SYDNEY, AUSTRALIA
5 — 11 SEPTEMBER 2024

34TH ANNUAL GENERAL MEETING AND CONFERENCE

# The Society of Mining Professors

## Conference Proceedings

# THE SOCIETY OF MINING PROFESSORS

# 34TH ANNUAL GENERAL MEETING AND CONFERENCE

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# FOREWORD

I am honoured to welcome you to the 34th Annual General Meeting (AGM) of the Society of Mining Professors (SOMP), to be held in Sydney from 5–11 September 2024. Hosted by UNSW Sydney's School of Minerals and Energy Resources Engineering, in partnership with the AusIMM, this AGM promises to be a momentous occasion, blending professional development, collaboration, and multicultural experiences in one of the world's most iconic cities. This year is of particular significance for UNSW as we celebrate our 75th anniversary—a major milestone that reflects decades of leadership in education, research and collaboration under the inspiring motto 'Celebrating Progress for All'.

Fifteen years ago, in 2009, my mentor, Professor Bruce Hebblewhite, first welcomed SOMP to UNSW—an event that marked the beginning of my involvement with this exceptional Society. That gathering not only introduced SOMP to Australia for the first time but also ignited a journey that I have continued with great pride and dedication. Since then, I have served SOMP in various capacities, from the Members Development Committee to leading the Research, Development and Industry Committee, and as Editor-in-Chief of Mines of The Future. Now, having the privilege to welcome SOMP back to Sydney once again, and serving as the President of our Society, is a distinct honour and personal milestone.

SOMP is a global leading Society of dynamic and engaged members—currently representing approximately 300 individuals from 128 organisations across 46 countries. We are united by our shared commitment to promoting sustainable mining practices, fostering knowledge exchange, and facilitating research and mining educational collaboration. Central to our mission is the advancement of knowledge to equip future mining and minerals professionals with the skills necessary to meet the evolving demands of the minerals industry.

This year's theme, 'Building Tomorrow Together – Integrating Technology and Embracing Diversity in Mining,' encapsulates our shared vision for the future. Through these principles, SOMP's activities, led by its committees, play a crucial role in preparing mining and minerals academics to thrive in a rapidly transforming landscape, driven by technological advancements, social acceptance and the imperative for greater diversity and inclusivity. The future of mining requires not just technical expertise but also a broader understanding of how innovation can be harnessed to address complex challenges such as sustainability, energy transition, and digital transformation. SOMP's initiatives focus on ensuring that our members are well-prepared to meet these challenges with confidence and competence. I am confident that our commitment to 'connecting people and fostering growth' will continue to thrive in SOMP well into the future.

We have developed an engaging and interactive program based on our main themes, designed to inspire meaningful discussions, spark innovative ideas, and foster deeper connections among our global Society. Alongside thought-provoking presentations, poster sessions, panels and workshops, our program includes visits to some of the most technologically advanced mining operations. Our program is designed not only to inspire but also to provide a platform for our members to discuss the future skills required to navigate and lead in a rapidly evolving and challenging mining and academic landscape.

As we look ahead, SOMP remains resolute in its commitment to fostering academic excellence and professional growth within the minerals industry. Through the support of strong educational programs, targeted training activities, and international collaborations, SOMP will continue to prepare our members for a rapidly changing industry, ensuring they are ready to face tomorrow's challenges with innovation, responsibility, and resilience. Moreover, SOMP is committed to helping its members develop high-quality educational programs and training activities that support the academic growth of early-career researchers and students.

Raising social awareness and improving the perception of the minerals industries is a key element of our mission. We aim to emphasise the critical role that mining plays in society and to align this with sustainable development goals. By fostering pride in our disciplines and promoting the important global contributions of mining, SOMP helps shape the future workforce by developing a strong sense of purpose and accountability.

Finally, I extend my sincere thanks to all who contributed to making this event possible, particularly UNSW Sydney's Faculty of Engineering and the School of Minerals and Energy Resources Engineering. Special gratitude goes to the authors and presenters for their invaluable work, the organising committee and committee chairs for their dedication, and our sponsors for their support in ensuring the success of the event. Organising such an event requires considerable effort, experience, and enthusiasm. I would like to acknowledge the team from the AusIMM for their tireless and professional work in bringing this event to life.

On behalf of the Organising Committee, I warmly welcome you all to Sydney. I look forward to a fruitful exchange of ideas, new collaborations, and memorable experiences that will shape our future. Let's continue building tomorrow, together.

Yours faithfully,

Professor Serkan Saydam FAusIMM

2023–2024 SOMP President

# CONFERENCE SUPPORTERS

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## Members development



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# Education

# Development of a mine closure and sustainable transitions micro-credential – challenges and perspectives

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## ABSTRACT

The continuously growing demand for critical minerals translates to finding and exploiting new mineral resources, meaning numerous new mining projects are expected to initiate operations. Accordingly, these operations must be properly closed and rehabilitated when production ends. Mine closure and post-mining transition are critical stages in a mining operation's life cycle. Such processes involve the planned and systematic measures to conclude mining activities and restore the affected area to an environmentally sustainable condition. Transforming mining economies to enable communities and other stakeholders to build a successful post-mine future is a constantly growing challenge.

As mining matures worldwide, the need for professionals with the skills to engage with the many dimensions and impacts of mine closure is accelerating. Closure practitioners typically move from other parts of the mining industry. Hence, there is an urgent need to create resources that provide essential knowledge in this field. Training professionals in mine closure and post-mining transition is essential to address closure's environmental, social, legal, and financial aspects effectively.

This educational gap has attracted the interest of stakeholders worldwide, who have initiated research projects, workshops, webinars, and online resources. Accordingly, the University of Queensland (UQ) and Curtin University (CU) have partnered with CRC TiME to develop the first Massive Open Online Course (MOOC) entitled 'The Foundations of Mine Closure and Sustainable Transitions.' This project aims to build the workforce's capacity to engage with and deliver effective mine closure and post-mining transitions and formalise professional skills development. A pilot course was launched in October 2023 with 407 participants from 33 countries. In this work, we discuss the challenges during development, the feedback received, and the future perspectives of this foundational course that will enable an element of standardisation in training those involved from the multiple perspectives of those impacted by mine closure.

## INTRODUCTION

- What is left behind after mining activities come to an end?
- What happens with the mined-out lands, and the footprints of the operations?
- How do we deal with the degradation of the environment surrounding a mining project?
- Do we have enough adequately trained engineers and scientists to ensure a proper mine closure plan and a sustainable post-mining transition to other activities or land uses?

These are some of the questions that come to mind as we have already entered a new boom era of the global mining industry, in which the need for critical minerals is expected to skyrocket mining production (IEA, 2021; Hammond and Brady, 2022). This continuously growing demand is translated to the need to find and exploit new mineral resources, meaning numerous new mining projects are expected to initiate operations. Accordingly, these new mining projects must be properly closed and rehabilitated when production ends. Otherwise, many challenges and risks may arise (Dzakpata *et al,* 2021; Hattingh, Stevens and Bliss, 2021).

Mine closure and post-mining transition are critical stages in a mining operation's life cycle. These processes involve the planned and systematic measures to conclude mining activities and restore the affected area to a safe, stable, and environmentally sustainable condition (Dzakpata *et al,* 2021). Multidisciplinary conditions govern mine closure planning and post-mining transition. Transforming mining economies to enable communities and other stakeholders to build a successful post-mine future is a constantly growing challenge. Regulatory frameworks are being tightened, and financial instruments are mobilised to secure funds to address the risks of abandonment. Greater awareness of political and social risks from unclosed mines influences investor markets (Hattingh, Stevens and Bliss*,* 2021).

As mining matures worldwide, the need for professionals with the skills to engage with the many dimensions and impacts of mine closure on many stakeholders is accelerating. Closure practitioners typically move into the closure arena from other parts of the mining industry, other professions or parts of Government (Dzakpata *et al,* 2021).

Hence, there is an urgent need to create resources that provide essential knowledge on closure. Training professionals in mine closure and post-mining transition is essential to address closure's environmental, social, legal, and financial aspects effectively. It ensures that mine closure plans are conducted and executed responsibly, minimising negative impacts and contributing to sustainable development.

This project aims to build the workforce's capacity to engage with and deliver effective mine closure and post-mining transitions and formalise skills development in professionals involved in the mine closure process. These professionals could be within the mining industry, suppliers to the mining-related industry, or Government and non-government organisations. The newly developed foundational course in mine closure and post-mining land uses enables standardisation in training those involved in mine closure from the multiple perspectives of those impacted by mine closure.

The topics covered in the Foundations of Mine Closure and Sustainable Transitions were determined in consultation with an Advisory Group and included:

0. Getting Started.
1. Post-mining transitions in the life cycle of a mine and host community.
2. Regulation, policy and practice.
3. Economics, finance and asset closure planning.
4. Social aspects of closure.
5. Environmental management through asset closure and beyond.
6. Recognising Indigenous culture through mine closure and post-mining land use.
7. Mine closure as a complex system…where next?

The MOOC is available on the edX platform as a standalone credential accredited through existing edX protocols (https://edge.edx.org/courses/course-v1:UQx+FMCTx1+2T2023/about). The volume of learning represented by the course content (including assessments) aims to approximate one unit of study at a university. It allows for future stacking towards an award program of study at institutions that choose to adopt it. The material is available through a Creative Commons licence to encourage uptake and use in other applications. The course has been designed to offer further opportunities for modification and use in other environments.

## BACKGROUND

The educational gap in mine closure has attracted the interest of stakeholders worldwide, who have initiated research projects, workshops, training programs, webinars, and online resources, among other activities. One of the earliest attempts at an international level was recorded in 2011 when Edumine in the U.S. developed a 15-hour course to recognise and discuss the multidisciplinary components of mine closure. The course was available for a fee to subscribers of the Edumine platform. After completion, the participants would attain an Edumine Certification (Edumine, 2011).

In 2016, a collaboration between African and Australian academia, industry, and government stakeholders resulted in 25 senior civil servants from 13 African nations participating in a seven-week training program focusing on best practice principles in mine closure in the African context. An expanded eight-week training program was delivered in 2019, combining activities across countries, mine sites, industries, and government agencies to inform further mine closure best practices in Africa, Australia, and other countries (Murdoch University, 2016).

Furthermore, the Indian Institute of Technology (IIT) Kharagpur in India is offering a 12-week online course in 'Mine Closure and Sustainability Planning' (Swayam, 2022). Although initially, the course was designed for undergraduate and postgraduate students of the IIT Kharagpur, it is also available to mining industry professionals worldwide, offering a certificate upon completion. Other online courses are focused only on specific aspects of mine closure (Hatari Labs, 2021). In South Africa, NWU also offers a short course on ecological rehabilitation and mine closure through its Business School (NWU, 2023). This course will acquaint managers and operational personnel with the principles, legal requirements and implications, relevant technical aspects, approaches, plans, problems and solutions related to rehabilitation and mine closure.

In mid-2023, the Australasian Institute of Mining and Metallurgy (AusIMM) announced the launch of a Professional Certificate in Integrated Mine Closure. This new eight-week online course will be completed before the end of 2024 (AusIMM, 2024). The critical topics of this new course will be environmental stewardship, social responsibility, and collaboration and expertise.

Recognising the significant gap in the educational space of mine closure, UQ and CU partnered with CRC TiME to co-develop the world's first Massive Open Online Course entitled 'The Foundations of Mine Closure and Sustainable Transitions'. This collaborative effort, funded by the Cooperative Research Centre for Transformations in Mining Economies (CRC TiME), is part of its education and training portfolio. CRC TiME, the world's only research organisation dedicated to bringing together diverse stakeholders, is part of the Australian Government's Cooperative Research Centres Program, which supports collaboration between industry, researchers, and communities.

The consortium's goal was to develop flexible learning materials to suit a range of learner archetypes, providing learners with options to engage with the material in diverse ways (eg as an opportunity to develop and enhance skills or as a stepping stone into other recognised accreditation pathways, such as through an industry body or tertiary institution).

The intention is not to replicate any existing material that may be available (such as closure practice guidelines or the online courses mentioned above) but to focus the content on critical gaps and what might be missed, including governance, social and cultural dimensions to address what closure means for a variety of stakeholders (which can include government, regulators, and community representatives of varying types).

The development of this massive open online course aims to offer the content to the broadest possible audience, providing learners with options regarding the cost of engagement. Learners can enrol in the course for free (audit) or pay a small fee to access additional materials, including assessment, and be eligible to earn a verified certificate.

A crucial part of meeting these goals was the engagement with an Advisory Group (including the mining industry and CRC TiME partners), which brought industry expertise into the design and development of materials, complementing the project team's expertise in integrating disciplinary perspectives and delivering transformational learning.

## COURSE DEVELOPMENT

The development of the MOOC was built on previous relevant work done by researchers at the two universities and the work of CRC TiME in a range of ways. The University of Queensland and Curtin University have a history of partnership in developing MOOCs – most recently, the 'Foundations of Modern Mining' course (www.edx.org/certificates/professional-certificate/uqx-curtinx-foundations-of-modern-mining) sponsored by the Minerals Council of Australia. This online course was also developed on the edX platform that was used for the Foundations of Mine Closure and Sustainable Transitions.

Core principles for the course have been informed by CRC TiME research, and content for the training was drawn from case studies relevant to CRC TiME and its partners. An Advisory Group was established, and both universities leveraged their extensive industry networks and those of CRC TiME and its partners to engage appropriate stakeholders in content development and delivery.

In addition to providing training materials and case studies on the more technical aspects of closure planning, landform stability, tailings, waste and water management, and ecosystem restoration, the course also delves into the social aspects of closure. Materials were developed from recent research by the UQ Consortium on the Social Aspects of Closure (https://www.mineclosure.net/) and CRC TiME research on post-mining land use (Dzakpata *et al,* 2021; Beer *et al,* 2022; Hamblin, Gardner and Haigh*,* 2022), and Indigenous People Inclusion (Measham *et al,* 2021; CRC TiME, 2022; Miller-Sabbioni *et al*, 2023). The 'ARC Training Centre for Healing Country' also collaborated with the project team to develop Indigenous content for inclusion in the course, ensuring a comprehensive and inclusive learning experience (https://archealingcountry.com.au/).

