of the TMR® equipment and serves as a valuable aid during the operation. Source: A. Fichtner, F. Reuter

At the end of the training, the course participants undergo a final examination at seven skills stations, which is conducted as an "Objective Structured Practical Examination" (OSPE). This ultimately demonstrates the acquired skills competence level and documents the course quality. In order to validate the course content and classify it in relation to the level of care of the public rescue service, randomly selected public rescue service personnel with different levels of training completed the identical OSPE examination. For this purpose, only the specific practical skills were tested while maintaining the working environment and equipment of the public rescue service. Within the clearly defined skills set of the TMR®-instructed mine rescue men, the final scores were statistically equal to professional paramedics of public emergency rescue services. Compared to the paramedic basic level subgroup, the mine rescue team achieved even better test results. In order to evaluate the quality of the acquired skills after several months, the identical participants of the mine rescue team were subjected to a new OSPE examination after a six-month exercise-free interval. This showed that the acquired medical skills could be applied sufficiently and without statistically demonstrable loss of competence even after six months. The comparison of the test results of the mine rescue teams with the reference group public rescue service and the subgroup basic level paramedics is shown in Figure 4.

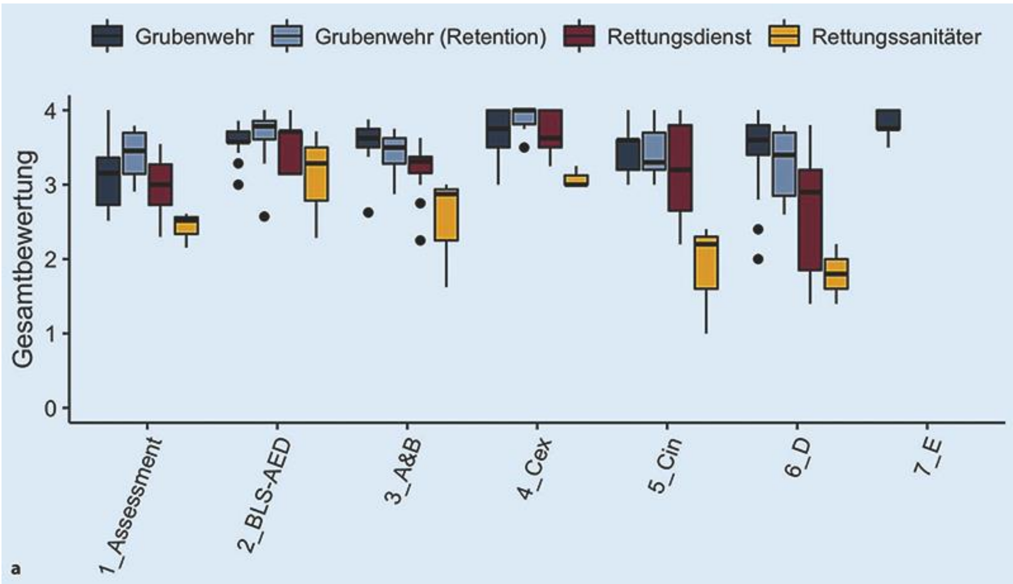

Figure 4: Validation results of the TMR® course compared to the public ambulance service (Med Klin Intensivmed Notfmed DOI 10.1007/s00063-021-00861-w). Source: A. Fichtner, B. Brunner

6 Equipment Configuration

During the development of the medical equipment, the specific underground environment was taken into account and the equipment was adapted according to the difficult operating conditions with wetness, dirt, narrowness, limited visibility conditions, potentially non-breathable atmosphere as well as long escape routes and special transport requirements. Compared to the regular rescue service, this resulted in a much more compact emergency backpack, which nevertheless covers the entire spectrum of operations in terms of the skills taught. In functional, removable pockets, the equipment is stowed in a logical sequence according to the treatment blocks (Figure 5).

Figure 5: Backpack (47 cm long) with included deployment scheme and equipment completely stowed except for the environment-specific stretcher. Photos: D. Müller, F. Reuter

When selecting the equipment, it was focused on easy and safe handling with a steep learning curve. The use of an exercise-intensive – and in the case of circulatory centralization often (even under ideal conditions) difficult to apply – peripheral venous access, for example, was avoided. Instead, for the administration of drugs and fluids an access (E.Z.-I.O. T.A.L.O.N., Teleflex) to the bony vascular system was used, which can be easily inserted at the sternum after short practice on the phantom. To minimize stress and forego the teaching of profound differential therapeutic expertise, the use of drug dosage calculations was omitted. Instead, the available drug dosage forms were selected from the point of view that a complete ampoule is always drawn up and administered for the care of adults. For airway protection, a Laryngeal Mask Airway Supreme (Teleflex) is used, which can be easily inserted by the user into the lower pharyngeal region with a final fit on the larynx and which fulfills the insertion and sealing properties required for the special operating conditions. For ventilation, the Oxylator FR 300B (Panomed) is used, a pressure-controlled semi-automatic and self-contained ventilator, the mine rescue teams are already familiar with. With the aid of a specially developed patient card, the mine rescue team can quickly and clearly document the detected injury pattern and the administered therapy, and hand over the patient to the public rescue service in a structured manner (Figure 6).

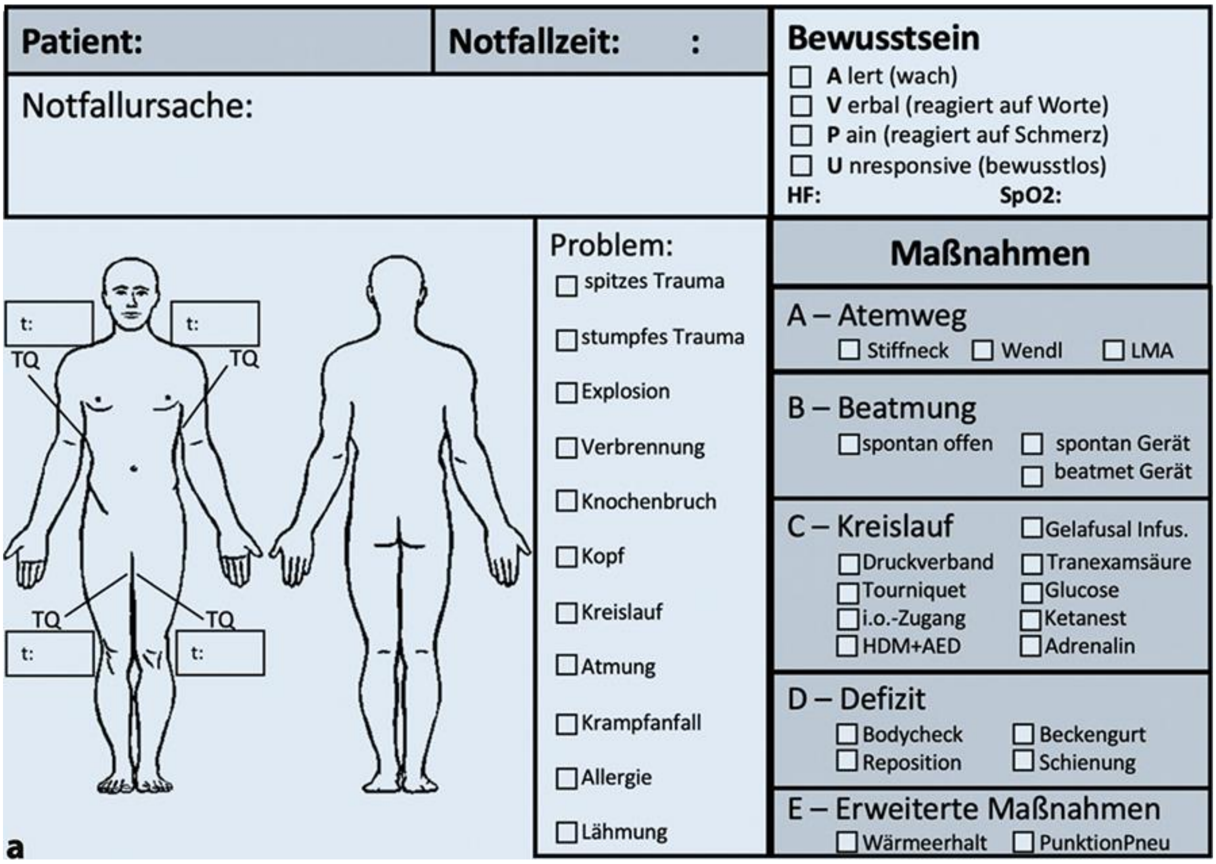

Figure 6: Measure documentation on A5 format attachment card (Med Klin Intensivmed Notfmed DOI 10.1007/s00063-021-00861-w). Source: A. Fichtner, F. Reuter

7 Quality Control

In order to control and maintain the quality level of the TMR® courses conducted in the individual companies, the respective examination results are always statistically evaluated and compared with the initial validation results. So far, the results of all participants, who successfully completed the course, were statistically without any difference compared to the study participants in the course validation (Figure 7). So far, practical utilization of the training content in real life-threatening accidents in mining has not yet been reported. However, the demonstrated skill development of the course graduates clearly shows the potential to close the gap of lacking professional emergency medical care in mining and remote areas of resource industry The TMR® concept has already been presented at several national and international conferences, such as the Annual Meetings of the Mine Rescue Teams, the Plant Fire Brigades Association and the German Social Accident Insurance Institution for the Raw Materials and Chemical Industry (BG RCI), Society for Mining, Metallurgy and Exploration Annual Conference and International Mines Rescue Body Conference.