The approach to developing the course was based on the project team's highly successful previous collaboration to co-create the Professional Certificate in the Foundations of Modern Mining. Development occurred in stages and consultation with the Advisory Group. The following sections describe in detail the steps taken from the project's inception to the course design, development, beta testing, piloting, completion of the course, and feedback received.

## Project inception

The idea of establishing a MOOC for Mine Closure and Post-Mining Transitions was developed into a concept by researchers from the University of Queensland, Curtin University, and CRC TiME. The proposal developers (from UQ and CU) discussed several topics with industry partners, governmental officers, and community stakeholders under the auspices of CRC TiME to shape this course's objectives, content, and desired outcomes. The feedback received from the external participants in these meetings was efficiently used to optimise the project's concept, structure, and methodology.

The project was initiated in June 2023, and the project team engaged with an Advisory Group of experts in mine closure, rehabilitation, and post-mining training to develop and finalise the micro-credentials content structure, learning goals, and learner archetypes (primary audience). The aim was to deliver all the modules by the end of 2023 and have the beta version of the online course running from October 2023 until February 2024. From this process, the course aim was developed:

> *To foster life-long learning and understanding of the complexities surrounding mine closure and post-mining land utilisation and establish a foundation for enhancing the capabilities of all stakeholders involved in the process.*

The learner types fall into two broad categories, as outlined in Table 1:

**TABLE 1**

Learner types.

| Knowledge, innovation, safety | Legacy, belonging |
|---|---|
| Have some experience (early to mid-career) | Not working in the sector (but may be in related industry sectors) |
| Working in the sector | Can have impact on (eg government, regulators) or be impacted by (eg communities, landholders) closure and post-mining transitions |
| Encompass a wide range of roles that are directly (eg technical teams of various disciplines, land access teams, closure practitioners) or indirectly (legal and finance professionals, project teams) associated with mine closure | Are interested in developing skills and understanding of closure |
| Are lacking some basic skills and knowledge on closure and what closure means for a variety of stakeholders | |

After completing the course, learners will be able to:

- Demonstrate the benefits of taking a whole-of-business (or holistic) approach to closure.
- Compare regulation and policy across different jurisdictions and how this relates to best practice.
- Understand that closure planning and execution is a multi-disciplinary area – not just for environmental practitioners.
- Explain and reflect on the significance of social performance aspects of closure for the resources sector.
- Assess land and water management practices through asset closure and beyond.
- Articulate the processes that ensure respectful and effective practices throughout an operation.
- Evaluate the cost of closure.

## Design and development

After stage 1, the initial course content macro design was developed. The goal was to develop course material for 20–30 hrs, followed by an assessment requiring another 20–30 hrs to complete and submit for marking. The assessment in this beta version of the MOOC was not marked. This design was subject to alterations as the course development progressed, and the final course content was optimised.

Accordingly, the Advisory Group reviewed the course's initial macro-design and discussed it with the learning designers and content experts; the latter then progressed to the micro design, in which more detailed information, guidelines, content ideas, case studies, literature sources, and links were collected to start building the content. The content material developers collaborated with the media and learning design teams to ensure that high-quality, publicly available, and copyright-free content was to be inserted into the modules.

The concept of this course was to have consecutive modules that narrate the story of mine closure and post-mining transition, highlight the challenges and opportunities and how these are linked with the different groups and stakeholders, whether these are the investors, the industry professionals, the legislators, the workers, the local society, or the First Nations People. Much of the content in one module could be efficiently and effectively included in other modules. This shows the interaction between the modules and the necessity to include all these aspects in this course.

The edX platform provides many options and possibilities to make the learning experience multitasking, engaging, and interactive. Tools were implemented to provide as much and as vivid experience and knowledge as possible.

- <u>Videos</u>: Each module contains several videos that illustrate and explore key ideas. The participants can speed them up or slow them down as they prefer. Depending on the speed of their internet connection, they can also view the videos in full screen or in high definition or download videos to watch later on their mobile devices.
- <u>Text</u>: Distilling complex ideas into 3 mins is hard. That is why the trainees can find that the concepts covered in each video are also explained in the surrounding text.
- <u>Readings</u>: The readings focus on the content the trainees cover in each module. There are also references and additional readings if the trainees choose to dig deeper into the topics covered. These materials are not graded and are denoted by a 'Digging Deeper' banner.
- <u>Ungraded Activities</u>: Throughout the course, a number of interactive activities are provided to help participants engage with the topics covered more deeply. These materials are not graded.
- <u>Discussion Forum</u>: Developing a deeper understanding of the topics in this course is not something acquired passively. It requires practising thinking, analysing and making arguments while progressing throughout the course. The trainees can practice their thinking in the discussion forum with other participants and moderators in the course.

- Each module has several discussion threads on the critical issues covered where participants can join in, reflect on what has been covered, and challenge the ideas presented. These forums will be moderated to point the trainees in the right direction (assuming there is a right direction), but much learning comes simply from responding to others.
- Ungraded Assessments: At the end of Modules 1–6, the trainees find either a short quiz or a reflection activity. These reinforce knowledge and understanding of each module's relevant content and enhance the learning experience. The module quizzes can be completed at any time before the course ends. The reflection activities are found in the latter half of the course, allowing the participants to consider and analyse their own understanding of the content. As with the quizzes, the reflection activities can be completed any time before the course ends. However, the recommendation is to complete them sequentially after each relevant module.

The beta version of the online course involved 'assessments' that were not graded and the participants' progress through this free training was not restricted if they chose not to complete them. Nonetheless, the trainees were highly encouraged to attempt these activities as they will confirm and extend their learning and prove useful should they continue with the full edX version of this course (to be released in late 2024). The optimised version will include a few extras and enhancements that will enable the participants to attain a Verified Certificate after completing the graded assessments.

Navigation through the different modules of the course is easy. Green ticks are used as a visual aid designed to assist the participants with measuring their progress in the course. These checkmarks appear when all the written content or videos displayed on the page are viewed or when the trainee submits answers for the activities or questions on that page (Figure 1). Each module unit is represented by an icon that indicates the (primary) type of material in the unit.

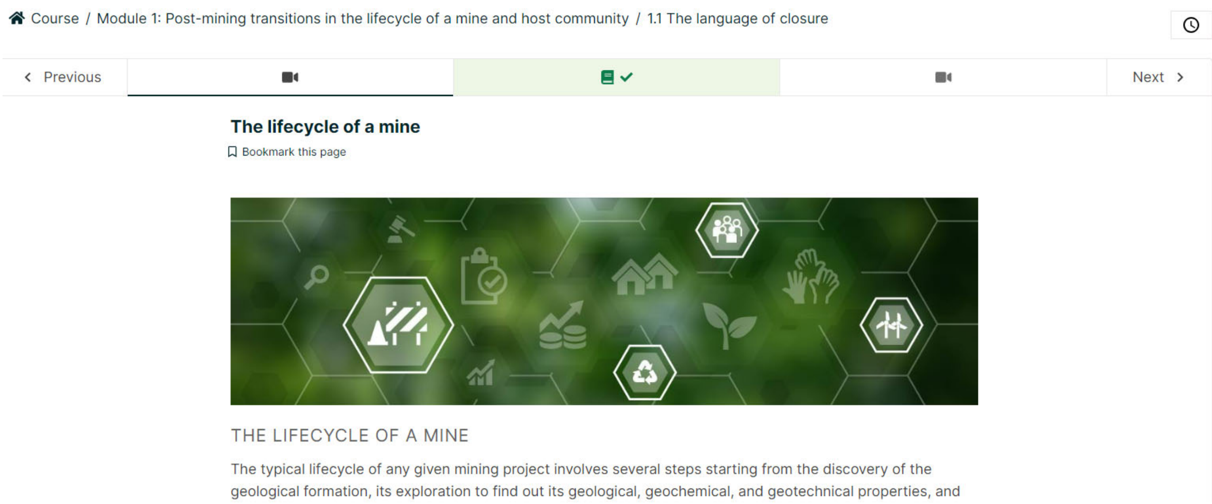


**FIG 1** – Navigation interface for the course.

The learners can linearly move through the course using the arrows on the two sides of the navigation bar or hover and click on the links on the top, which can bring them back to the course table of contents or to the beginning of the Module they are navigating at the time (Figure 1). Hence, the learners can go back and forth between sections, units, and modules. This is very helpful, given the interconnectivity between the Modules' content, highlighting the holistic perspective of this course. Figure 1 also illustrates the tailored course banner for Module 1. Accordingly, customised banners were generated for all modules, highlighting the disciplines/research areas discussed in each.

## Content creation and beta testing

Having established the design principles and strategy, the course development team created the learning materials, which the Advisory Group would initially review and beta-test. The plan was to develop, upload, test, review, and then gradually release the modules. As part of the course creation process, the build team engaged with many experts, who were interviewed or provided content that is acknowledged and can be viewed in the course.

The material was collected, validated, and reviewed internally (before being reviewed by the Advisory Board) by the course development team in collaboration with renowned experts in specific areas (mineral economics, waste management, water management, social acceptance, and inclusion of Indigenous People, among other disciplines). These experts were recruited from the University of Queensland, Curtin University, CRC TiME, the governmental sector, and the mining industry in Australia and worldwide.

The initial macro-design of the course was subject to minor changes and adjustments depending on the material, interviews, and case studies collected, and the knowledge generated. Accordingly, an updated table of contents was created (Table 2). The duration of the modules remained unchanged (20–30 hrs in total).

**TABLE 2**

Updated table of contents for the MOOC.

| | |
|---|---|
| Getting started<br>[60 mins] | • Welcome to the course<br>• Navigating the course<br>• Preliminary survey |
| Module 1: Post-mining transitions in the life cycle of a mine and host community<br>[180 mins] | • Module introduction<br>• The language of closure<br>• The multi-disciplinary nature of closure<br>• Operationalising closure planning in the mine life cycle<br>• Closure processes as a complex system<br>• Progressive rehabilitation<br>• Post closure transitions (post-mining activities)<br>• Module summary<br>• References and further resources<br>• Check your knowledge (Five Questions) |
| Module 2: Regulation, policy, and practice<br>[240 mins] | • Module introduction<br>• History of closure<br>• The governance ecosystem<br>• Jurisdictional variations<br>• Best practice<br>• Module wrap-up<br>• Check your knowledge (Five Questions) |
| Module 3: Economics, finance, and asset closure planning<br>[240 mins] | • Module introduction<br>• Importance of closure and economic challenges<br>• Strategic closure cost assessment<br>• Tactical closure cost assessment<br>• Operational closure cost assessment<br>• Risk assessment, liabilities, and closure outcomes<br>• Relinquishment and perpetual management<br>• Module summary<br>• References and further resources<br>• Check your knowledge (Five Questions) |
| Module 4: Social aspects of closure<br>[240 mins] | • Module introduction<br>• Social aspects of mine closure<br>• Integration of social aspects in mine closure planning and management<br>• Understanding the social context, impacts, and opportunities<br>• Understanding impacts and opportunities<br>• Managing social transitions<br>• Mine closure and local development<br>• Community and stakeholder participation |

| | |
|---|---|
| | • Check your knowledge<br>• Module wrap-up<br>• Digging deeper |
| Module 5: Environmental management through asset closure and beyond<br>[240 mins] | • Module introduction<br>• Abandoned mines<br>• Baseline assessment<br>• Landform design<br>• Water management<br>• Safe waste disposal<br>• Rehabilitation and closure plan<br>• Module wrap-up<br>• Digging deeper<br>• Reflection activity |
| Module 6: Recognising Indigenous culture through closure and post-mining land use<br>[240 mins] | • Module introduction<br>• Indigenous inclusion in closure planning and execution<br>• Connection to country<br>• Dimensions of values<br>• Indigenous business<br>• Engagement principles<br>• Module summary<br>• References and further resources<br>• Reflection activity |
| Module 7: Mine closure as a complex system...where next?<br>[60 mins] | • Course wrap-up<br>• What next? Closure as a journey not a destination<br>• Feedback and evaluation<br>• Digging deeper |
| Final Assessment | • Final Assessment |

The assessment includes formative and summative tasks for learners to test their knowledge. A mix of assessment types has been included with either ‘test your knowledge’ quizzes or short written reflections at the end of each module. The final summative assessment task is to produce a reflective written piece.

The quizzes and reflection activities at the end of each module involved multiple-choice and true-or-false questions, fill-in-the-blank challenges, and sequencing quizzes. The reflection activities required the participants to respond to specific prompts. For the beta version, the responses were not marked. However, for the final edX version with Certification, the content development team will review the assignments based on already established marking rubrics.

People from the CRC TiME leadership were invited to record a welcoming message to the course participants. In addition, each module involved a ‘welcome to the module’ video where experts narrated the contents and highlighted the essential aspects.

Many of the experts also agreed to be interviewed, and their recordings became available to the course participants. Each expert was asked targeted questions that would be uploaded in specific modules to enhance the participants’ learning experience. Several case studies and mine closure example projects were derived from the industry and the literature.

The MOOC offers a multimedia learning experience combining different content forms: text, audio, graphics, animation, videos, and communication applications (Figure 2). All content forms were explicitly cited, and additional resources were available for the learners to dig deeper.