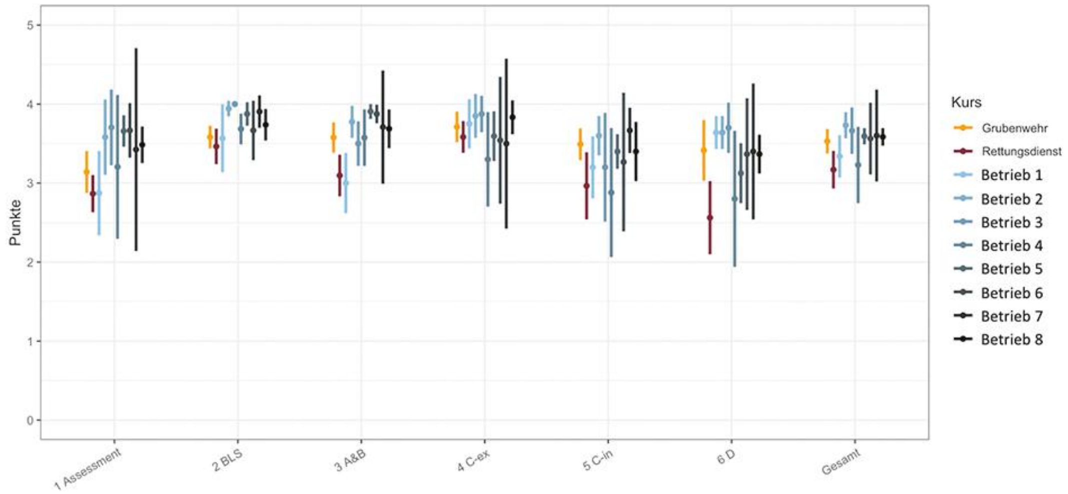

Figure 7: Ongoing continuous quality control of TMR® course results comparing OSPE results of the initial validation group with participants results from industry courses. Error bars represent the 95 % confidence interval. In companies with participants without mine rescue qualification, a broader variation of results is noticeable despite no statistical difference. This might be due to a less advanced mental model regarding the scope of human rescue. Source: A. Fichtner, C. Staak, B. Brunner

8 University Curriculum

In order to sensitize future mining engineers to a high value of responsibility with regards to health and occupational safety – already during their university education, the teaching of emergency medical and physiological backgrounds of the TMR® concept has been introduced as fixed part of the curriculum at the TU Bergakademie Freiberg from the winter semester 2022/23. This offering expands and supplements previous content on personnel safety such as the modules “Safety and Rescue Works in the Extractive Industries” and “Student Mine and Gas Safety Brigade”, which have already been offered for several years.

The four-part block lecture “Industrial Safety and Emergency Medicine for Engineering Professions” with a duration of two hours per semester week is currently offered in the Studium Generale and in the Diplomingenieur-programme “Geotechnical Engineering, Mining and Geo-Energy Systems (GBG)”. Furthermore, they are firmly integrated into the new Diplomingenieur-programme “Geoengineering” and here especially in the “Mining” specialisation, which will be introduced from the winter semester 2023/24.

The purpose of this lecture is to awaken the basic understanding of the necessity of a pre-emptive emergency medical secured work environment at an early stage, in order to provide the necessary information to the future responsible persons and decision makers, so that they can make necessary organizational decisions in their later area of responsibility with regards to staff safety and health. In addition to the positive evaluation results to date, the high demand by students and also employees reflects the relevance of the topic and shows the interest of future engineers in aspects of necessary emergency medical protection for personnel in their area of responsibility.

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Education challenges

From Lab to Market: Empowering PhD Candidates in the Raw Materials Sector through Entrepreneurship

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Abstract

The main objective of the Entrepreneurial Program for PhD Candidates is to train future talents for industry via organizing three PhD schools by providing 6 ECTS credits per education event. The Program will identify the doctoral students in the Baltic States (Estonia, Latvia, Lithuania) and RIS regions of Italy, Slovenia, and Slovakia and help them with commercialization and upscaling aspects of PhD students research development into business ideas in the field of sustainable materials.

1 Introduction

Our everyday life depends on the Raw Materials supply. That can be challenging for our industries to have the raw materials to produce the needed equipment for any sector that is important for our societies (security, defence, health care, etc). Therefore, the Raw Materials sector is continuously searching for new talents for the industry at any level.

For the PhD candidate level is important to educate the candidates for future challenges. How to be a successful PhD student? What skills and knowledge are the most valuable for the PhD student in the 21st century? The latest tendency in academia shows that being a successful PhD student is not always related to publishing. Throughout graduate studies, it is important to consider not only the growing importance of research and obtained findings but also to identify the needs of modern society and implement the practical use and commercialization aspect of the dissertation project.

2 The Needs of PhD Candidates on Research

Tallinn University of Technology (Estonia) together with partner universities Riga Technical University (Latvia), Kaunas University of Technology (Lithuania) developed an innovative entrepreneurship program designed specifically for PhD candidates in the raw materials sector.

This course program aims to empower and equip aspiring entrepreneurial minded PhD candidates with the necessary skills, knowledge, and resources to navigate the unique challenges and opportunities in the raw materials sector while fostering innovation and sustainable development.

PhD candidates need specific skills to develop their research work with high level peer-reviewed papers, and the commercialization of the research outcome is also important for the economy. Therefore the PhD candidates will increase their knowledge and experience, improve their networking in-between academic fields and industry on how to bring the research results to the market and do the commercialization and upscaling.

3 Entrepreneurship program

The entrepreneurship program for PhD candidates in the raw materials sector involves PhD candidates from any discipline because you need to build interdisciplinary teams to succeed in the raw material sector. For building successful teams, we need to educate PhD candidates on key components of entrepreneurship, and these skills can be used always also when they are doing their own research for a research project to defend their thesis. The entrepreneurship program consists of three PhD schools by providing 6 ECTS credits per education event (Table 1). PhD candidates get skills via specific task lists and assignments, which are commonly used in entrepreneurial education and will guide the PhD candidates trough the real building of the startup or spin-off.

Table 1: Entrepreneurship program with three PhD schools

School	Timing	Topic
Starting Summer School	June 2024	Market and the customer
Developing Autumn School	November 2024	The Business case
Investor Readiness Winter School	March 2025	Investor Readiness

Key components of the program include Interdisciplinary Approach (challenges and pains in the industry); Entrepreneurial Skill Development (market fit, the market size for the solution, interviews with potential customers etc.); Industry Collaboration (mentorship and incubation); Sustainability and Social Impact (ESG and SDG development goals). These key components are delivered via online course material, summer/autumn/winter schools (Table 1) and an incubation period after school (Figure 1).

Figure 1: Students in a lecture "Sustainability and Challenges"

To summarise, this Entrepreneurial program for PhD candidates seeks to drive technological advancements, promote sustainable practices, and unlock the economic potential of mineral resources. It aspires to create a new generation of entrepreneurial leaders who will shape the future of the raw materials industry, driving innovation, economic growth, and environmental stewardship.

4 Acknowledgement

The Entrepreneurial program development and first piloting is supported by EIT Raw Materials. The course structure, goals, aims, tasks, and assignments are developed together with partner organizations. The author would like to thank colleagues who have added the input to the syllabus: Vaida Morkunaite, Goda Kacilevičiūtė, Mindaugas Bulota from Kaunas University of Technology; Santa Krastiņa, Kristiāna Kārkliņa, Brigita Dejus, Davids Stebelis from Riga Technical University; Rainis Venta from Tallinn University of Technology.

Best practices of academia-industry collaboration in Spain and Peru: The case of the Epiroc University-Company Chair and the Hub and Spokes Model

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2 Universidad Nacional Mayor de San Marcos, Peru
3 Clausthal University of Technology, Germany
4 Epiroc, Peru

Abstract

Digitalization, automation, and sustainability have been moving forward in many industries, including mining, providing numerous benefits, but also challenges. These challenges involve not only to the industry, but also the academy since universities are responsible for updating the education and training of future mining professionals to the constant changes and new training profiles required.

It is due to the need for constant updating in the educational training of students that private companies must be active promoters of the approach to new trends and market needs.

Since 2018, the Universidad Politécnica de Madrid has implemented the Epiroc University-Company Chair which involves the committed participation of Epiroc in an elective lecture in cooperation with the university which has increased the skills of the students and strengthen the relationship with the industry.

In 2021, the Universidad Nacional Mayor de San Marcos not only adopted the Spanish model but also developed it to a Hub & Spokes model of collaboration between industry and academy as an action to integrate a network of universities. This collaboration model has already enabled eight universities in one country to develop a massive online course on Mining Technology. The collaboration is not only closed to the student participation in one lecture but also on master classes by top-notch industry experts and even promoted an international network of collaboration with Ecuador and Colombia.

This paper aims to highlight the development process, requirements, challenges and impact such collaboration model has brought to both the industry and academy participants from the experience of both countries Spain and Peru.

Integrating interdisciplinary projects in engineering curriculum

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Abstract

One of the challenges graduates face in the workplace is communicating and working in teams with internal and external customers coming not only from different fields but also whose viewpoint or objective is completely different. In order to address this issue in the Department of Engineering and Industrial Design at Magdeburg-Stendal University of Applied Sciences, a compulsory interdisciplinary project was introduced into the engineering curriculum. The objective is to teach students from different academic programs how to work together to reach a common goal. Depending on the respective field, each student uses different language, thought processes, methodologies, and tools. On top of that come the individual personalities that will need to work together. From a didactic perspective the actual content of the project is secondary to the soft skills and team skills being acquired. While students have regular meetings with academic advisors, they are on their own in the project group with regards to how to organize meetings, tasks, documentation, etc. At certain points of the project students are required to give short presentations, an exercise in pitching their ideas. In the end, students can make those critical first mistakes when working in complex groups but in a safe environment. Integrating this type of project work in the curriculum gives graduates an advantage when entering the workforce.

Challenges and opportunities in making the educational offer more attractive at the Faculty of Geoengineering, Mining and Geology of Wroclaw University of Science and Technology

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Abstract

A trend of decreasing interest in mining engineering studies has been observed at Polish universities in recent years. This happens in spite of the major metamorphosis connected with the sustainable development concept and new technologies applied in the world mining industry. The challenge of this discrepancy was the reason why the Faculty of Geoengineering, Mining and Geology of Wroclaw University of Science and Technology undertook various activities aimed at modifying the curricula and developing new study programs to make the educational offer more attractive for students, as well as adapting it to the dynamically changing, sustainable and technologically advanced global raw materials industry. Furthermore, newly developed curricula are designed to fulfill market requirements over the next decade. At the Faculty, during the last two years, five new study programs in different fields of study have been developed, these are: Geoinformatics, Geothermal Energy Engineering, Raw Materials Engineering, Applied Geology and Occupational Health and Safety. These changes contributed to the increase in the number of candidates who applied for the first year of studies by approximately 300 %. A great emphasis is also placed on enhancing the internationalization of studies. These activities are mainly possible thanks to the international cooperation with leading centers in Europe through the implementation of educational projects co-financed by the European Institute of Innovation and Technology (EIT) and EIT Knowledge and Innovation Communities Raw Materials (EIT RM). Projects implemented in recent years at the Faculty of Geoengineering, Mining and Geology include: CEDF, CEE-SIMP, GEOSUSTAIN, OpenYourMine, MOBI-US, TIMREX, RIS Internship, MEITIM, ALCASIM. These international educational projects helped to develop new innovative teaching methodologies and course contents focused on sustainable development, circular economy as well as on new digital technologies, not to forget about soft skills such as communication, management, innovation and entrepreneurship.

Defining the Mining Engineering Graduate of the Future – Mining Engineering Education Within the European Union Vs. Industry Demands and Challenges

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Abstract

In a holistic approach, using qualitative and quantitative data, the mining engineering graduate of the future is pictured according to the requirements and future challenges of the raw materials industry. To realize the goals of the Paris Climate Agreement, European Green Deal, and sustainable development, critical raw materials (CRMs) are required and crucial for a great variety of strategically important branches, applications, and goods that define our modern everyday life. While the demand for CRMs is anticipated to surge dramatically in the near future, the EU's own supply of most CRMs is alarmingly low. Strongly dependent on imports from many quasi-monopolistic supplier countries, the EU is currently left in an economically and strategically unfavourable position. To satisfy the increasing raw materials demand and to strengthen the EU's competitiveness and strategic resilience against countries outside the EU, a boost in (local) raw materials production and skilled mining engineering graduates, educated according to the principles of environmental and social sustainability to plan and operate the mines of the future, are required. Therefore, courses within mining engineering education offered by universities in the EU are being evaluated on undergraduate (Bachelor's) and graduate (Master's, Dipl.-Ing. and Diploma) level, with a focus on the implementation of contents related to future challenges of the raw materials sector. In a mixed methods approach, the key areas of interest (of the modules) are being summarized, presented and discussed with experts from the mining industry. Based on expert interviews an online survey on mining engineering education was initiated. Finally, the quantitative and qualitative information is used to define the mining engineering graduate of the future.

1 Introduction

Every three years since 2011, the European Commission has released a criticality list of non-energy and non-agricultural raw materials. Access to critical raw materials is vital for technological advancements and an improved quality of life. However, the number of materials declared as critical is continuously increasing. The criticality list in 2011 included only 14 CRMs, but as of 2023, it has grown to over 34 raw materials. [1] Currently, less than 3 % of CRMs are produced in Europe, jeopardising EU climate and sustainable development goals, especially in the light of geopolitical conflicts and global pandemics. [2] The ongoing difficult situation between Russia and Ukraine has exacerbated the economic instability of the EU, and disruption introduced by the worldwide COVID-19 pandemic. The EU is currently encountering food and energy crises, impaired trade relations, elevated inflation, and reduced economic growth rates while being dependent on quasi-monopolistic supply chains of raw materials. [3] Although the circular economy may partially contribute to the supply of CRMs, it is far from adequate given the substantial growth in demand anticipated in the next decades (up to 10 - 20 times), necessitating a boost in EU-level raw material production. [2] As the raw-materials supplier to the economy, the mining sector must grow at an unparalleled rate to provide for the required technological shifts, regardless of its traditional reputation as a time consuming, highly capital-intensive industry [4]. To meet the needs of novel technologies, such as electric vehicles, a minimum of 74 new mines will be necessary by 2035, assuming each mine produces an average of 45000 metric tons of Lithium per year [5]. While the demand for raw materials is accelerating mining engineering graduates prepared for the future challenges of the raw materials sector to operate the mines of the future are required. In the form of numerous efforts to reduce foreign dependency on resources and to enable a digital and equitable future, EU projects such as NetHelix [6], Mine.IO [7], and AGEMERA [8] are worth mentioning as examples, while AGEMERA is involved in developing higher educational institution courses to increase awareness on Critical Raw Materials (CRMs) and their significance in our everyday way of life [9].

2 Methodology

To develop practical mining engineering education, it is imperative to ascertain the future challenges faced by mining companies and the corresponding requirements for training future mining engineers. This is particularly relevant in terms of Mining 4.0 and sustainability. Therefore, in a mixed methods approach, companies of the mining industry have been involved in discussing the issue. To achieve the goal what the mining engineering graduate of the future shall look like, the approach was undertaken in four phases, illustrated in Figure 1.