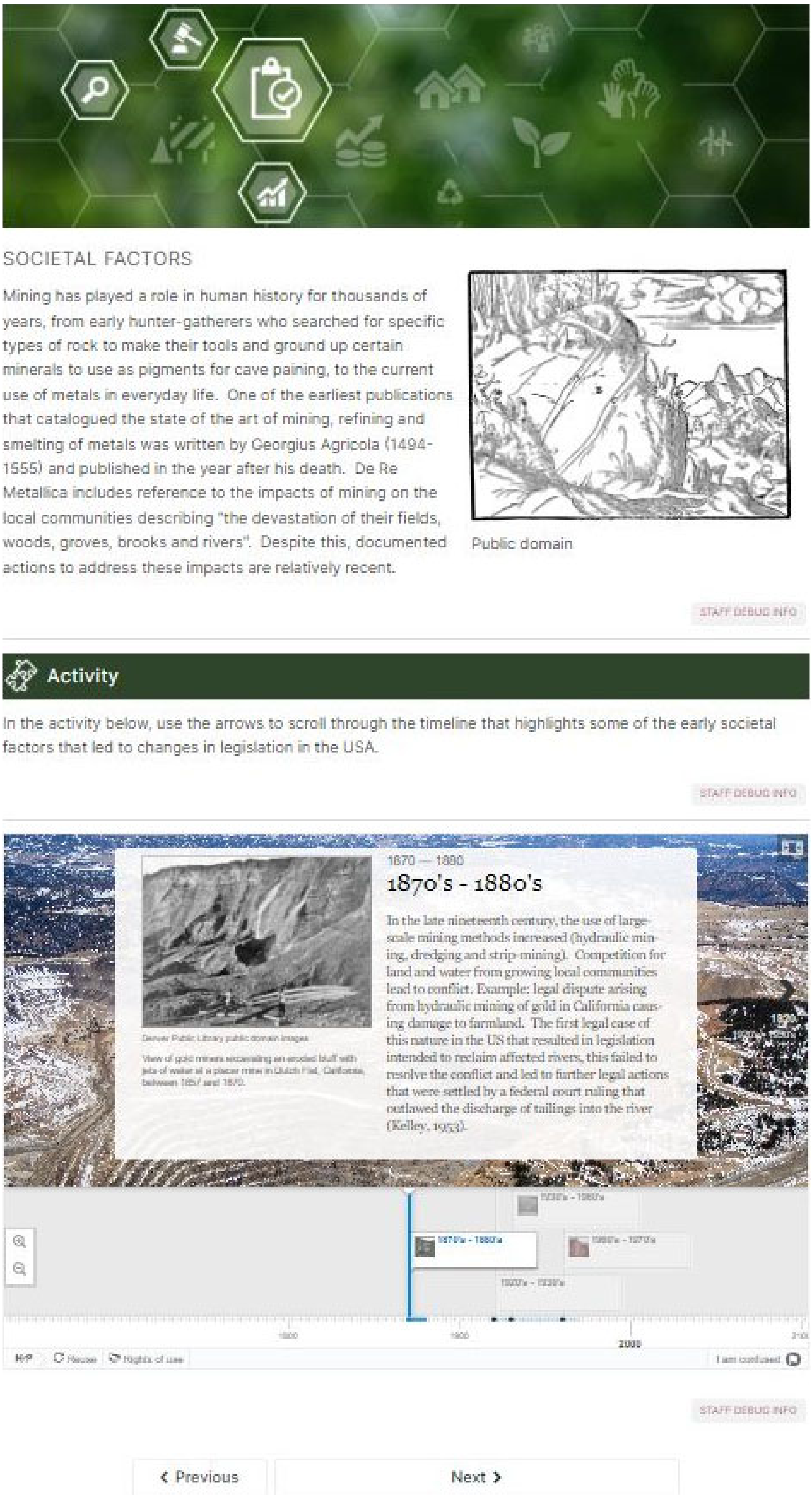


**FIG 2** – Content sample displaying a timeline animation.

## Piloting

The Advisory Group provided contacts for beta testing. The role of the beta testers was to provide feedback on specific content in the course. The feedback from this process and additional data sources (including the course analytics and learner surveys) will be used to refine the course content following the delivery of the course pilot (beta version).

The initial release of the course was in ‘instructor-paced’ mode, where the content was released on a fixed schedule over a defined period. This approach allows for responsive refinement of course materials based on learner feedback. The pilot version of the course was released on the edX EDGE platform, a testing area of the edX platform.

As such, in consultation with the course team and CRC TiME, the decision was made to make the pilot version freely available without an option for a verified certificate. Learners who expressed interest in certification have options for enrolling in the self-paced release of the course, scheduled for 2024. This course will be on the edX platform, where existing certification protocols exist.

## Review and reflect

The learners were asked to complete a preliminary survey before initiating the course to allow the project team to understand them and use the data for internal analysis (only). The 159 responses we received were kept anonymous. The data and information collected remain confidential and should not be distributed to third parties. The questions in this preliminary survey focused on gathering the following information:

- Why the trainees are taking this course.
- What is their current connection to the mining industry.
- In which area of mining are they involved or interested in.
- If they intend to complete the course and interact with other learners.
- What are their learning goals.
- If they have any connection to UQ or Curtin University.
- If they are currently studying.
- If this is their first edX course or have they enrolled in others.
- How did they hear about this course.

Upon completion of the course, the trainees were asked to assist the course team with their valuable feedback by completing another post-course survey. The questions in this second survey were designed to gather the following information:

- If the course used an appropriate mix of text, videos, and interactive features, and if this material was informative and easy to follow.
- If the course length was appropriate, and how many hours they spent completing each module.
- If they felt they achieved their learning goals.
- What was their preferred device for accessing the course.
- Their written feedback, suggestions for improvement, and an overall rating of the course

Learner feedback and platform analytics have been reviewed so that planning for course refinements can be made before the ‘self-paced’ course is released. The analyses are discussed in the following sections.

# USERS FEEDBACK

Data on users and their engagement and experience with the course was collected in several ways, including specific feedback from beta tester surveys, analytics from the platform, and feedback surveys hosted within the platform and available to all enrolled learners. This data enabled understanding of the following:

- Do the learner characteristics align with the types identified in stage 1 of the course development process?
- How are learners experiencing the course content?

## The learners

The surveys helped the project team collect essential information. The analysis of the learners' identity is discussed hereinafter. Data from the course analytics shows that learners come from 33 countries worldwide. Most learners are from Australia (60 per cent), with Brazil (7.6 per cent) and Canada (7.3 per cent) being the next largest (Figure 3). Given the relatively soft launch of the pilot course, many participants (407) and the diversity of countries suggest a genuine appetite for this material.

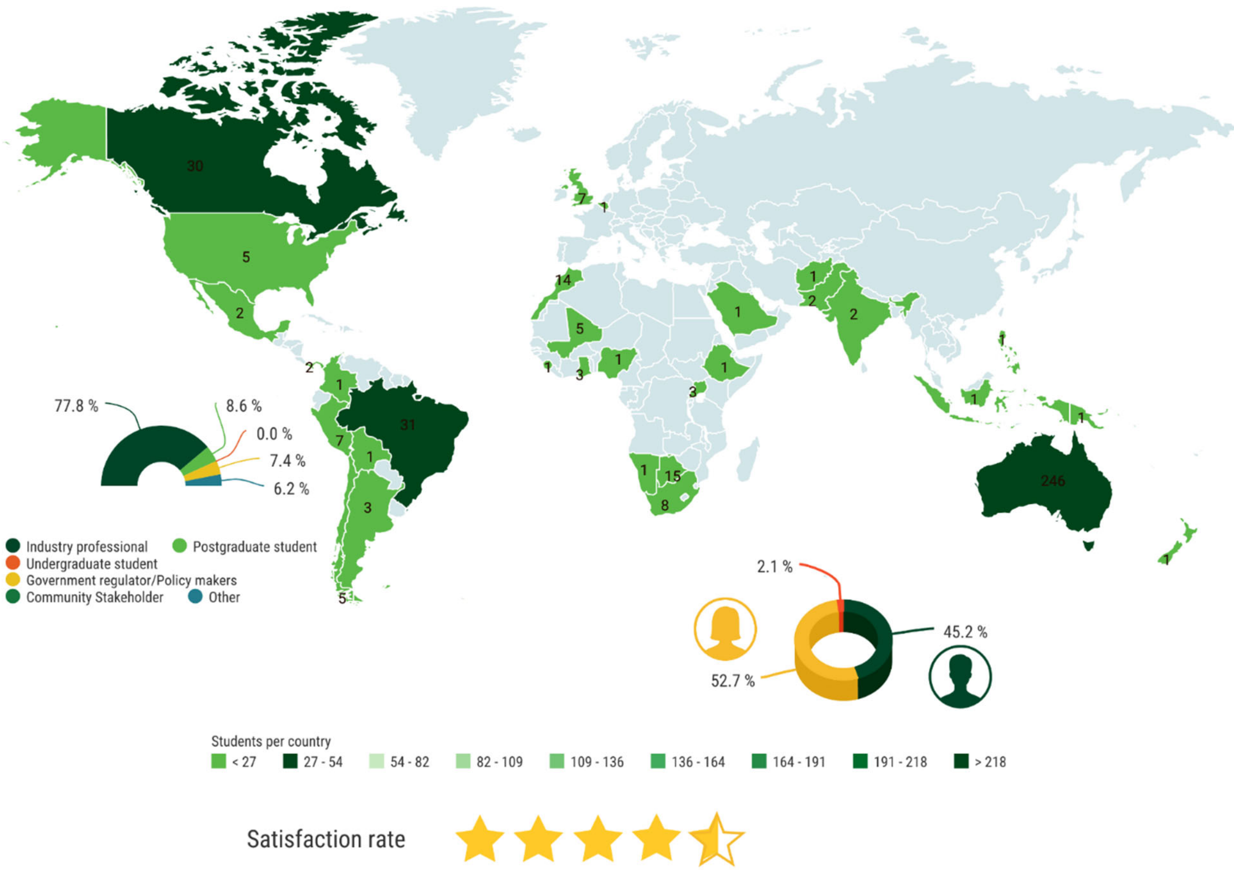


**FIG 3** – Summary of data presented graphically (N=407) conclusions.

Most learners who responded to the course survey are industry professionals (>77 per cent), with postgraduate students (8.6 per cent) and government regulators/policy makers (7.4 per cent) as the following largest groups (Figure 3). These generally represent the learner types envisaged in Stage 1 of the course development. Learners impacted by mine closure (eg landholders/community) were not significantly represented in the instructor-led course.

There was close to gender parity in the course, which is encouraging. In other mining-related MOOCs (eg the Foundations of Modern Mining), the courses are male-dominated; typically less than one-third of the cohort identifies as female. Upon inquiring about their reasons for enrolling in the course, most learners' responses were categorised into two main areas: for knowledge and skills development or as part of career advancement efforts. These motivations are in alignment with the course's stated objectives.

## The course experience

Based on the beta testing feedback, the participants highlighted several positive aspects of their learning experience. Figure 4 shows examples that encapsulate what they appreciated about the course.

**Combining Videos and Text-Based Learning**

- **"Worked well together combining videos and text-based learning."** This feedback underscores the effective integration of multimedia resources with textual content, enhancing the learning experience by catering to different learning styles

**Clear and Intuitive Layout**

- **"I think the layout is suitable for most people. Very clear and intuitive."** This quote reflects the user-friendly design of the course, which facilitates easy navigation and understanding, making the learning process more accessible to a broad audience.

**Vertical Structure and Sequence**

- **"Vertical structure makes sense to encourage students to work through it in sequence."** This feedback highlights the logical organisation of the course content, which guides learners through the material in a structured manner, ensuring a cohesive learning journey.

**FIG 4** – Learning experience feedback from beta testing.

These quotes reveal that the course's design, which combines various learning materials formats and presents them in a well-structured layout, significantly contributes to a positive educational experience for the learners.

Key suggestions included incorporating more interactive scenario questions to help students apply knowledge better and offering course materials in downloadable formats for easier access. Participants also suggested including diverse teaching methods, like lectures from industry leaders. These responses underscore the importance of interactive elements and varied learning formats in course design.

## CONCLUDING REMARKS

The necessity for having an open training program related to mine closure and post-mining land uses, as well as the notable gap in the educational space, fuelled the development of this MOOC. The response to launching the beta version was overwhelming, and the expressions of interest for the upcoming full version of the course are vast.

While this massive open online course provides a solid foundation in mine closure planning and sustainable transition to post-mining, it also opens doors to higher-level postgraduate qualifications. Moreover, it offers a parallel track for Indigenous and First Nations stakeholders, incorporating culturally appropriate adjustments and delivery modes through community consultation.

This can result in developing new stackable micro-credentials that go into more depth in areas of specific interest (eg closure and the Indigenous estate, the economic and social aspects of closure, integrated risk analysis for mine closure, and closure planning).

In developing the micro-credential, some of the challenges were:

- To develop flexible learning materials that suit a range of learners, providing them with options to engage with the material in diverse ways (eg as an opportunity to develop and enhance skills or as a stepping stone into other recognised accreditation pathways, such as through an industry body or tertiary institution).

- To offer the content to the broadest possible audience. EdX, the platform hosting the content, has a global reach and allows learners to enrol in the course for free (audit) or pay a small fee to access additional materials, including assessment, and be eligible to earn a verified certificate.
- Due to time constraints, certain elements were not included in the course's initial build. Such elements are regarded as additional material, mostly from case studies worldwide, which the course team aims to incorporate in future iterations.

### Next steps

Participants' feedback has been instrumental in identifying gaps within the content and highlighting areas for improvement and expansion. The next phase involves the course's release on edX, marking a significant milestone in its availability to a global audience. This step is crucial for extending the course's reach and impact, facilitating through a well-orchestrated marketing strategy to broaden the participants' demographic. Emphasis is placed on attracting non-industry participants and enriching the learning community with diverse perspectives and experiences.

## ACKNOWLEDGEMENTS

We extend our heartfelt gratitude to all individuals and organisations who contributed to the development of our Massive Open Online Course (MOOC) Foundation of Mine Closure and Sustainable Transitions. Our work has been enriched and made possible through the collaboration, expertise, and dedication of a diverse group of stakeholders. In addition, we are deeply grateful for the generous support provided by the Cooperative Research Centre for Transformations in Mining Economies (CRC TiME).

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# Assessment to study for an MSc in Mining Engineering by differently qualified applicants at Wits University, South Africa

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## ABSTRACT

The National Qualifications Framework (NQF) Level 9 (masters) program at the University of the Witwatersrand, School of Mining Engineering (Wits Mining) is very popular for anyone in the mining industry. In addition to mining engineers, applicants come from a wide variety of backgrounds including geology, mine planning, mine survey, rock engineering, human resources, and financial. The Faculty of Engineering does allow non-engineers to register for the MSc (Engineering). These applicants are considered to be differently qualified applicants (DQA). DQA includes all students who do not have a BSc degree in Engineering, accredited through the Washington Accord, as specified in the Faculty Standing Orders on Higher Degrees. Wits Mining has outlined various routes for DQA students to gain a seat in the master's program and comply with the Faculty Standing Orders on Higher Degrees. Attendance and successful completion of the NQF Level 7 Introduction to Mining short course is a requirement for all DQA students. This two-week short course covers a variety of topics which would be of interest to anyone wishing to understand more about mining engineering. In addition, the course introduces prospective MSc students to the various academic elements which would be required to complete the postgraduate degree. This course traditionally runs once or twice a year (April and July or July and September) and serves as a primary screening tool for the School to identify the applicants who will not be able to complete a master's degree. This course typically attracts between 35 and 60 delegates, with about half completing the course successfully. There is a further requirement to obtain >65 per cent for the assignment report or the DQA are required to provide evidence of authoring a peer-reviewed paper. Only about a quarter of the delegates meet both criteria. The Introduction to Mining short course is considered an essential tool for ensuring students with the right academic competency enter the MSc program.

## INTRODUCTION

Wits Mining caters to a multidisciplinary group of students in the MSc program. This includes many students who do not have a mining engineering background, such as geologists, mine surveyors, extraction metallurgists, financiers, mine planners, rock engineers, geostatisticians, ventilation specialists, and a range of mining production personnel who do not hold a BSc (Eng) in mining engineering. Wits Mining is currently ranked 12th in the world in the QS ranking for Mineral and Mining Engineering (QS, 2024), making it highly desirable for postgraduate studies for students worldwide. Many of these students have mining engineering degrees that are not accredited through the Washington Accord (International Engineering Alliance, 2024).

A review of the entry requirements for the various Master of Science in Engineering (MSc (Eng)) and professional Master of Engineering (M Eng) programs at the University of the Witwatersrand typically requires an NQF Level 8 Bachelor of Science in Engineering (BSc (Eng)) or equivalent cognate qualification. Furthermore, a minimum average mark of >=65 per cent is required for those progressing straight from the BSc (Eng) into the MSc (Eng), or relevant working experience is described for differently qualified applicants (DQA) (The University of the Witwatersrand, 2024a, 2024b, 2024c). The DQA tables differ for each engineering discipline but usually cater to applicants who do not hold a BSc (Eng) degree and provide routes for these prospective students to gain acceptance into the engineering postgraduate programs. Most of these routes include working experience and a form of a NQF Level 8 postgraduate diploma, such as a Graduate Diploma in Engineering (GDE). DQA typically are limited to the various professional MEng degrees in the various engineering disciplines.

The introduction of the Higher Education Qualifications Framework (HEQF) and the updated Higher Education Qualifications Sub-Framework (HEQSF) (Nel, 2014), along with changes in the University of the Witwatersrand funding model, resulted in Wits Mining phasing out the GDE in Mining Engineering as well as the professional MEng degree. The entry requirements into the NQF Level 8 GDE were lower than the requirements for a Master of Science in Engineering (MSc (Eng)), which is at the NQF Level 9. The GDE allowed students to complete six modules and graduate with the qualification. If students wished to progress to a master's degree, they had the option to complete an additional six modules (including a mini-design) and graduate with the professional MEng degree. The GDE thus previously served as the entry requirement for the DQA into the master's degree.

Entrance into the Mining MSc (Eng) program is guided by the General Rules for the Faculty of Engineering and the Built Environment (The Faculty Registrar Faculty of Engineering and the Built Environment, 2024) and Wits Mining (School of Mining Engineering, 2023). DQA are those who do not hold a BSc (Eng) degree in Mining Engineering accredited through the Washington Accord. DQA students are also limited to an MSc 50/50. Figure 1 shows the various routes for DQA to gain entry into the Wits Mining MSc (Eng) program.

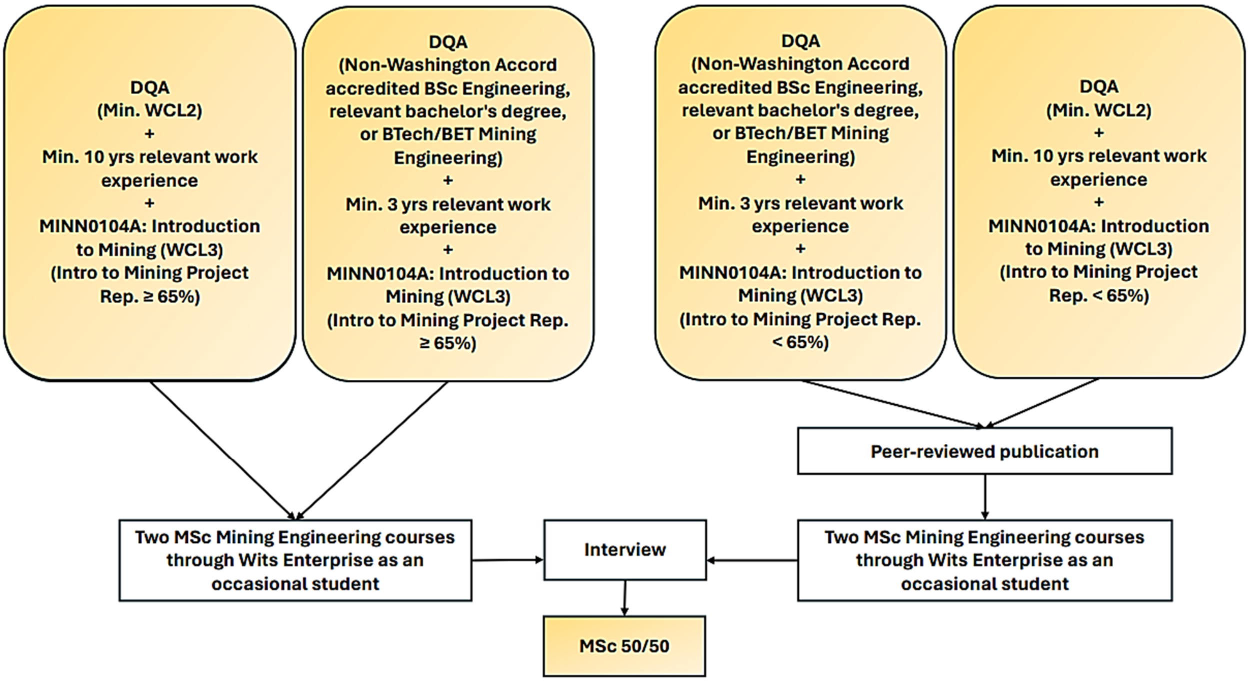


**FIG 1** – The pathways for DQA to an MSc (School of Mining Engineering, 2023).

In Figure 1, it can be observed that a common requirement for all DQA students is the successful completion of the Wits Mining Introduction to Mining Course (School of Mining Engineering, 2023). It is noteworthy that the Introduction to Mining is categorized at the Wits Course Level (WCL) 3, which is equivalent to NQF Level 7. Although the Introduction to Mining is not considered a standalone qualification, it is a prerequisite specified by the Wits Mining for admission to the MSc (Eng) program. Additional requirements include a minimum of ten years of work experience for those whose highest qualification is at WCL 2 (NQF 6), three years of work experience for those with a maximum qualification at WCL 3 (NQF 7), and a minimum score of 65 per cent for the Introduction to Mining project report. DQAs who achieve less than 65 per cent for the project report must provide evidence of a peer-reviewed publication (conference or journal paper) (School of Mining Engineering, 2023).

## INTRODUCTION TO MINING COURSE

The Introduction to Mining Course is a two-week program which typically runs twice per year. The topics covered include:

- Basic mining terminology.

- The mining value chain from exploration to mine closure and rehabilitation.
- The different mining methods including massive mining, narrow reef mining, coal mining, surface mining and mechanical excavation.
- The various technical systems found in mining including ventilation, rock engineering, mine surveying and mine planning.
- The basics of mine financial valuation.
- Mineral processing techniques.
- Policy, legislation and regulations in mining.
- Mining engineering research including library use, critical thinking, research planning and report writing.

There are two assessments for the course (a three-hour exam and a project report) and delegates require a weighted average of 50 per cent to successfully complete the course. The course is presented by a combination of Wits Mining academic staff, as well as external industry representatives.

The project report is assigned to the delegates on the last day. The topic is specific and require the delegates to do an extensive review of available literature to cover the topic adequately. The level of marking is the same as what would be applied during the various MSc modules students will encounter when completing the MSc coursework. Recent research report topics include:

- The implementation of new technologies and the concept known as 'intelligent mining' or 'Mining 4.0'.
- The South African energy crisis and the transition to green, sustainable energy sources.
- The social licence to operate.
- The Fourth Industrial Revolution.
- The impact of South African mining policy on exploration expenditure in South Africa.
- The Mine of the Future and the impact on the South African mining industry.
- New technologies in mining.
- The future of junior mining companies in South Africa.

The reports are assessed using the following criteria:

- Does the introduction clearly identify the fundamental question and is there a suitable abstract for the report.
- Has the student shown innovation in finding relevant sources of information which are clearly understood, extensive relevant and logical discussion with appropriate and clear figures and tables.
- The research topic is critically analysed.
- There are clear conclusions and recommendations.
- All sources of information are properly cited and correctly referenced.
- The report is professionally presented using the formatting guidelines of the Faculty of Engineering and the Built Environment.

The exam is written two weeks after the course, and delegates have four weeks to complete the written research report.

The course also serves to introduce prospective future students to the Wits Mining and familiarizes them with the structure, presentation, and assessment of a typical MSc module. Prospective students have the opportunity to network with their peers from the mining industry as well as with university academic staff. Moreover, they can discuss their research ideas with potential supervisors. Before acceptance into the MSc program, DQA are interviewed, and one of the criteria that the interview panel focuses on is the student's research ideas. Therefore, it is highly beneficial for prospective students to have a clear idea of their research topic before the MSc application process.

## SUCCESS RATES FOR THE COURSE

The successful completion of the Introduction to Mining should be viewed with two criteria:

1. Above 65 per cent for the research report.
2. Overall mark above 50 per cent.

It should be noted that not all delegates attending the Introduction to Mining course aim to gain entry into the MSc program. The course is designed to cater to individuals within or on the periphery of the mining industry who wish to learn more about mining engineering. Many of these delegates do not complete both assessments. Additionally, many delegates choose not to submit the research report if they realise that their chances of completing the course are very low, especially after considering their exam performance. Table 1 provides data on the number of delegates attending and the number of delegates who submitted both assessments over the last ten years.

**TABLE 1**

Introduction to mining results.

| Course | Number of delegates attending the course | Number of delegates submitting both components | The average mark for the exam (%) | The average mark for the research report (%) | Overall average mark (%) for delegates submitting both components | Number of successful delegates (overall pass and >65% for report) |
|---|---|---|---|---|---|---|
| November 2014 | 34 | 31 | 55 | 59 | 57 | 11 |
| July 2015 | 40 | 33 | 51 | 64 | 56 | 15 |
| July 2016 | 38 | 36 | 49 | 55 | 52 | 12 |
| April 2017 | 35 | 31 | 49 | 60 | 54 | 9 |
| July 2017 | 35 | 31 | 46 | 54 | 50 | 7 |
| July 2018 | 37 | 35 | 52 | 56 | 54 | 10 |
| September 2018 | 45 | 35 | 46 | 50 | 47 | 8 |
| July 2019 | 40 | 28 | 45 | 58 | 51 | 6 |
| October 2019 | 54 | 44 | 46 | 52 | 48 | 11 |
| November 2020 | 44 | 45 | 43 | 57 | 47 | 12 |
| April 2021 | 46 | 35 | 38 | 53 | 43 | 10 |
| July 2021 | 45 | 29 | 40 | 52 | 46 | 9 |
| July 2022 | 67 | 47 | 44 | 53 | 49 | 17 |
| July 2023 | 63 | 48 | 43 | 59 | 50 | 17 |
| September 2023 | 49 | 37 | 40 | 63 | 50 | 17 |
| Totals and weighted averages | 672 | 545 | 46 | 56 | 50 | 171 |

Table 1 reveals that the overall average mark for the course is only 50 per cent. Of the delegates who submit both components for assessment, only 31 per cent meet the criteria for entry into the MSc program (25 per cent of those who register for the course). A significant proportion of the delegates (19 per cent) who register for the course fail to submit one or both of the assessments. Unfortunately, records are not kept for how many of the delegates registering for the Introduction to

Mining course are doing so as part of an MSc application. However, it is estimated to be at least three quarters based on a show of hands during the welcoming session.

Figure 2 shows the number of successful attendees on the courses.

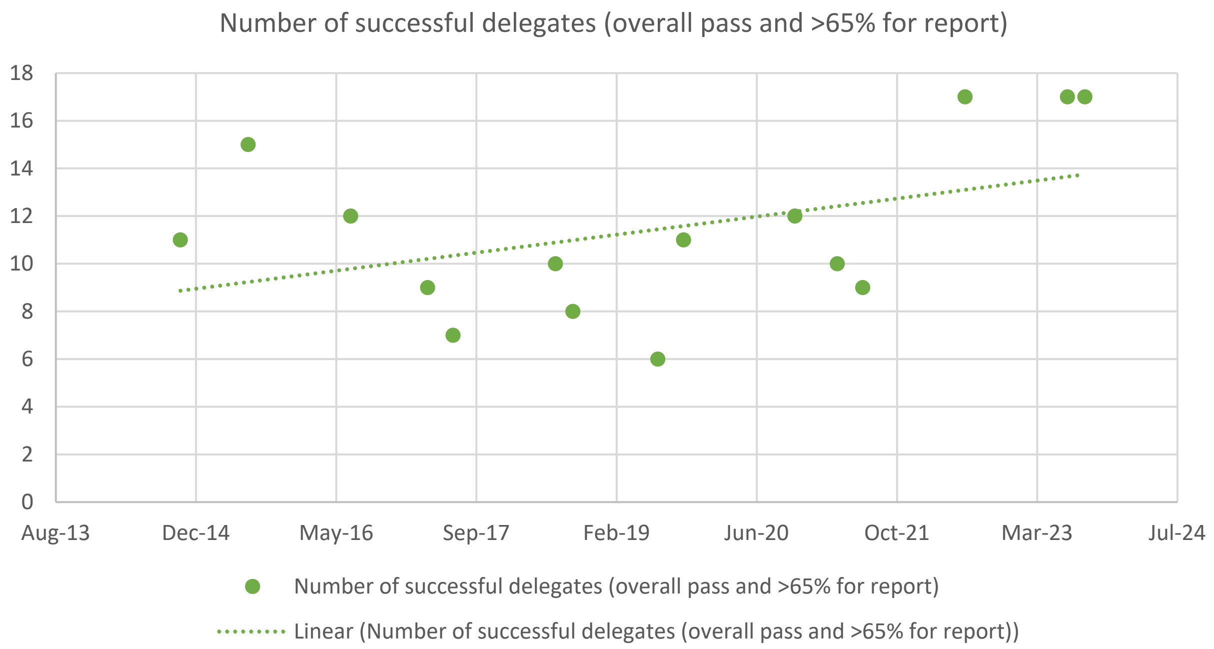


**FIG 2** – Number of successful Introduction to Mining delegates.

It can be observed in Figure 2 that there has been an upward trend in the number of successful attendees on the course. The course was held once in 2014, 2015 and 2016, but due to increased demand, it was run twice in 2017, 2018 and 2019. The 2020 course was affected by COVID-19 and was held online. In 2021 and 2023, the course ran twice, while in 2022, it ran only once but with very high delegate numbers. The increase in delegates and the number of courses being run shows that demand for places in the MSc (Eng) program is increasing. Very few of the DQAs have published peer-reviewed papers, meaning that achieving a score of >65 per cent for the research report is vital for their successful application into the MSc (Eng) program.