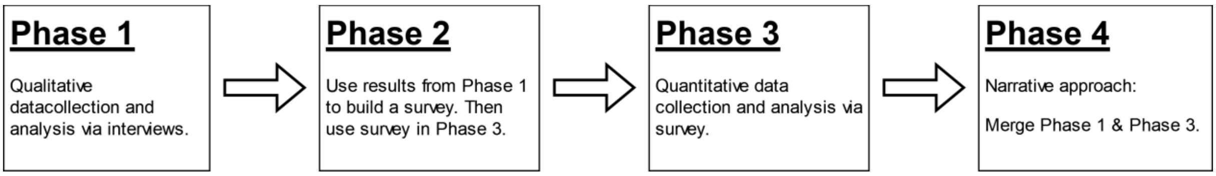

Figure 1: Conceptual steps of the methodology followed to develop a complex intervention, adapted from [10]

The mixed methods approach describes the combination of collecting quantitative and qualitative information. While quantitative methods offer precision and reliability in the context of an analysis and are particularly suitable for analysing large data sets and testing hypotheses, they lack the ability to perceive implicit findings "between the lines". [11] In combination with information on mining engineering courses offered within the EU dealing with the challenges of tomorrow and expert interviews to capture non-quantifiable relationships that exist beyond mere numbers, an online survey was prepared, aimed towards the mining industry.

2.1 Preparation of Information on Mining Engineering Education

In preparation on the following phases, data on various mining programs within the EU was collected, serving as the basis for the contents of the semi-structured interviews and the online survey. The individual course categories currently offered on future oriented topics were summarised and are displayed in Table 1. The data collection was limited solely to programs that can be classified as "Mining Engineering". For this purpose, a Google search was conducted for study offerings in each EU country using the key word "mining engineering". Bachelor's, Master's, and Dipl.-Ing. degrees were considered, while doctoral programs were excluded. Often, it was not clear whether a study program was indeed “mining engineering”, just merely related to "mining engineering" or “mining engineering” but under a different terminology. Therefore, at EU level, several universities that provide courses in the field of "mining engineering" or similar were contacted for clarification (illustrated in Table 1).

Table 1: Questions for universities offering mining engineering education

Questions for the contacted universities	
Nr.	Question
1	Does the overview include any study option(s) you wouldn't classify as “mining engineering”?
2	Is/Are there any study program(s) [also only available in your local language] that you would categorise as “mining engineering” that is/are not listed in the overview?
3	If you answered question Nr. With yes, what is/are the names of such study program(s)? Could you provide me with a link to the program(s)?
4	Regarding question 3: Is/Are the (mentioned) study program(s) available in both English and the local language?
5	What other university/ universities in your country do you know of that offer(s) (a) study program(s) in the field of “mining engineering”?

2.2 Phase 1: Expert Interviews

During Phase 1, experts from various mining companies were interviewed (face-to-face, online, or by telephone). The use of different interactions allowed for a diverse range of perspectives to be captured. Per definition experts are seen as personas (involved in the mining sector) who can demonstrate either theoretical knowledge (epistemic expertise) or practical experience (performative expertise) [12]. Although there are different views on how an expert interview should be structured, it is generally regarded as a special type of guided interview for analysing phenomena and processes at meso and macro level [13, pp. 175-190]. The guided interviews were semi-structured and took between 30 to 60 minutes each, depending on the interviewee's enthusiasm. Questions were formulated beforehand, but in no fixed number or order. Semi-structured means that all relevant information and opinions of the participants should be captured, but at the same time there should be room for the interviewees' own narratives, whereby the order of the questions may be left [14]. The different interview topics were developed through an iterative process, with the proposed technique of [14], serving as a guide. This means that prior to the expert interviews, questions were formulated, and systematically arranged tests were carried out with participants from the Institute of Mining and Special Civil Engineering at TU Bergakademie Freiberg. The questions were then used in the interviews with industry experts. Following each interview, the questions underwent reassessment as part of an iterative process. Promising subjects, which were not previously included in the questions, were transformed into new questions for subsequent interviews. The research method reached saturation when no new significant insights could be gained in the final iteration [15, p. 27]. As there were no new question topics identified during the eight interviews, it was deduced that there are five primary categories for question topics, which were subsequently divided into subcategories. These categories and subcategories are displayed in Table 2.

2.3 Phase 2: Online Survey

A total of 60 individual companies of the raw materials sector were invited to participate in an online survey, which was distributed in the form of personally addressed e-mails. The questions of the online survey which resulted from the expert interviews had in many places predetermined answers while in other places open questions were integrated.

Table 2: Questions of the semi structured interviews and online survey

Nr.	Topic	Subtopic	
1	Basic information about the respondent	1.1	What is your status of employment?
		1.2	How many years of professional experience do you have?
		1.3	What management position do you have in your company?
2	Basic information about the company of the respondent	2.1	In what field(s) is your company active?
		2.2	What is the number of employees of your company?
		2.3	Where is your company active?
3	Employment of mining engineers	3.1	Does your company occupy at least one mining engineer?
		3.2	Is your company planning to hire a mining engineering graduate withing the next five years?
		3.3 - 3.4	What position could a recent mining engineering graduate receive in your company?
		3.5	Should a mining engineering graduate do a Master's after his Bachelor's degree?
		3.6	Is a mining engineer a generalist or a specialist?
		3.7	What is your definition of a mining engineer?
		3.8	What are you looking for when hiring a mining engineering graduate?
4	Higher education of the mining engineer	4.1	What challenges of the future are of highest relevance for your company?
		4.2	How much do you agree on the following statements regarding the integration of courses into mining engineering education?
		4.3	How should the following topics be included in higher education mining engineering courses?
		4.4	Were do you see additional challenges?
		4.5	How could your company contribute to making the education of a mining engineer as practically oriented as possible?
5	Additional comments	5.1	Feedback and comments?
		5.2	Are there any additional aspects that should be addressed?

3 Phase 3: Combined Results

After just four days, the response rate dropped significantly and after a week there were no further responses to the online questionnaire. Therefore, a preliminary conclusion was conducted following the participation of a total of 35 individuals.

The qualitative answers were recorded, paraphrased and assigned to a corresponding upper- or lower-level topic (previously displayed in Table 2), using anchor examples. The results of the expert interviews and the online survey were condensed and are presented in the following tables, with the most significant results highlighted in bold.

Table 3: Summary of expert interviews (EI) and online survey (OS)

Nr.	Question	Answer	Interviews	Online survey
1	Basic information about the respondent			
1.1	What is your status of employment?	Employed	6 ppl.	75.76 %
		Self-employed	2 ppl.	21.21 %
		Retired	None	3.03 %
1.2	How many years of professional experience do you have?	over 50 years	None	9.09 %
		40 - 49 years	None	9.09 %
		30 - 39 years	2 ppl.	42.42 %
		21 - 29 years	2 ppl.	12.12 %
		11 - 20 years	1 p.	9.09 %
		8 - 10 years	1 p.	6.06 %
		4 - 7 years	2 ppl.	9.09 %
		1 - 3 years	None	3.03 %
		< 1 year	None	0.00 %
1.3	What management position do you have in your company?	Upper	5 ppl.	63.64 %
		Middle	2 ppl.	30.30 %
		Lower	1 p.	6.06 %
2	Basic information about the company of the respondent			
2.1	In what field(s) is your company active?	Shaft Design & Construction, Mine rehabilitation; Supply of mining consumables; Automation of mining processes; Consulting; Extractive sector	Exploration of deposits; Production of mining machinery and equipment; Supply of mining consumables; Tunnelling; Shaft Design & Construction; Underground mining; Surface mining; Processing and refinement of raw materials; Energy sector; Research and development; Government/authorities; Associations; Consulting; Communication and publishing industry, as well as Other	
2.2	What is the number of employees of your company?	over 5000	3 ppl.	14.71 %
		2000 - 4999	1 p.	2.94 %
		1000 - 1999	2 ppl.	5.88 %
		500 - 999	None	14.71 %
		≤ 499	1 p.	23.53 %
		≤ 40	1 p.	17.65 %
		≤ 10	None	20.59 %
2.3	Where is your company active?	only Germany	None	50.00 %
		Internationally	All	50.00 %

3	Employment of mining engineers			
3.1	Does your company occupy at least one mining engineer?	Yes	All	91.18 %
		No	None	8.82 %
3.2	Is your company planning to hire a mining engineering graduate within the next five years?	Yes	All	58.82 %
		No	None	11.76 %
		I do not know	None	29.41 %
3.3 - 3.5	Should a mining engineering graduate do a Master's after his Bachelor's degree?	Yes	7 ppl.	86.21 %
		No	None	6.90 %
		It depends	1 p.	6.90 %
3.6	Is a mining engineer a generalist or a specialist?	Generalist	7 ppl.	72.41 %
		Specialist	None	20.69 %
		It depends	1 p.	6.90 %

The interviewees as well as the participants of the online survey were asked to provide their definition of a mining engineer. Examples of the responses are presented in Table 4.