## DIFFERENTLY QUALIFIED APPLICANTS' PERFORMANCE ON THE MSC DEGREE

Wits Mining and the Faculty of Engineering and the Built Environment are evaluated based on successful graduations rather than the number of students in the various programs. Therefore, there is pressure to ensure that the right candidates are selected for the degree programs to improve the pass rate. Allowing DQAs to register for the MSc program poses a significant risk for Wits Mining. Many DQAs have extensive industry experience but lack the academic background to operate at the MSc level. This becomes particularly evident as students' progress from the modules to the research component of the 50/50 MSc (Eng) degree. The 50/50 MSc (Eng) requires the student to complete four modules for 20 credits each and the research methodologies module for 10 credits. The research report accounts for the balance of the 180 credits.

To address this issue, the School of Mining Engineering has introduced an additional requirement for DQAs to complete two MSc (Eng) modules as occasional students before registering as MSc students. This approach alleviates some of the time pressure in the MSc program (two years for part-time students, with a maximum extension of two years). This provides additional time to focus on the MSc (Eng) research report (School of Mining Engineering, 2023).

Currently, there are 125 students registered for the MSc (Eng) degree. Six of the students are registered for MSc by dissertation, with the remaining 119 registered for the MSc 50/50. Of these students 56 are DQA and have successfully met the entry requirements, including passing the Introduction to Mining course with >65 per cent for the research report.

## CONCLUSIONS

The Introduction to Mining course is a core component for a successful application to the MSc (Eng) degree for DQAs. The course must be passed overall (>50 per cent), and the mark for the research report must be above 65 per cent (or evidence of a peer-reviewed paper must be provided). These criteria were added by the Wits Mining due to the phasing out of the GDE and MEng, and the route for DQAs to obtain a master's degree. The Wits Mining caters to mining personnel from a range of disciplines, not just mining engineers. Many of these DQAs see a master's degree as critical for their advancement in the mining industry, and their own disciplines do not offer a specific qualification suitable for them. The 50/50 MSc (Eng) allows them to continue their postgraduate studies in a format that combines their work life with their academic pursuits.

The Wits Mining receives far more applicants than the resources allow for and thus needs to ensure only suitable candidates are admitted to the postgraduate program. The successful completion of Introduction to Mining has become part of the application screening process. Many of the delegates who attend the course realize that they would not have been successful if they had gained entry into the MSc (Eng) degree and identify the need for other forms of development to ensure their academic success in the future. This is particularly noted in their research and writing skills, which are fundamental to any postgraduate degree.

## ACKNOWLEDGEMENTS

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# Securing the future of the historic mining towns, through of mining heritage – World Mining Heritage sites and sustainable development

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## ABSTRACT

In this paper we will emphasise the important role that the protection of mining heritage can have on the search for alternative solutions in the context of sustainable development in areas where mining has been the only local economic engine for long periods time. For this reason, it is of vital importance to protect and enhance this heritage as a potential source of wealth and an alternative for the future development of many depressed mining areas.

The enhancement of mining heritage contributes, in general, in all aspects (ecological, economic, social and cultural) to achieve a sustainable development of mining town and communities.

There are a number of places where mining and metallurgy has played a key role in the lives of these territories. For this reason and others, they have been declared 'World Heritage Site' (WHS). This demonstrates the importance of the mining industry has had in transforming societies, landscapes, regions and cities around the world through the history of mankind.

In this article we have listed and briefly described these places, their relation to mining and the importance of that statement has been for the sustainable development of those territories.

The society must know the important role that mining has had on the history and development of humanity and the transformation of landscapes, regions and cities around the world through history.

# From mines to minds – exploring immersive learning's influence in mining engineering education

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## ABSTRACT

Mining education entails mastering complex analysis and visualisation of geological data and extraction methods. It traditionally relies on textbook models and computer-aided design software for visualisation. The existing methods, once successful in their era, now encounter challenges due to the evolving demand of the mining industry. The industry now seeks professionals equipped not only with theoretical knowledge but also with practical expertise. This shift is driven by the recognition that students often struggle to reconcile traditional approaches with real-world observation and, consequently, face limitations in applying their knowledge in practical scenarios. Educators are embracing a paradigm shift towards immersive learning experiences in response to this imperative need. Moreover, this system integrates a series of virtual reality human-machine interaction hardware, so students can quickly learn the required skills. This paper aims to explore the revolutionary potential of immersive learning methods in mining engineering education when comparing their impact on students' learning outcomes and engagement with traditional pedagogy. The research methodology employs a comprehensive investigation into the effectiveness of immersive learning using surveys and data analysis methods. Data was collected using pre- and post-VR exposure surveys. The data was analysed with an R analytics tool considering factors like learning outcomes, engagement, and satisfaction. The immersive education tool employed in the experiment replicates the San Xavier Underground Mining Laboratory as a digital twin. Participants for the study were recruited from the mining engineering program at the University of Arizona, USA. This research contributes significantly to pedagogical innovations preparing future mining engineers with practical skills for success in a dynamic professional landscape. The adoption of immersive learning methods can help bridge the gap between theoretical knowledge and producing well-rounded and highly skilled mining engineering graduates.

## INTRODUCTION

Mining education entails mastering the complex analysis and visualisation of geological data and extraction methods, traditionally relying on textbook models and computer-aided design software. In mining engineering, hands-on learning is crucial to traditional methods that often fall short. For students to develop practical experience and understand the complex geological ore formation and mapping, geotechnical instabilities, underground support systems, ore blasting design, and hazard identifications, underground and surface mining visits are the conventional approaches. While visiting the actual mines is beneficial to student learning, it is time-consuming to organise, expose students to mine risk, and students may not be allowed to access certain areas during the visit – limiting the full learning experience (Fei and Anbi, 2011). An alternative method that requires less time, is safe, and allows full access to mine facilities with full experience as visiting the mine is desirable. Technological advancements are shifting the focus to more adaptive, evidence-based learning tailored to individuals. Virtual reality (VR) is a significant innovation in this area as it provides precise and immersive educational simulation that enhances the learning experience (Jindal, Mittal and Bansal, 2023). Immersive VR has been integrated into engineering pedagogy including areas such as biomedical, environmental engineering, and mechanical engineering (Wilkerson *et al,* 2022; Tanbour, 2022; Han, Weeks and Leite, 2023). Fei and Anbi (2011) proposed a VR model for mine safety education without providing actual visualisation of the mine and the model was not tested to assess the mine safety experience and acceptability of the approach by the students. Zhang, Wang and Li (2011) developed a VR system for a mechanised mining face using OpenGL and Visual C++ 6.0. While the authors proposed a VR learning experience model, the model was not evaluated by students to understand its practicality and acceptance to use in the classroom environment. Grabowski and Jankowski (2015) experimented with the use of VR for training 21 young miners in coal mining and concluded that employing VR may improve the training experience. Zhang (2017) studied the use of head-mounted-based VR for drilling training in underground mines. Though the number of participants was very small (ten), however, the author concluded that VR may improve the drilling experience in underground mines. Literature shows a lack of implementation of VR for evaluation and educational purposes (Zhang, He and Mitri, 2019). This creates a gap for a thorough exploration of the link between VR and evidence-based practices in mining engineering education.

VR can simulate operations and mining scenarios, allowing students to better understand the mining process. Therefore, a critical question arises: How effective is immersive learning in enhancing students' outcomes to traditional instructions?

This context sets the stage for exploring the impact of immersive learning on student outcomes and engagement, comparing traditional instruction with adaptive and immersive technologies that contribute to the discourse on innovation in engineering education.

## RESEARCH METHOD

The study investigates the impact of immersive learning on mining engineering students at the University of Arizona. Evaluating how VR simulations affect learning outcomes, engagement, and satisfaction comparing it with traditional teaching methods. The population includes junior and senior mining engineering students as an experimental group. The immersive education tool used in the experiment is a digital twin (DT) of the San Xavier (SX) Underground Mining laboratory owned by the University of Arizona and neighbouring surface mines.

Participants were recruited through announcements in a mining engineering class and email reminders for survey participation, with extra credit incentives to encourage participation. The tools used in this study include Oculus Rift VR headsets and MineLife software (SX digital twin). Data was collected using Qualtrics and analysed using R programming language and R studio.

The data collection method comprised pre- and post-VR exposure surveys. The pre-survey aimed to gauge initial perceptions and expectations regarding VR technology, including questions on prior VR experience, their confidence in using VR for learning, enthusiasm about VR, and understanding of surface and underground mine planning (Table 1a). During the VR session, students in the experimental group used Oculus Rift headsets to engage in an immersive learning experience using Minelife software. These sessions were conducted in the classroom and provided technical support for smooth operation. The students were asked to fill out the survey which took not more than 2 mins. Post-survey assessed students' experiences, perceived advantages, and challenges of using VR compared to traditional methods. It includes questions on additional qualitative data collected through some closed and open-ended questions to gather detailed insights into student's perceptions (Table 1b).

Pre- and post-survey data were analysed using R to identify changes in student perceptions and learning outcomes. Statistical tests, such as paired t-tests and ANOVA, were used to compare the experimental and control groups. Qualitative responses were done using thematic analysis to identify common themes and insights. The study was approved by the University of Arizona Institutional Review Board.

**TABLE 1A**

Pre-survey questions.

| Questions | Options |
|---|---|
| Rate your level of experience with VR technology | Novice<br>Advanced beginner<br>Competent<br>Proficient<br>Expert |
| How do you feel about utilising VR technology as a learning aid in this course? | Very Unenthusiastic<br>Unenthusiastic<br>Indifferent<br>Enthusiastic<br>Very Enthusiastic |
| I am more motivated to participate in the course because of the prospect of a VR experience | Strongly disagree<br>Disagree<br>Indifferent<br>Agree<br>Strongly Agree |
| I feel I understand surface/underground mine planning and design | Strongly disagree<br>Disagree<br>Indifferent<br>Agree<br>Strongly Agree |
| I feel good before going into the virtual environment | Strongly disagree<br>Disagree<br>Indifferent<br>Agree<br>Strongly Agree |
| How confident do you feel about your abilities to use VR as a learning tool? | Level of Confidence on a scale of 0–100 |

**TABLE 1B**

Post survey questions.

| Questions | Options |
|---|---|
| On a scale of 1 to 5, rate the level of realism of the virtual environment | Very Poor<br>Poor<br>Average<br>Good<br>Very Good |
| The VR environment improved my understanding of the course concepts | Strongly disagree<br>Somewhat disagree<br>Neither agree nor disagree<br>Somewhat agree<br>Strongly agree |
| Some people experience motion sickness. Did you feel that? | Yes<br>Maybe<br>No |
| I sometimes found that I become very involved with the virtual reality world | Strongly disagree<br>Disagree<br>Indifferent<br>Agree<br>Strongly Agree |
| I felt that I was standing in the mine | Strongly disagree<br>Disagree<br>Indifferent<br>Agree<br>Strongly Agree |
| In order of priority, which teaching method do you prefer in relation to this course? | Videos<br>Traditional classroom setting/PPT<br>VR |
| Did the immersive learning experience help you retain the course material better than traditional teaching methods (eg ppt)? | Yes<br>No<br>Not Sure |
| Did the immersive learning experience help you retain the course material better than traditional teaching methods (eg ppt)? | Yes<br>No<br>Not Sure |
| Would you like to see more immersive learning experiences incorporated into your courses? | Yes, I think it would be helpful<br>No, I don't think it would be helpful<br>Not sure |

## RESULTS AND DISCUSSION

The pre-survey revealed that most students (n=45) were novices with no prior experience with VR technology, this indicates the need for introductory training before integrating VR into the course (Figure 1a). Enthusiasm (Figure 1b) for VR varied, with many students feeling enthusiastic to very enthusiastic (55.6 per cent) but a significant portion remained indifferent, and a smaller group was unenthusiastic. This also suggests a need to address anxieties and boost interest in Virtual Reality potential.