Table 4: Answer samples from question 3.7 "What is your definition of a mining engineer?" (EI+OS)

3.7 "What is your definition of a mining engineer?"	
Professional Competence	Personal Attributes
• Generalist possessing knowledge of classical extraction methods and capable of adapting them to new challenges using advanced technologies while also exploring alternative approaches (to resource extraction) • Background in natural and geological sciences, comprehensive understanding of mining tasks • Familiarity with underground and surface mining, knowledge of specialized underground construction techniques, degree in Engineering • *... and more*	• Proactive individual • Strong analytical skills • Leadership qualities • Adaptive learner • Willingness to get hands dirty • Innovator & Creativeness • Open-minded • Collegial • Humility (towards tradition) • Enthusiastic; Adventurous spirit; • *...and more*

Additionally, the priorities of respondents in hiring a mining engineer were discussed. Table 5 displays selected findings from both expert interviews and the online survey.

Table 5: Answer samples from question 3.8 "What are you looking for when hiring a mining engineering graduate?" (EI+OS)

3.8 "What are you looking for when hiring a mining engineering graduate?"	
Professional Competence	Personal Attributes
• Sound education in mining prospecting and delineation of deposits, mine planning, rock mechanics, mining and conveying technology, ventilation, management of processing residues, basics of cost estimation (CAPEX and OPEX) for mining projects, fundamentals of economic evaluation of mining projects, sales, and business administration. Software: Mine planning software, AutoCAD or equivalent, MS Office, fluent in English • Solid education and (technical) expertise • Practical experience • Comprehensive knowledge ranging from permits to extraction, processing, • Ability to delve into other areas • ... *and more*	• Willingness to perform and learn, communication skills, teamwork, foreign language proficiency (English) • Flexibility regarding travel, resilient, clever • Etiquette, especially in an international context • Willingness to invest effort and learn, vocational interests, comfortable with interpersonal interactions • Interest, openness, IT, multilingualism • Dedication / commitment / willingness to tackle challenges • Ability to work independently, quick grasp of concepts, good communication skills • Languages: German and English, additional languages are welcome • Resilient, enduring, strong character • Precise usage of correct terms • Teamwork – basic project management and organization skills – flexibility, self-initiative • ... *and more*

Based on the previously examined study offerings within the EU, various challenges of the future were identified, that are currently being addressed in mining engineering education. The online survey participants were instructed to rate the importance of these challenges for their respective companies on a scale of 1 - 5, as seen in Table 6.

Table 6: Answers from question 4.1 "What challenges of the future are of highest relevance for your company?" (OS)

4.1 "What challenges of the future are of highest relevance for your company?"	
Category	Average Rating
Social skills, for example interaction with employees or customers	4,32
Environmental protection; impact assessment / life cycle assessment	4,09
Sustainable corporate management	3,96
Social acceptance and stakeholder involvement	3,88
Approval and planning procedures	3,70
Recruitment of new talent	3,64
Internationality and globalization	3,62

Risk assessment, crisis & health management, safety and rescue operations	3,62
Groundwater management	3,59
Circular economy, sustainable development in the raw materials sector	3,59
New extraction technologies	3,57
Post-mining, land reclamation, and after-use concepts	3,44
Cybersecurity	3,40
Treatment, handling, and recycling of mining residues and contaminated sites	3,35
Automation in the raw materials sector	3,32
Labor law and responsibility in mining	3,31
Renewable or alternative energy sources	3,26
Use of (mining) software	3,24
Artificial intelligence	3,15
Digital twins	3,07
Explanation: 1 = No relevance; 2 = Low relevance; 3 = Relevant; 4 = High relevance; 5 = Highest relevance	

After question 4.2, participants were tasked with rating their level of agreement with statements relating to the integration of future challenges on a scale ranging from 1 - 5 (displayed in Table 7).

Table 7: Answers from question 4.2 "How much do you agree on the following statements?" (OS)

4.2 "How much do you agree on the following statements?"		
Statement	N	Average Rating
Key areas of interest regarding future challenges should be offered as specialisation	28	3,96
Universities should provide interested students with opportunities for further education on future challenges outside of their curricula (for example Massive Open Online Courses, Micro Credentials / Micro Degrees)	28	3,86
Mining students should have various mandatory modules in which mining-specific key areas of interest regarding future challenges are explored in depth	32	3,66
Mining students should have the option to choose from different elective modules in which mining-specific key areas of interest related to future challenges are explored in depth	33	3,06
Integrating the basics of future mining-specific challenges into existing modules or courses of mining education is sufficient	33	2,73
An introduction to future mining-specific challenges is sufficient	33	2,06
Explanation: 1 = Do not agree at all; 2 = Do not agree; 3 = Neither agree nor disagree; 4 = Agree; 5 = Agree completely		

Subsequently, the online survey participants were requested to classify the recommended future topics, expressing whether they should not be incorporated into the curriculum at all, only as fundamental components within current modules, as optional or mandatory modules, or as specializations. The results can be seen in Table 8.

Table 8: Answers from question 4.3 "How should the following topics be included in higher education mining engineering courses?" (OS)

4.3 "How should the following topics be included in higher education mining engineering courses?"					
Topic	A)	B)	C)	D)	E)
Environmental protection; impact assessment / life cycle assessment	0	6	3	17	0
Social skills, like interaction with employees or customers	3	6	3	12	2
Risk assessment, crisis- / health management, safety and rescue operations	0	6	5	12	3
Approval and regional planning procedures	0	6	6	12	2
Groundwater management	0	5	5	11	5
Labor law and responsibility in mining	1	9	3	10	2
Post-mining, land reclamation, and after-use concepts	0	4	9	10	3
Social acceptance and stakeholder involvement	4	7	4	9	2
New extraction technologies	1	6	6	9	4
Treatment, handling, and recycling of mining residues and contaminated sites	1	4	9	9	3
Handling of (mining) software	1	1	14	8	2
Cybersecurity	3	8	5	7	3
Sustainable corporate management	4	3	9	7	3
Internationality and globalization	2	11	7	4	2
Renewable or alternative energy sources	2	6	12	4	2
Automation in the raw materials sector	1	6	12	4	3
Circular Economy, sustainable development in the raw materials sector	1	2	12	4	6
Digital twins	3	6	11	3	3
Recruitment of new talent	5	5	11	3	1
Artificial intelligence	3	5	15	0	3
Explanation: Concept A): Not at all; B): Integration of basics into existing modules; C): Optional course; D): Mandatory course; E): Specialization					

The participants of the online survey and the expert interviews were asked how their companies could contribute to making the curriculum as practically oriented as possible. In summary, the following suggestions (depicted in Table 9) were synthesised.

Table 9: Summary of answers regarding question 4.5 "How could your company contribute to making the education of a mining engineer as practically oriented as possible?" (EI+OS)

4.5 "How could your company contribute to making the education of a mining engineer as practically oriented as possible?"
• Involvement in networks and associations • Collaborations in recruitment • Thesis projects; Practical assignments • Internships • Guest lectures from the industry • Project participation • Specialized joint events and lecture series

4 Conclusions

As a result of an evaluation of mining engineering courses within the EU, expert interviews and an online survey, industry needs were derived, thus indicating possible trends in the training of future mining engineers.

It was repeatedly mentioned in the expert interviews and the online survey that a mining engineer's expertise is founded upon his wide-ranging knowledge of theoretical and applied fundamentals on natural sciences, mathematics to mining-specific engineering. With his scientific and analytical background, a mining engineer is able to identify problems and their sources, categorize them professionally, and develop solutions, considering various approaches. Thus, the mining engineer will remain a generalist in the future [online survey (OS): 72.41 % agree; expert interviews (EI): 7/8 agree], with a "true" specialization typically occurring later on during the professional career (EI: 8/8 agree). Even though a mining engineer is a generalist, he should be able to pursue various opportunities for further education during his studies, in line with the industry's (future) challenges. These opportunities comprise specializations (OS: average rating 3.96/5), extracurricular education such as micro degrees (OS: average rating 3.85/5), and compulsory courses (OS: average rating 3.66/5). Regarding future challenges, it was found that including only the basics in existing mining-specific modules (OS: average rating 2.73/5), or solely offering introductory events on the subjects (OS: average rating 2.06/5), was considered insufficient. Survey participants were given the chance to link different challenges of the future with integration options for the mining engineering syllabus. Subjects such as "internationalisation and globalisation", "labour law and responsibility in mining", "cybersecurity", "social acceptance and stakeholder involvement" and "digital twins" were the most frequently selected topics to be potentially integrated into existing modules. Among the compulsory optional courses, the top five included subjects such as "artificial intelligence", "use of (mining) software", "renewable or alternative energy sources", "automation in the raw materials industry" and "circular economy and sustainable development in the raw materials sector". The topic of "environmental protection, impact assessment / life cycle assessment" was selected most frequently, in terms of necessity for integration as a mandatory module. The Top 5 mandatory topics include as well “approval and regional planning procedures”, "risk assessment, crisis management, health management, mine safety and rescue" and "social competencies for example interaction with employees or customers". For developing a field of specialization, subjects like "circular economy, sustainable development in the raw materials sector", "groundwater management", "new extraction technologies", "risk assessment, crisis management, health management, mine safety and rescue", and "Post-mining, recultivation and after-uses" were among the top choices. Regarding potential fields of study, experts recommended focusing on comprehensive thematic complexes based on potential professions or career paths after graduation, or the interests of potential employers. The mining engineer of the future should, therefore, receive the necessary foundation through their education to develop solutions for problems related to equipment, processes, methods, or projects within the mining field, based on the current state of science and technology and the requirements of his employer. This entails contemplating progressively intricate technical, social, health or safety-related, ecological, legal, and economic aspects, which specialists see as key challenges of the future. Possible positions for a recent graduate within a company were frequently mentioned as “assistant to the board of directors”, “junior sales engineer”, “area or site manager” or “project manager”. A mining engineer should aim for a higher degree (Master's or Dipl.-Ing.) (OS: 86.21 % agree) and take time to deepen his professional knowledge during his studies (EI: 6/8 agree). Additionally, when asked what to look for when hiring mining engineers, it was noted that striving for a higher degree is in most cases of advantage for a graduate, but the degree itself is not the sole significant factor. The overall impression matters encompassing aspects as mining specific expertise, practical and international experience, social competencies, and language skills. Both the online survey and expert interviews highlighted the necessity for mining engineers to be competent in mining terminology and their meanings in their native language, as well as in English, with 50 % of online survey participants indicating that their companies operate in at least one country outside of Germany. A mining engineer may assume a leadership role following graduation and consequently have personnel responsibilities (EI: 6/8 agree). Skill in interacting with staff or clients (OS: 4.32/5) were crucial, along with knowledge on sustainable business practices (OS: 3.96/5). These two categories were among the Top 3 challenges for the surveyed individuals. Hence, the mining engineer of the future should be capable of operating in an internationally oriented and multicultural team, encompassing various (age) groups and areas of expertise, as well as interacting with people unfamiliar with mining, being able to express complex subject-related content, ideas, issues, and solutions according to the situation and person he deals with, both in his native language and at least one other foreign language (English being a requirement). Mentioned in two expert interviews, due to the expected interaction with people, mining engineers must be taught to think, independently, and critically, to question and to be open to criticism. Through their education, a mining engineer should receive practical training to address a range of problems, which vary based on industry specialisations, company size and structure. Mining engineers will be familiar with traditional approaches and encouraged to find new ones. Beyond involvement in networks and associations, students will establish connections with the industry by undertaking internships, participating in specialized joint events and lecture series, working on thesis projects, and engaging in practical assignments. Furthermore, the mining engineer of the future will identify his profession through close interaction with the industry, collaboration in recruitment, and guest lectures in cooperation between universities and the industry.

5 Outlook: Continuing What Works and Adding What's New

In summary, the definition of the mining engineer of the future is a complex ongoing procedure that relies on a variety of processes, trends or stakeholders and their direct and indirect interaction with the mining sector.

According to impressions obtained from the online survey and expert interviews it could be concluded that the mining engineer of the future is a generalist, possessing a broad, future oriented range of competencies and continues what has proven as effective while shaping the new. The mining engineer of the future does have a comprehensive understanding of the entirety of the system he is part of as well as the individual processes that are within. The mining engineer is attuned to the diverse needs of the stakeholders of future mining projects and the (geopolitical) mechanisms inherent to the mining industry. Depending on his international work environment, he can apply his expertise purposefully and effectively communicate with both those unfamiliar and familiar with the mining field. This begins from the earliest stages of planning a project and extends throughout the entire value chain, from inception to completion and beyond.

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Mining Engineering in International or Intelligent: Can these attract college students?

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Abstract

The universities have been facing the issues of the declining interest to study mining engineering among youngsters. This paper took the mining programs at Chongqing University of China as an example to compare the college students' preference between the mining engineering in international program and intelligent mining program. It conducted the time series analysis based on the data of the program selection for the college students at the second year. The number of the students and their GPA for each program were obtained from 2013 - 2023. The paper discussed the possible reasons for the students' preference. It thus proposes the solutions for increasing students' interest in mining engineering.

Keywords: Mining Engineering in International; Intelligent Mining Engineering; Enrollment effect

1 Introduction

The mining profession has a glorious historical tradition, and countless mining workers have made great contributions to the revolutionary cause. In China, more than 80 % of the industrial raw materials come from the mining industry [1]. But along with the contemporary socio-economic development, high-tech industries have been updated and iterated, and new professions have sprung up, the glory of the mining profession has gradually dimmed and faded from the public stage. The traditional idea of "doing a job, loving a job" has been lost. On the other hand, the public impression of mining engineering works is still in a harsh and dangerous environment. The students have prejudiced against the tough profession, lack a sense of professional identity, and do not have a firm belief in learning. In recent years, the quality of mining engineering enrollment and employment has deteriorated, and Chinese mining industry still suffers from a lack of industry adaptability [2].

With the development of science and technology, mining engineering is also constantly innovating and developing. Traditional international mining projects have been gradually replaced by intelligent mining projects, which use advanced technology and equipment to mine minerals more efficiently. The recognition degree of mining engineering students to their major determines the level and quality of the mining technology to a large extent, which directly affects their passion for mining and their sense of responsibility and mission to contribute to the development of the mining industry. The major a student learns is closely related to his or her employment destination and job position after graduation. The level of recognition of the major a student learns affects their learning enthusiasm to a large extent, and even determines his or her career intention and attitude towards possible jobs in the future.

At present, there are more than 30 universities majoring in mining engineering / intelligent mining engineering in China, and about 3000 mining engineering technical talents are trained every year, but the proportion of high-level technical and management talents is less than 20 %. As can be seen from the data in the Table 1, the number of mining engineering graduates has generally shown a downward trend in recent years, and the size of graduates has generally become smaller.

Table 1: Number of mining engineering graduates from representative universities in recent five years (data from annual employment quality reports of universities)

Serial	University Name	Graduation Year	Number of under-graduates	Number of master's students	Number of doctoral students	Total
1	Northeastern University	2021	64	24	12	100
		2020	68	33	12	113
		2019	51	42	28	121
		2018	82	39	44	165
		2017	81	32	28	141
2	Chongqing University	2021	52	36	15	103
		2020	53	38	16	107
		2019	52	32	17	101
		2018	52	30	17	99
		2017	103	39	20	162
3	China University of Mining and Technology (Beijing)	2021	95	45	23	163
		2020	113	54	11	178
		2019	70	95	28	193
		2018	84	56	28	168
		2017	47	38	21	106

Due to the technological development trend of intelligent transformation and upgrading of traditional mining projects, the demand for high-level top-notch innovative talents is soaring, and universities with mining engineering majors are in urgent need of taking the responsibility of cultivating a large number of high-level intelligent mining technology and management talents.

This paper, from the the enrollment point of view, analyzed the attraction of mining engineering in international and intelligent mining engineering to college students, to provide reference for universities to attact more excellent students major in mining engineering. The Mining Engineering program at Chongqing University has two tracks, Mining Engineering (International Version) and Intelligent Mining Engineering. Mining Engineering (International Version) started in 2013, and Intelligent Mining Engineering is a new major set up by Chniese Ministry of Education in 2021. However, it remains to be explored if these can attract good students who are choosing their major.