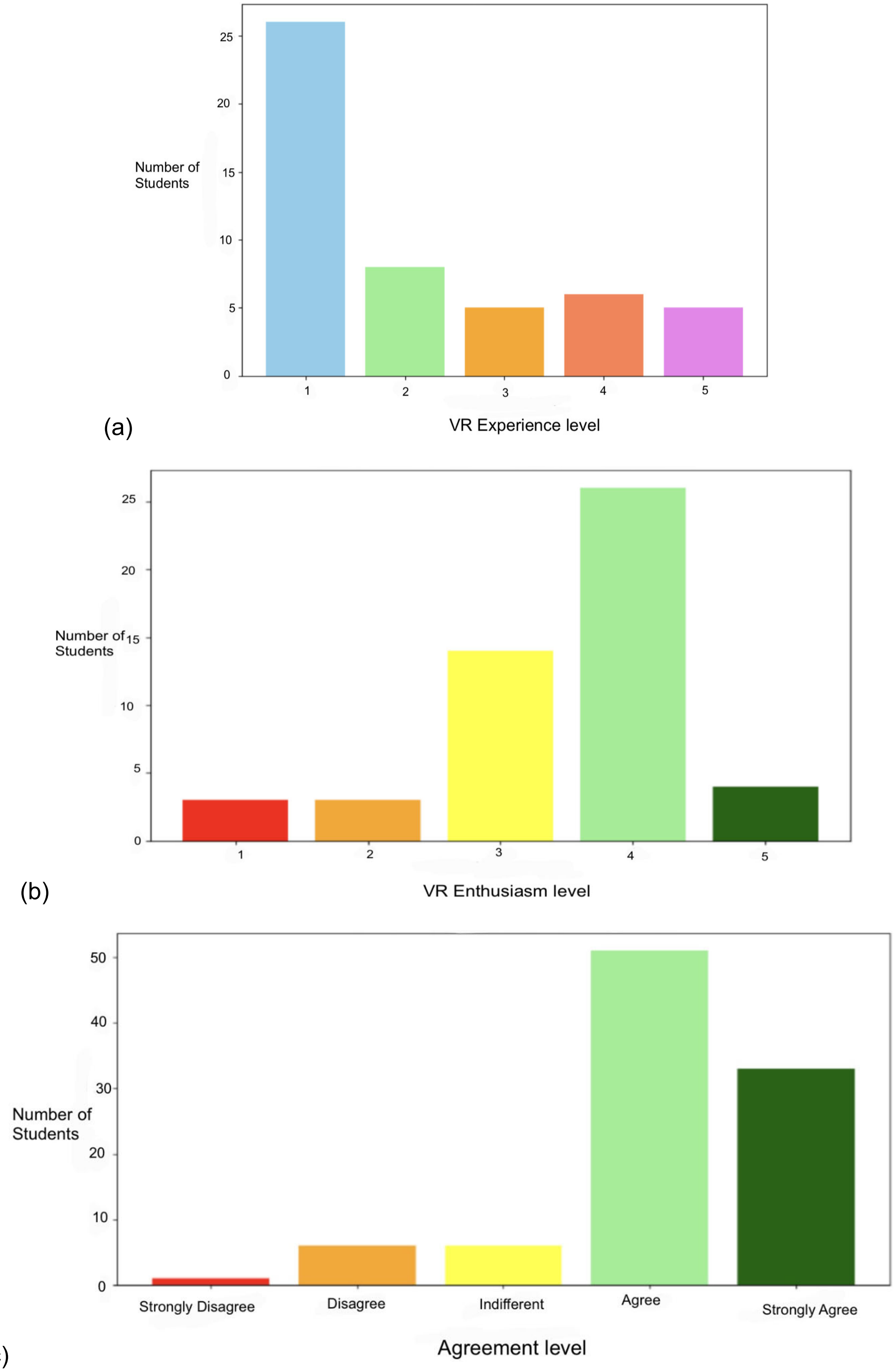


**FIG 1** – (a) Distribution of VR experience levels (n=45); (b) Distribution of VR enthusiasm (n=45); (c) Distribution of agreement on VR usefulness (n=45).

Regarding Virtual Reality's usefulness for learning surface and underground mine planning, student opinions ranged widely on a scale from strong agreement to strong disagreement with many students unsure (Figure 1c). Since 62 per cent of students were Virtual Reality novices. It was expected that their opinions would vary widely, ranging from strong agreement to strong disagreement, with many expressing uncertainties. Since 62 per cent of students were Virtual Reality novices, initial discomfort with Virtual Reality was expected, highlighting the need for tailored instruction and support. However, the study faced limitations, including the absence of a control group and a small sample population. The overall study underscores the importance of introductory Virtual Reality training and strategies to enhance student enthusiasm and the perceived usefulness of Virtual Reality in education.

The results underline the effectiveness of immersive VR technologies in enhancing educational outcomes in mining engineering. VR's capability to simulate detailed and complex mining environments offers students a deeper, more practical understanding of the field, which is often difficult to achieve through conventional classroom-based teaching. This study suggests that VR not only improves engagement and satisfaction but also facilitates a deeper comprehension of intricate mining operations.

## CONCLUSIONS AND FUTURE WORK

Immersive learning technologies such as VR represent a transformative approach to mining engineering education. Effectively implementing it will bridge the gap between theoretical knowledge and practical application. Virtual Reality has the potential to significantly enhance the educational landscape to prepare a new generation of mining engineers for the complexities of their future careers. This research will support the broader integration of Virtual Reality technologies into educational curricula, aligning with the industry's evolving demands for skilled and practical adept professionals.

In our research, we aimed to explore the potential of VR in enhancing mining engineering education. We implemented VR-based modules to provide students with a practical immersive learning experience that complements their theoretical studies. Based on our results, we concluded that integrating VR technologies into educational curricula significantly improves students' understanding and retention of complex concepts. This approach aligns with the industry's evolving demands for skilled and practically adept professionals, supporting the broader integration of VR technologies in education.

Future research directions include expanding the sample size to involve a larger and more diverse group of students (100+), incorporating a control group in future experiments to provide a more robust comparison between Virtual Reality and traditional teaching methods, and conducting longitudinal studies to assess the long-term impact of immersive learning on the student's performance and career readiness. Addressing technical challenges related to viewpoint, spatial location, realism, and media modes in Virtual Reality simulations will optimise educational benefits.

This comprehensive methodology ensures a detailed understanding impact of immersive learning on mining education providing a foundation for future research and improvement in education practices. Immersive learning technologies, such as VR, represent a transformative approach to mining engineering education. By effectively bridging the gap between theoretical knowledge and practical application, VR has the potential to significantly enhance the educational landscape, preparing a new generation of mining engineers for the complexities of their future careers. This research supports the broader integration of VR technologies into educational curricula, aligning with the industry's evolving demands for highly skilled and practically adept professionals.

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# The mining degree apprenticeship – the future of mining engineering education in the UK

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## EXTENDED ABSTRACT

In August 2020 during the Covid-19 pandemic the University of Exeter decided to stop the undergraduate degree in Mining Engineering offered by the Camborne School of Mines (CSM). This was the last such course in the UK following closures since 2000 of similar courses at Leeds University, Nottingham University and the Royal School of Mines in London. A low number of applicants was cited as the reason, a trend that was just not limited to the UK, but has been noticed in many other countries. This was an existential threat to the future of CSM.

Faced with a lack of students and degree level qualifications, the UK mining industry, through the Mining Association of the UK (MAUK) made the decision to pursue the development of a Level 6 Degree Apprenticeship (DA). A degree apprenticeship is essentially an apprenticeship at the degree level and are a new type of programme promoted by the UK Government and offered by some universities. Like other apprenticeships, these programmes are developed by employers, universities, and professional bodies working in partnership and combine working at a mine with studying part-time at a university. Apprentices are employed throughout the programme, and spend part of their time at university and the rest with their employer. The course fees are paid by the Government from a levy imposed on employers related to their overall employment costs. This levy can be drawn down by companies for all levels of training, not just degree apprenticeships.

Degree Apprenticeships develop knowledge, skills and behaviours (KSBs) required for a specific job role and combine this with academic learning at the appropriate level. Degrees offered as part of the apprenticeship are aligned to the qualification descriptors and relevant subject benchmarks.

## THE DEVELOPMENT OF THE DEGREE APPRENTICE SPECIFICATION

In order to develop such an apprenticeship a detailed specification has to be developed by industry following an identified need, and subsequently approved by the Institute of Apprenticeships and Technical Education and then signed off by the relevant Minister. This specification consists of an ‘Occupational Standard’ and an ‘End Point Assessment (EPA) Plan’.

An occupational standard is a short and concise document that describes the KSB’s needed for someone to be competent in the occupation’s duties. The EPA plan details the independent assessment that apprentices must take after their formal education and training. This will confirm whether they have achieved the KSB’s needed to undertake the occupational standard’s duties and therefore pass the qualification. This EPA is integrated into a degree course, normally as the last element and upon successful completion, the apprentice receives both a degree and a Level 6 qualification.

A small working group made up from members from MAUK, CSM and HM Inspectorate of Mines, developed the specification over a period of six months and in doing so considered what mines and mine management of the future may look like both domestically and internationally, and identifying content adequate for this. Once developed, a period of wider consultation took place with mines through the UK’s Mines Qualifications Committee. This specification was submitted in March 2022 and approved and signed off by the Minister the following October (IfATE, 2022).

In total the Group identified 28 knowledge requirements, 20 skills requirements and eight behaviours that formed the standard. An example of some of these KSB’s (IfATE, 2022) can be seen in Table 1.

**TABLE 1**

Example of some of the Mine Management Standard KSB's.

| Knowledge |
|---|
| K1: The mining life cycle including the key regulations, standards and guidance that influence the design, construction and operations and closure of mining operations. |
| K2: Physical geology on the mine environment, including the physical properties of rock, soil and mineral deposits and the impact of weathering, plate tectonics and geomorphic features. |
| K4: Design principles of mines and layout including geology and geomechanics, layout, size and position of mine entries and roadways, and the systems and equipment used for extraction and mine support. |
| K10: Mineral preparation, processing, and waste management techniques including the use of separation techniques, methods of concentrating and further refining, the handling and transport of bulk solids and the safe, sustainable disposal of mineral waste and tailings. |
| K19: The principles of mine closure and legacy risk management. |
| **Skills** |
| S2: Undertake the mine design process, incorporating elements such as mine layout, roadway design, scheduling, resourcing and ventilation. Determine the impact that these decisions have |
| S4: Collect, analyse and use data from mining and asset management systems to review the impact on operation, using the outputs to improve the safety, efficiency and effectiveness of the mining system. |
| S17: Manage and lead others including conflict management. |
| S18: Plan and manage own time. |
| **Behaviours** |
| B2: Act as a role model and advocate environmental, ethical, and sustainable practices. |
| B3: Collaborate and promote teamwork across disciplines. |
| B4: Adapt and is resilient to challenging or changing situations. |
| B5: Lead by example to promote accessibility, diversity and inclusion. |

The EPA consists of: (i) a submission of a portfolio of evidence showing how the apprentice meets the KSB's that consists of a logbook completed over the four years of study, workplace document and records and course assignments; (ii) a final project and presentation; and (iii) a professional interview with independent assessors.

## THE DEVELOPMENT OF THE PROGRAMME STRUCTURE and SYLLABUS

Anticipating the successful approval of this specification, CSM started to create a programme and syllabus built around the duties and KSB's. In creating this programme consideration was not only taken by the knowledge and experience of staff, but also from looking at other institutions and courses as well as best practice (such as Society of Mining Professors, 2019). In addition, an Industry Advisory Board was formed to seek guidance and provide industry insight on the revitalised curriculum and to assess the level of potential interest in the proposed degree-level blended learning programme an online survey was conducted. This gave encouraging results suggesting that there is significant interest from industry in the programme and structure, not just from within the UK but also from overseas.

Right from the start various modes of delivery were considered. Many other such apprenticeships delivered the teaching (knowledge) face to face through a number of residentials each year. For example, the Civil Engineering Apprenticeship at the University of Exeter, which runs for five years, teaches over four two-week blocks every three months. Having just come out of Covid where online delivery was accelerated, it was decided to use this approach for the majority of the teaching as in the consultation, block teaching wasn't considered favourable. CSM's location in the far south-west of the UK also ruled out the possibility of face to face day release.

It was decided to run the course over four years and the degree-level blended learning curriculum (shown in Figure 1) provides engineering fundamentals in year 1, key mining skills in year 2, mine design skills in year 3 and core business and leadership skills in year 4. The middle column of this figure shows the essential topics and the column on the right shows the modules that would deliver the content with one module running per typical University term and the number shows its credit value.

| | | |
|---|---|---|
| **Year 1: Engineering Fundamentals** | **Engineering Maths & Data Analytics (2)**<br>**Engineering Fundamentals (2)**<br>**Mine Challenge Project (3)**<br>**Professional & Key Skills (1)**<br>**The Mining Life Cycle (1)** | **1) Mining Life Cycle & Professional Practice (30)**<br>**2) Engineering Fundamentals (30)**<br>**3) Mine Challenge Project (30)** |
| **Year 2: Key Mining Skills** | **Applied Engineering Principles (3)**<br>**Orebody Exploration & Characterisation (1)**<br>**Applied Geomechanics (1)**<br>**Mining Excavation & Planning (2)**<br>**Geomatics (2)**<br>**Safety & Hazard Management (2)**<br>**Energy Transition & Sustainability (3)** | **1) Resource Characterisation (30)**<br>**2) Resource Development (30)**<br>**3) Energy & Sustainability (30)** |
| **Year 3: Mine Design Skills** | **Mining Digitalisation & Automation (1)**<br>**Mineral Processing, Tailings & Integrated Resource Recovery (3)**<br>**Excavation Design & Optimisation (2)**<br>**Tunnelling and Underground Space (2)**<br>**Applied Machine Learning in Mining (1)**<br>**Ventilation & Occupational Environmental Engineering (2)**<br>**Mine Closure & Legacy Risk Management (3)**<br>**Individual Research or Business Improvement Project (Year 4)** | **1) Digitalization & Automation (30)**<br>**2) Design & Optimisation (30)**<br>**3) Material Processing (30)** |
| **Year 4: Core Business Skills & Leadership** | **Project & Enterprise Risk Management (1)**<br>**Business Evaluation & Continuous Improvement (1-3)**<br>**Macro Economics & Strategic Thinking (2)**<br>**Mineral Economics & Asset Management (2)**<br>**Tactical & Strategic Planning: Life Cycle Analysis (1)**<br>**Environmental Social Governance (1)**<br>**Group Feasibility Study (1-3)** | **(1-3) Feasibility & Business Improvement (30)**<br>**1) Environmental Social Governance (30)**<br>**2) Economics & Risk Management (30)** |

**FIG 1** – Programme content and taught modules.

When not formally studying the apprentices are undertaking their normal employment roles whilst at the same time collating evidence on a continual basis of how they are putting the KSB's into practice in their jobs. Overall the course consists of approximately six hrs a week of remote learning, up to four weeks of on-site activity (one two week residential at CSM and seperate site visits) per annum and the implementation of skills and behaviours in the workplace. The site investigation element is one of the unique aspects of the programme, in essence using UK mines as classrooms whereby all the apprentices meet up undertaking their assessments through vocational activity at the most appropriate operations for that activity and in doing so see and work in other operations then their own. These UK Mines all are part of MAUK and this was considered as best practice by IfATE.

## THE FIRST YEAR

The first cohort of 14 students from across the UK resource sector started the programme in September 2023. They have a range of experience: from mine surveyor, rock bolt coordinator, shift supervisors to production managers and even a mine manager of a small bathstone mine. Figure 2 shows the cohort during their first site visit at Aberpergym Colliery in Wales


**FIG 2** – The first cohort (Oct 2023).

Their two week residential in Cornwall in April 2024 consisted of face to face teaching of engineering principles for their ‘Engineering Fundamentals’ module, engineering labs, visits to local mines and quarries and team building exercises. At the time of writing the apprentices have started their ‘Mine Challenge Project’ which is looking at the logistics of reopening a small fluorspar mine one of the UK’s national parks. There are bi-yearly meetings with employers and an experienced academic mentor has been employed who visits the apprentices at their mines every couple of months.

The course has been heavily promoted and was even mentioned in the UK Governments critical metals strategy (UK Government, 2022). It was very pleasing that during a visit to CSM by HRH the Princess Royal, she officially ‘launched’ the course raising the profile further (see Figure 3 showing Her Royal Highness along with the University of Exeter’s Vice Chancellor and the CSM student president). We are currently accepting applications for September 2024 entry which will open up the model to potential overseas applicants who are working at mine sites internationally.


**FIG 3** – The Royal Launch of the Programme.

## CONCLUSION

This new programme has been a success, judging by the level of interest shown and in feedback so far from apprentices and their employers. By being future leaders within the resource industry, these apprentices can play a major role in the delivery, direction and stewardship of a greener and more responsible extraction of natural resources. Although introduced to provide a short-term alternative to a full-time undergraduate degree, it presents a new and exciting alterative mode of delivery that has clear benefits to those studying. Whilst the first cohort has consisted of experienced mine operatives, it is pleasing to see some employers recruiting school leavers with a view to registering them on the next intake. It is also pleasing to report that CSM is now looking to restart its full-time degree within the next 18 months giving opportunities to those interested in the subject who are just leaving school or not working at mines. However, the long-term success of all this depends on industry, academia and professional institutions working together to better promote our industry to young people. With the energy transition our industry has never been so important and we have a ‘once in a generational’ opportunity to remould and change the perceptions of mining for the better within society and amongst young people to show the range of opportunities and subjects (not just engineering) to encourage them to join us.

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# Unique and comprehensive approach to raw materials education, covering Life Cycle Assessment/Costing (LCA/LCC)

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## ABSTRACT

The European Union (EU) has committed under the EU Green Deal to become the first carbon-neutral continent by 2050 by introducing innovation and relevant education. For that purpose PhD level course program will focus on Life Cycle Assessment/Costing (LCA/LCC) and new business development, which are in high demand from EU industry partners. Emphasising converting the acquired knowledge into actionable entrepreneurship. This program will prepare the talents with innovative solutions/ideas to apply for entrepreneurship funding in other EIT activities, additionally the PhD student teams can validate their business idea via EIT Jumpstarter while also providing them with the necessary skills and knowledge in LCA/LCC and new business development. Our goal is to support the EU's efforts to achieve its carbon-neutrality objective by enabling the next generation of green entrepreneurs to develop sustainable business practices. The uniqueness of the course lies with one of the biggest challenges for the industry and those who perform the LCA/LCC analysis which is the lack of understanding of a common 'language' and methodologies and what information is required from the industry to perform proper LCA/LCC analysis to support the green transition.

To be successful, we have identified industrial associate partners and start-ups who are open and willing to be the source of real LCA/LCC case studies for the course to enable students to co-create feasible solutions through open innovation while supporting networking and matchmaking opportunities. This allows to prepare young professionals who are ready to communicate using language used by LCA and LCC experts and use their new knowledge to enhance sustainability at EU companies, as well as empower them to move their ideas from knowledge to application via new business development.

# Enhancing mining engineering education through competition-driven project courses

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## INTRODUCTION

Mining Engineering relies on collaboration with various other disciplines, such as Electrical Engineering, Mechanical Engineering, Civil Engineering, Computer Science and Engineering, and Chemical Engineering. As the mining industry swiftly transitions into the digital mining era, the demand for advanced technologies such as Artificial Intelligence and the Internet of Things is increasing. To equip future mining professionals with the necessary skills, the University of New South Wales (UNSW) has implemented multidisciplinary group projects within its Mining Engineering programs at the School of Minerals and Energy Resources Engineering (MERE).

## DESN2000 MINING STREAM

In the second year of undergraduate study at the Faculty of Engineering, Introduction to Engineering Design and Innovation (DESN2000) is a core subject, meaning it is compulsory for all undergraduate students. DESN2000 aims to further develop students' skills in engineering design, particularly focusing on the early stages where innovative concepts are created in response to open-ended problems. We developed a project entitled 'Small is the New Big.'

So far, the global mining sector is dominated by large-scale mining. However, with the development of science and technology, particularly the rapid progress in unmanned machinery and artificial intelligence, it is time to consider a new small-scale mining system. This system would use small machinery with AI to achieve high efficiency and reduce the environmental footprint, especially in extreme environments. In this project, each group of students (three to four members) should choose one extreme environment scenario from the following:

- the moon
- asteroid
- deep sea
- Mars.

To make the design work more motivating, we identified real competition opportunities and made them optional topics. For instance, since 2021, the Over the Dusty Moon Challenge (Dusty Moon) (Colorado School of Mines, 2024) has been available. In 2023, we added NASA's Revolutionary Aerospace Systems Concepts Academic Linkage (RASC-AL) Large Scale Lunar Crater Prospector competition (NASA, 2024). In 2024, we added the Australian Rover (Lunar) Challenge (The University of Adelaide, 2024) and the University Rover (Mars) Challenge (The University Rover Challenge, 2024).

Table 1 shows the number of students enrolled in DESN2000 and the number of groups that selected the competition projects. In 2021 and 2022, after completing DESN2000, the designs for the Dusty Moon Challenge were submitted to the competition. Both were selected as one of the six teams globally to advance to the second stage of the competition. The 2022 team's submission was the Lunar Cable-Car Conveyance System (LCCS), inspired by conventional cable-car systems used on Earth, which are lightweight, use very low power, and can traverse rugged terrain unimpeded. The 2023 team's submission was an Autonomous Slat Conveyance System (ASCS), which was based on the outcome of DESN2000 (2022) and Vertically Integrated Projects (VIP) MINEX (2022).

**TABLE 1**

Number of students in DESN2000 and the number of groups that selected the competition projects.

| Year | Student no (female) | No of groups selected competition project |
|---|---|---|
| 2021 | 8 (1) | 1 Dusty Moon |
| 2022 | 7 (2) | 1 Dusty Moon |
| 2023 | 12 (2) | 1 Dusty Moon and 1 RASC-AL |
| 2024* | 22 (4) | 1 Lunar and 1 Mars |

*From 2024, MERE's DESN2000 moved from Term 3 (September to December) to Term 2 (May to August).

As the second-stage in-person competition requires building a prototype and DESN2000 has concluded, another scheme is needed to support this activity. We use the VIP program to provide this support. The VIP program allows us to recruit students from any discipline within the Faculty of Engineering, enabling us to create a multidisciplinary team to work on the prototype (as different skills are needed) and attend the in-person competition. In this way, we have linked DESN2000 and the VIP program. Students from MERE can learn from students in other schools, and students from other disciplines get an opportunity to learn about the mining sector.

## VIP PROGRAM MINEX PROJECT

The VIP Program is an innovative approach to enhancing higher education by involving undergraduate and postgraduate students in ambitious, long-term, multidisciplinary project teams led by UNSW researchers. UNSW is a member of the worldwide VIP consortium. VIP programs are currently active in over 40 universities, with more than 4500 students participating per term globally. At UNSW, there are currently 18 projects underway as of 2024, including MERE's project called MINEX.

MINEX was started in 2020, there were two topics: Mine Internet of Things and Space Mining. We noticed that even we tried our best to design the project and involved industry partners, there lacks of motivation for students to work on projects.

In 2022, MINEX introduced the Over the Dusty Moon Challenge for the first time to support the in-person competition. Two members of the original DESN2000 team, Mathisuthanan and Hu, joined the VIP program. Among them, three are MERE undergraduate students, while the others are from Mechatronics or Aerospace disciplines. Barnett, a PhD candidate specialising in space mining from MERE, served as both the tutor of DESN2000 and the mentor of the MINEX project. We clearly observed that students showed great enthusiasm for the competition, with the competition day serving as the most effective deadline for their tasks. Five team members, including Barnett, attended the in-person competition held in June at the Colorado School of Mines in the US. Due to funding constraints, we were unable to send all members to Colorado. After two days of intense competition, the UNSW team secured third place (see Figure 1).

(a) (b)

**FIG 1** – (a)The UNSW Over the Dusty Moon 2022 team: Ramanan Mathisuthanan, Shiran Elilvathanan, Peter Johnson, Runzhe Hu, Yamin Ahmed, Seonik Cho and Nick Barnett; (b) Competing during the Over the Dusty Moon 2022 challenge and the award.

In 2023, two DESN2000 students, Slater and Prince, joined the VIP program, while other members came from various disciplines within the Faculty of Engineering. Additionally, two members from VIP MINEX 2022, Johnson and Elilvathanan, continued their work on the project. Our prototype, weighing only 27 kg, was the lightest system in the competition and consumed the least amount of power at 22 W/hr. As a result, the UNSW team secured second place this time (see Figure 2).

(a) (b)

**FIG 2** – The UNSW Over the Dusty Moon 2023 team: Peter Johnson, Duncan Slater, Finn Prince, Justin Fang and Nick Barnett (Gregory Chirakkachalil, Sanika Raje and Shiran Elilvathanan are not in the photo); (b) Competing during the Over the Dusty Moon 2023 challenge.

After the competition, the team had the opportunity to participate in various activities, such as visiting NASA's Jet Propulsion Laboratory, Honeybee Robotics, attending related conferences, and more.

The team's success in the Over the Dusty Moon challenge has been greatly supported over the past two years by their generous sponsors: Fleet Space Technologies, Maptek, Rocscience, Redwood Technology (RedwoodTEQ), Roobuck, Office of the New South Wales Chief Scientist and Engineer, and MERE. Their achievements have also received widespread attention. For example, the team's performance made it into the Australian Space Agency's Top 5 headlines the week following the 2023 competition. The impact of these competition-driven project courses has exceeded our initial expectations. Furthermore, the success of these projects has motivated more new students to choose competition-driven projects.

Unfortunately, the Over the Dusty Moon Challenge did not continue in 2024, and we are uncertain about its return in 2025. Nevertheless, we recognise the value of competition-driven project courses. In 2024, the MINEX VIP team participated in the Aqualunar Challenge (UK track), which aims to solve the challenge of purifying water on the Moon to support future human space exploration. The

UNSW team has been selected as one of the ten finalists and will have the opportunity to visit Europe and participate in the second stage of the competition (UK Space Agency, 2024; UNSW, 2024). Table 2 summarises the composition of the MINEX VIP team.

**TABLE 2**

Number of students in VIP team.

| Year | Student no (students from other disciplines) | Competition project |
|---|---|---|
| 2022 | 6 (3) | Dusty Moon |
| 2023 | 7 (5) | Dusty Moon |
| 2024 | 8 (6) | Aqualunar |

## FUTURE WORK

In DESN2024, we introduced the Mars Rover and Lunar Rover Challenges. Two groups have chosen these topics, and the MINEX VIP will soon begin recruiting members for the Rover team, with plans to participate in the competitions in 2026.

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# Factors influencing the University mining engineering students' employment intention at the mining industry – a case study of Chongqing University, China

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## ABSTRACT

In the new era while the material living conditions have improved, more university students are willing to work in the big city. The mining industry is usually far away from the big city. At present, we are facing the challenge that college students majoring in mining engineering have a weak desire to choose the job in the mining industry after graduation. On the other hand, the industry is shortage of the talents. In order to address this issue, this paper took Chongqing University of China as a case study to explore the employment intention of the university students majoring in mining engineering and identify the factors influencing the students' employment intention at the mining industry. This study is based on the theory of planned behaviour (TPB) to design the survey on the willingness of mining engineering students to work in the mining industry. The survey was conducted in January 2024 by online questionnaires among students majoring in mining engineering in Chongqing University. A total of 222 valid questionnaires were obtained. Data were input into SPSS and Amos software programmes for analysis. The results show: the attitude, perceived behavioural control, and perceived benefits of mining major college students all have significant positive effects on the mining employment intention, the attitude has the greatest impact. Subjective norms and perceived risks affect the mining employment intention by influencing attitudes, and both have a negative impact. According to the results of the data analysis, suggestions are proposed to enhance the willingness of mining major students to choose the jobs at the mining industry. For example, establish an incentive mechanism and provide rewards and honours to college students who are willing to engage in mining work for stimulating their enthusiasm and motivation. Provide more internship and training opportunities for college students to earlier understand mines and increase their practical experience in mines, and thus enhance their employment willingness in mining industry.

## INTRODUCTION

### Background

With the development of social economy and the acceleration of industrialisation, the mining industry has always been one of the pillar industries of the national economy. In China, more than 80 per cent of the industrial raw materials and more than 90 per cent of the energy come from mineral resources (Chen *et al,* 2022). However, with the transformation of the global economic structure and the increasing awareness of environmental protection, the mining industry is facing some challenges, and many countries are gradually reducing their dependence on traditional mining resources and shifting towards more sustainable economic models. At the same time, the employment concepts and expectations of college students are constantly changing. With the development of society and the improvement of education level, they pay more attention to aspects such as work environment, salary and benefits, and personal development space. The workers (Cai and Da, 2023; Tian, 2023) found that the overall employment enthusiasm of college students is not high, and they are more willing to go to institutional units and first-tier or second-tier city, pursuing generous monthly salaries and high-level education.