2 Students' Perceptions of the Major of Mining Engineering

In order to put forward corresponding improvement measures, we have carried out relevant investigations and studies.

The test tool is the college students' professional identity scale, which is designed by referring to the questionnaire on college students' professional identity. There are 23 items in total, divided into four factors: the relevance of professional identity (professional and its matching degree, a total of four items), cognitive professional identity (professional understanding of the basic situation, a total of five items), interested professional identity (professional emotional appeal, a total of six item), behavioral professional identity (professional behavior, a total of eight items). Five points were used in the scale (1 for total non-conformity, 2 for comparative non-conformity, 3 for uncertainty, 4 for comparative conformity, and 5 for complete conformity). A total of 227 valid questionnaires were collected.

As can be seen from the Figure 1, students have the lowst interest in the major. Because mining engineering involves mining, mining and other work, it may be mistaken for a difficult and dangerous occupation, which will affect students' interest in the major.

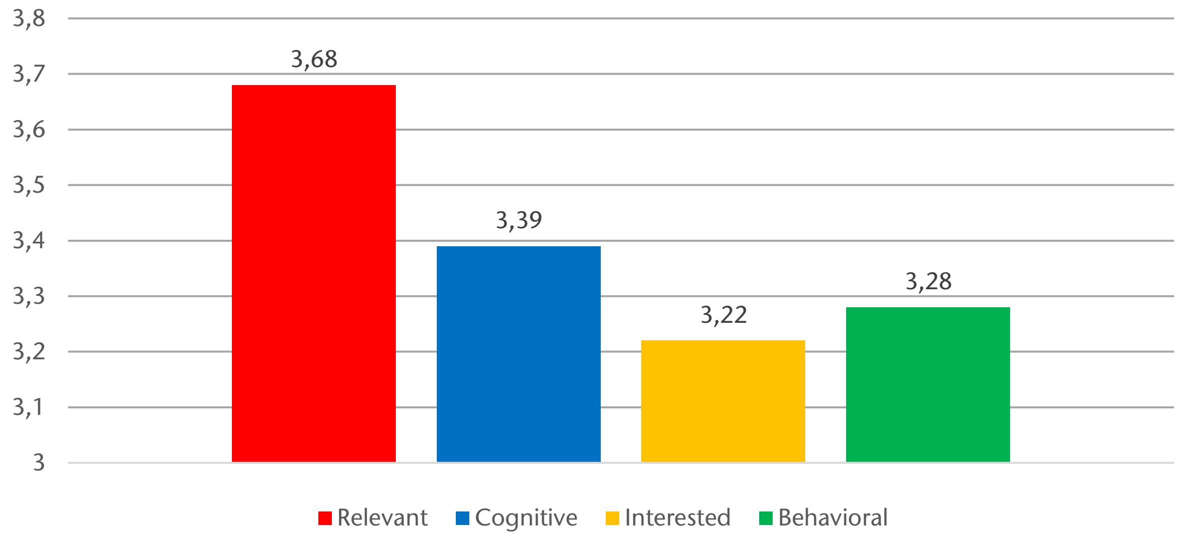

Figure 1: Average chart of the total specialty accreditation level for B.Sc.

In addition, mining engineering is a comprehensive engineering subject. In the learning process, students need to master the knowledge of geology, mechanical engineering, material science, chemistry and other fields. If students lack relevant knowledge base, it will increase the learning difficulty and frustration. On the other hand, students have a high degree of recognition of the relevance of their majors, and most of them are able to clearly recognize their own majors, including understanding the external evaluation of their majors and the status of their majors in the university, and so on. As a matter of fact, after a long period of university study, more college students tend to prioritize seeking employment opportunities in their own majors. The matching of majors will make them feel that their studies are useful and it is easier for them to give full play to their own specialties and get better career development, and on the other hand, it is because the longer the college students devote to their majors, the more they feel that they may have wasted their time if they do not engage in majors-related industries.

3 Enrollment effect of International and Intelligent Mining Engineering

3.1 Mining Engineering (International Version)

Grade 2013 - 2017: Mining major division (international class and parallel class), nearly 100 % of the top students choose international class. According to statistics, 19 students graduated from the Mining Engineering International Class of 2017 chose to pursue further studies and nine were directly employed.

Grade 2018 - 2020: College internal mining and safety large-scale for major division (Safety Engineering, Mining Engineering in International, Sining Engineering), international class has competitive ability with safety engineering: the first round of admission, students have similar GPA.

According to statistics, 17 students graduated from the Mining Engineering International Class of 2018 chose to pursue further studies and nine were directly employed. Twelve students graduated from the Mining Engineering International Class of 2019 chose to pursue further studies and six were directly employed.

Grade 2021: Engineering and Energy large-scale division (Mining engineering diversion admission did not complete the target).

Table 2: Number and transfer rate of mining engineering majors from 2014 - 2023

Year	2014	2015	2016	2017	2018
Transfer rate of mining engineering	13.50 %	11.90 %	35.60 %	33.30 %	34.60 %
Number of mining engineering admissions and admissions	126	101	90	81	81
Remark	College entrance examination registered for mining engineering, a year after the application to change the major				
Year	2019	2020	2021	2022	2023
College internal mining and safety large-scale transfer of professional rate	24.30 %	12 %	13.70 %	—	—
The number of admissions to mining projects	52	56	54	34	44
Remark	College internal mining and safety large scale for major division			Engineering and Energy large scale division	

It is not difficult to see from Table 2 that the enrollment scale of mining engineering majors is decreasing year by year, and the rate of major transfer from 2016 - 2018 has been high. After the golden decade of coal, the mining industry has reached a bottleneck period, which has also led to a continuous decline in the number of students willing to study mining engineering. Starting from 2019, Chongqing University began to implement the enrollment of mining and safety classes, and although the number of enrollment is still small, the rate of changing majors is significantly reduced, proving that the enrollment of large classes has a certain effect on preventing the loss of students. At the same time, the choice of students in the diversion process can also prove the attractiveness of the international class of mining engineering for students.

Table 3: The College internal mining and safety large-scale for major diversion results of Chongqing University in 2020

GPA ranking	Volunteer direction	Remark
1	Mining Engineering (International class)	Eighteen of the top 20 students chose the international class
2	Mining Engineering	
3	Mining Engineering (International class)	
4	Mining Engineering (International class)	
5	Mining Engineering (International class)	
6	Mining Engineering (International class)	
7	Mining Engineering (International class)	
8	Mining Engineering (International class)	
9	Mining Engineering (International class)	
10	Mining Engineering (International class)	
11	Mining Engineering (International class)	
12	Mining Engineering (International class)	
13	Mining Engineering (International class)	
14	Mining Engineering	
15	Mining Engineering (International class)	
16	Mining Engineering (International class)	
17	Mining Engineering (International class)	
18	Mining Engineering (International class)	
19	Mining Engineering (International class)	
20	Mining Engineering (International class)	
⋮	⋮	
56	Mining Engineering	

It can be seen from Table 3 that most of the students with excellent grades have chosen the Mining Engineering (International class). Even when the student size is reduced every year, the quantity and quality of the Mining Engineering (International class) are guaranteed, which positively proves that the mining engineering international class is very attractive to students and is an effective measure for enrollment.

3.2 Enrollment effect of Intelligent Mining Engineering

According to the professional training program implemented by the university, intelligent mining talents should have two basic abilities: one is, to master the basic principles and application ability of intelligent mining; and the second is, to have an international vision and cross-cultural communication skills. Given that intelligent mining is still a rapidly developing discipline, intelligent mining talents should master the basic theory of artificial intelligence and intelligent mining technology, and have the theoretical basis and professional skills to develop new technologies in the field of intelligent mining. In addition, the study of AI courses and the future research and development work should also be international. According to the above analysis, intelligent mining talent positioning should be: with international vision and cross-cultural communication ability, system to master the basic theory of artificial intelligence and the basic principle and method of intelligent mining, can further study in intelligent mining and similar fields, or engaged in related engineering design and construction, production and technical management of high-level mining talents. Mining engineering professional international class training goal is: to adapt to the development trend of mining industry globalization, with generous professional foundation and international humanistic quality, can skillfully use English, with international vision, innovation ability and leadership potential, can in the field of solid deposit mining engaged in production, construction, management, design and scientific research work of senior mining engineers and mining enterprise management of international talents. The result of the students chosen major among intelligent mining and mining engineering is shown as Table 4. Thirteen of the top 20 students chose the Intelligent Mining.

Table 4: The intelligent mining engineering and mining engineering for major choose results of Chongqing University in 2023

GPA ranking	Volunteer direction	Remark
1	Intelligent Mining Engineering	Thirteen of the top 20 students chose the Intelligent Mining
2	Intelligent Mining Engineering	
3	Intelligent Mining Engineering	
4	Intelligent Mining Engineering	
5	Intelligent Mining Engineering	
6	Intelligent Mining Engineering	
7	Mining Engineering	
8	Mining Engineering	
9	Intelligent Mining Engineering	
10	Intelligent Mining Engineering	
11	Intelligent Mining Engineering	
12	Mining Engineering	
13	Intelligent Mining Engineering	
14	Mining Engineering	
15	Mining Engineering	
16	Intelligent Mining Engineering	
17	Intelligent Mining Engineering	
18	Mining Engineering	
19	Mining Engineering	
20	Intelligent Mining Engineering	

4 Conclusions and Suggestions

Based on the practice of Chongqing University, mining engineering in international and intelligent mining have effective to attract students than the traditional mining engineering. Eighteen of the top 20 students chose the mining in international and thirteen of the top 20 students chose the intelligent mining. The intelligent mining program only has one year practice and need the future more experience. It is important to improve the students' interests in mining.

5 Acknowledgement

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Recent practices in Japan to attract students to the mining industry and mining engineering education by using internships and other programs

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Abstract

The mining industry and mining engineering education in Japan face challenges such as the shortage of workforce, generational gaps, and more. To overcome these problems by attracting students to the mining industry and mining engineering education, internships and other programs have been conducted by universities and other institutions in collaboration with private companies and public institutions relating to mining industry. In the presentation, the authors introduce these programs in Japan and share how these programs have contributed to attracting students to the mining industry and mining engineering education by combining with the experiences of the author who joined these programs as a student and is working as a young researcher in the field of mining engineering.

1 Introduction

The mining industry and mining engineering education in Japan face challenges such as the shortage of workforce, generational gaps, et cetera. Especially, students' interests in mining engineering have become less and the shortage of work force has become more serious in mining industry and mining engineering education. Recently, students have tended to have more interests in the industries such as financial, consulting, plant engineering, media, etc. To retain the workforce in mining industry and mining engineering education, internships and other programs have been conducted by universities and other institutions in collaboration with private companies and public institutions related to mining industry. In this paper, the authors introduced these programs in Hokkaido University and other institutions in Japan and shared how these programs have contributed to attracting students to the mining industry and mining engineering education. Those were introduced and shared by combining with the experiences of the author who joined these programs as a student and is working as a young researcher in the field of mining engineering.

2 Recent practices to attract students to the mining industry and mining engineering education

2.1 International and domestic internships

In Division of Sustainable Resources Engineering, Faculty of Engineering, Hokkaido University, the programs of international and domestic internships have been provided to students. In the case of domestic internships, students join the short-term training at the mining companies or their related companies. Typically, students go to a limestone mine and have a good experience about the operation of a limestone mine. In the case of international internships, students usually go to foreign universities for 1 to 2 months and take lectures, go to site visit, and/or conduct experiments. The authors have sent students to U.S.A., German, Greece, Australia, Thailand, Vietnam, Philippines, Mozambique, etc. Through the internships, students can deepen and widen their knowledge about mining engineering and can experience what they learned in the lectures. When the author (Kosei Aikawa) was a 1st-year student in a master's course, he went to Chulalongkorn University, Thailand, for a month and visited a Sn-W mine, a coal mine, and a flotation plant of fluorite as a site visit. Especially, he had a good experience in a coal mine. He learned how to operate a coal mine very well by visiting all departments such as geology, mining, processing, wastewater treatment, environmental remediation, power plant, management et cetera. Though this experience, he had more interests in mining engineering and could imagine how he will work when joining a mining company. As the author experienced, these internship programs have helped the students have more interests in mining engineering.

2.2 Sustainable Resources Engineering Education Consortium

The consortium for sustainable resources engineering was established in 2022 by Hokkaido University and Kyushu University in collaboration with private companies and public institutions related to mining industry. This consortium aims to "strengthen and enhance the educational system for human resource development in Japan, and to build a new career and recurrent education system in the field of natural resources engineering by supporting students' overseas dispatch and corporate internships, as well as lectures by experts from companies". The consortium has held "workshops and symposiums as needed to share and update information on natural resources, and strengthen exchanges between related companies and university staff. Participating companies include not only resource-related companies, but also construction-related companies, commercial and trading companies, and information and communication related companies, which are potential employers for students in resource-related fields" [1]. Using the financial support from the consortium, students went to Australia or Greece as an international internship for a month last year. The purpose of the internship was to improve their communication skills for international activities and to understand and experience geological field surveys and the actual mine operations. At the workshops and symposiums, the consortium has provided students with the lectures by professors from foreign universities and experts from mining companies. As the results of these activities, some students will join the mining companies from April next year.

2.3 School of Resources and Materials

For mainly 3rd-year undergraduate students and 1st-year students in a master's course who major in mining and materials processing and their related fields, a short-term school have been annually conducted for about two weeks by The Mining and Materials Processing Institute of Japan (MMIJ). The attendees can learn basic and advanced knowledge about resources development including materials processing, resources recycling, environmental conservation and mineral economics. Basically, professors from Japanese universities provide basic knowledge as same as lectures in universities and experts from mining companies provide advanced knowledge based on their working experiences in mining industry. In addition to the lectures, attendees have a discussion about a theme related to resources and materials processing in each group. During the discussion, mining professors and experts give advice from the aspect of their specialty. Finally, attendees make a presentation on their theme on the final day of the school and can receive feedback from the mining professors and experts. After this school, attendees can join the domestic and international sit visit tours to go to mines and smelters [2]. When the author (Kosei Aikawa) was a 3rd-year undergraduate student, he joined this school and went to coal, copper, and gold mines, and a power plant in U.S.A. and Canada as an international site visit. There are few active metal mines in Japan, and their scales are much smaller than those of foreign countries. Therefore, he could realize that the scale of mine operations in foreign countries are very large and experience the actual mine operations. As a result, he was highly attracted to mining engineering and now is working as a young researcher in Hokkaido University, Japan.

3 Conclusions

In Japan, universities and other institutions have provided students with internships and other programs in collaboration with private companies and public institutions related to mining industry. These activities have attracted students and some students have decided to join the mining companies and their related companies and become researchers in the field of mining engineering. However, still the shortage of workforce in mining industry and mining engineering education is serious. To achieve the sustainable mining industry and mining engineering education, these activities are essential and should be continued in the future and we must make more efforts to overcome these problems.

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Stopping the Talent Leakage: How to Attract and Retain Parents as Part of an Inclusive Canadian Mining Workforce

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Abstract

The Canadian mining industry is facing a talent challenge. While the industry is committed to creating a more diverse and inclusive workforce, current numbers suggest that there is a labor market tightness and thus a limited pool of mining talent available. The retirement rate, expected to average about 2.4 % of the Canadian mining workforce over the next ten years, is decreasing the talent available for senior positions in the industry. The expected rate of employee exits from the industry (in favor of other industries), estimated around 5 - 6 % over the same period, further reduces the availability of talent. Additionally, the under-representation of women in the mining workforce, currently around 16 % of the total Canadian mining workforce, highlights the challenges the sector is facing in the attraction and retention of diverse groups. This study investigates one dimension of diversity, gender equity. In the context of gender diversity, anecdotal evidence suggests that women are not only less likely to enter the mining industry, but also more likely to leave the industry. This retention problem is often associated with two factors. First, a slower career trajectory of females in mining in comparison to other industries, causing women to seek career advancement outside the mining sector. And second, the impact parenthood has on women versus their male counterparts. We aim to identify career challenges and hurdles associated with becoming a parent as experienced by individuals in the mining sector. The final goal of the project is the development of realistic approaches for mining companies that allow a balance between supporting their employees with the achievement of their strategic objectives. This includes recommendations on policies that focus on gender equity to successfully overcome hurdles experienced by parents of all genders in the mining sector.
This presentation represents the first part of an industry-funded, two year cross-functional research project.