Higher education institutions are places for cultivating national professional and technical talents, delivering tens of thousands of professional talents to various industries in society every year. The Mining Engineering major is an educational base for cultivating and transporting specialised technical talents in coal mining and non- coal mining. Graduates from this major are one of the important sources of talent in the mining industry (Wang *et al*, 2023). The cultivation of talents in mining engineering and related fields usually requires long-term study and practice, the willingness of students to engage in this industry directly affects the future talent reserves. Therefore, it is very important to understand the mining employment intention of college students majoring in mining. The key to understanding the employment intention of college students is to analyse the various factors that affect their employment intention. Understanding the influencing factors affecting the employment of college students and exploring the influence of these factors are the key to promote the influence of these factors, and are also the key to promote the employment of college students. In order to enhance their mining employment intention of mining major college students, this article analysed the factors that affect the mining employment intention of mining major college students, so as to provide references for the training methods of mining major college students in universities and reserve more professional talents for the mining industry.

## Literature review

The theory of planned behaviour (TPB) states that an individual's willingness to behave is the best indicator of their propensity to perform a particular behaviour, and all variables that may influence behaviour can act on it by influencing their willingness to behave (Bosnjak, Ajzen and Schmidt, 2020). Many scholars both domestically and internationally use TPB for behavioural research, and most existing studies focus on behavioural intention or intention as the final outcome (Greaves, Zibarras and Stride, 2013; Yadav and Pathak, 2016; He, Yu and Fukuda, 2021; Tao, Duan and Deng, 2021; Gansser and Reich, 2023). The TPB model is a cognitive theory used to predict and understand human behaviour, and it effectively explains various behaviours in different fields (Yadav and Pathak, 2016; Ru, Qin and Wang, 2019; Wang and Li, 2022). Chen *et al* (2024) introduced the theory of perceived risk into the theory of planned behaviour, developed a 7-point Likert scale based on the extended theory of planned behaviour, and conducted a questionnaire survey on civil servants in Chongqing, China. Using descriptive statistical analysis and one-way analysis of variance to explore the willingness and differences of respondents. Using structural equation modelling to analyse the relationship between attitude, subjective norms, perceived behavioural control, perceived risk, and the willingness of respondents to implement cardiopulmonary resuscitation. Wang *et al* (2024) conducted an in-depth study on the formation of reduced plastic behaviour among Swiss citizens using the extended theory of planned behaviour models. The results indicate a significant and strong relationship between plastic risk perception and attitudes towards plastic reduction and environmental protection.

At the same time, many scholars have conducted research and analysis on employment intention. Ishitani (2011) analysed data covering the entire United States and concluded that race, major, and scholarship eligibility affect employment choices at an individual level. Luo *et al* (2021) empirically analysed the factors affecting graduate employment intention using structural equation modelling based on the theories of planned behaviour, attitude behaviour situation, and talent motivation. The results indicated that behavioural attitudes, subjective norms, social environment, and talent policies have a significant positive impact on graduate employment intentions, while perceived behavioural control has no significant impact. Previous studies (Zhang, Tian and Sohail, 2022) have shown that the employment intention of college students is influenced by various factors such as economy, society, university, family influence and individual level. Yan, Yuan and Ren (2023) used the Theory of Planned Behaviour as an analytical framework and employed a structural equation model to empirically analyse the impact of college students' cognition of new business forms on their employment intentions from three dimensions: attitude, subjective norms, and perceived behavioural control. The results showed that the more positive college students' attitudes towards new business forms employment, the stronger their intention to work in new business forms; In terms of subjective norms, the evaluation of new forms of employment by family, friends, teachers, and classmates significantly affects the employment intention of college students; Perceived behavioural control is a key influencing factor, and the evaluation of the income level, understanding level, information acquisition ability, and family economic conditions of new business formats by college students will significantly affect their employment intention.

Based on the above research, this article will use the TPB model and structural equations to analyse the factors of mining employment intention among mining major college students.

## MATERIAL AND METHODS

Based on the research content, this article uses the Theory of Planned Behaviour (TPB) to construct a hypothesis model. The Theory of Planned Behaviour (TPB) is based on the Theory of Reasoned Action (TRA), which holds that an individual's behaviour is determined by their behavioural intention, which is influenced by their behavioural attitude and subjective norms. American psychologist Ajzen (1991) added perceptual behavioural control variables to the TRA theory, thus constructing the Theory of Planned Behaviour. Based on the TPB theory, this article introduces two variables, perceived benefits and perceived risks. Benefit-risk assessment believes that individuals tend to weigh benefits and risks when making decisions. Specifically, benefits include profit, growth space and development opportunities, risks include poor working conditions, low income and family pressure (Ueland *et al,* 2012). Through integrating, the influencing factors of mining employment intention among mining major college students can be divided into the following five aspects.

### Attitude

The attitude of college students majoring in mining towards seeking employment in mines will directly affect their mining employment intention. Attitude is a predetermined position that an individual reflects a persistent liking or disliking to a specific object, as well as a positive and negative evaluation of a specific behaviour. The more positive an individual's attitude, the greater their intention, and *vice versa*. The attitude of college students majoring in mining towards employment in mining areas reflects their positive or negative evaluation of the behaviour of 'mining employment'. Negative evaluation will reduce the mining employment intention of college students majoring in mining, and *vice versa*. Based on this, the following assumption is proposed:

**H1:** The attitude of mining major college students has a significant positive impact on their mining employment intention.

### Subjective norms

Subjective norms refer to the pressure felt by others when making decisions, such as expectations and evaluations from family, friends, and schools. Previous studies (Uysal *et al,* 2016) have shown that the more closely related an individual or organisation is to the individual, the stronger the impact on individual decisions. In addition, relevant studies have found that subjective norms have a significant positive impact on the attitude of college students towards entrepreneurial behaviour. In the process of forming the mining employment intention of mining major college students, the attitudes of important individuals or groups will greatly affect the attitudes and mining employment intention of mining major college students. Based on this, the following assumptions are proposed:

**H2:** Subjective norms have a significant positive impact on the mining employment intention of mining major college students.

**H3:** Subjective norms have a significant positive impact on the attitude of mining professionals towards employment among college students.

### Perceived behavioural control

Perceived behavioural control is the perception of the relative difficulty of an individual when they are about to perform a certain behaviour, and multiple studies have shown that perceived behavioural control affects the occurrence of behavioural intention. In this study, mining college students were asked to assess whether they have the necessary abilities and resources to be competent for mining employment. When college students perceive that their abilities are stronger and their obstacles are smaller, their attitude towards mining employment becomes more positive and their intention is stronger. The perceived behaviour control of mining major college students on mining employment mainly includes their cognition of mining work, including whether they are competent for mining employment and whether they can adapt to the working environment of mining, which reflects the individual perception of the difficulty of mining employment by college students. When mining college students perceive that they have the stronger ability to work in mines and have fewer obstacles, their mining employment intention will be stronger. On the contrary, their mining employment intention will be reduced. Based on this, the following assumption is proposed:

**H4:** Perceived behavioural control has a significant positive impact on the mining employment intention of mining major college students.

## Perceived benefits

Perceived benefits refer to the value or usefulness that an individual perceives in taking a certain behaviour, which can include the sum of material benefits and spiritual benefits. In this study, perceived benefits refer to the profit, growth space, and development opportunities that college students believe can be obtained in mining employment, including their perception of the training and improvement opportunities they can enjoy in mining employment, as well as their self-worth realisation. The more benefits perceived, the better the development prospects perceived, and the more positive the attitude towards mining employment, the stronger the intention to go to mining for employment. Based on this, the following assumptions are proposed:

**H5:** Perceived benefits have a significant positive impact on mining employment attitude of mining major college students.

**H6:** Perceived benefits have a significant positive impact on the mining employment intention of mining major college students.

## Perceived risks

Perceived risks refer to the subjective judgment made by people regarding the characteristics and severity of a specific risk. The perceived risks in this study refer to the uncertainty, pressure, and challenges that college students may face in mining employment, mainly including the possible hard conditions in mines, lower salary and social security, pressure from family and society, and limited development space. At the same time, college students' understanding of the mine will affect their mining employment intention. Due to the difficult mining environment and the occurrence of mining accidents in recent years, many people hold a negative attitude towards mining employment, which indirectly brings public opinion pressure and obstacles to college students in a disguised form. Based on this, the following assumptions are proposed:

**H7:** Perceived risks have a significant negative impact on mining employment attitudes of mining major college students.

**H8:** Perceived risks have a significant negative impact on mining employment intention of mining major college students.

Based on the above analysis and assumptions, propose a research hypothesis model, as shown in Figure 1.

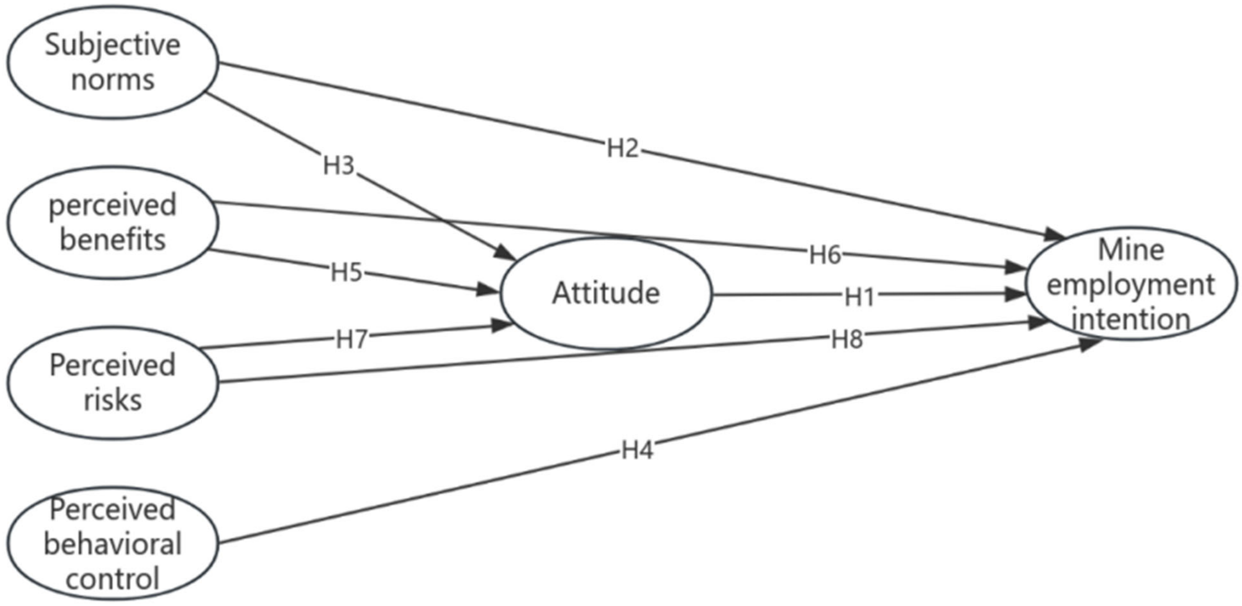


**FIG 1** – Research hypothesis model.

## Questionnaire design

Based on research objective and hypothesis model, design a questionnaire on the willingness of mining college students to seek employment in mines. After summarising the employment issues of mining college students, adapt the mature scale to obtain measurement items for all variables in this questionnaire. And conduct preliminary research on a small scale to improve the questionnaire content and obtain the final questionnaire. This questionnaire consists of two main parts, one is personal information of college students; The other part is the test item of the variable, including three measured items for attitude, subjective norms, perceived behavioural control, and mining employment intention, and four measured items for perceived benefits and perceived risks. The variable measurement scale adopts the Likert 5-level scale, with 1 to 5 representing completely disagree to completely agree.

# RESULTS

## Indicators and variables

The surveyed college students rate the results based on their level of recognition of the measurement items, as shown in Table 1.

**TABLE 1**
Measurement indicators and content of variables.

| Variables | Measure term | Content of measurement items | Mean value | Standard deviation |
|---|---|---|---|---|
| Attitude (AT) | AT1 | I am very interested in employment in the mining industry | 2.90 | 1.227 |
| | AT2 | I see a promising career in the mining industry | 3.04 | 1.231 |
| | AT3 | I think it is wise to work in the mining industry | 2.83 | 1.187 |
| Subjective norms (SN) | SN1 | I think my family and friends support me to work in the mining industry | 2.91 | 1.022 |
| | SN2 | The school I attend actively encourages and supports us in choosing employment in the mining industry | 3.49 | 1.112 |
| | SN3 | The government actively supports us in choosing employment in the mining industry | 3.27 | 1.101 |
| Perceived behavioural control (PBC) | PBC1 | I think I can adapt to the working and living environment of the mining industry | 3.08 | 1.193 |
| | PBC2 | I believe that the professional knowledge I have learned is competent for working in the mining industry | 3.35 | 1.102 |
| | PBC3 | I think I can communicate well with my colleagues in the mining industry | 3.37 | 1.149 |
| Perceived benefits (PB) | PB1 | Employment in the mining industry can enjoy many preferential policies | 3.09 | 1.100 |
| | PB2 | Employment in the mining industry can gain more social recognition and honours | 2.69 | 1.112 |
| | PB3 | Working in the mining industry will provide me with more opportunities to exercise and improve myself | 3.13 | 1.202 |
| | PB4 | Working in the mining industry will allow me to better realise my social value and contribute my youth to the country | 3.20 | 1.236 |
| Perceived risks (PR) | PR1 | Employment in the mining industry may face more difficult working and living conditions | 4.18 | 1.003 |
| | PR2 | Employment in the mining industry may face lower salary and social security | 3.34 | 1.181 |
| | PR3 | Employment in the mining industry may face social and family pressures, which is considered to have a low level of employment and no face | 3.50 | 1.183 |
| | PR4 | Employment in the mining industry may face tedious and boring work, limited development space, and poor prospects | 3.57 | 1.127 |
| Mine employment intention (MEI) | CEI1 | I am willing to work in the mining industry | 2.92 | 1.218 |
| | CEI2 | If given a good opportunity, I would choose to work in the mining industry | 3.14 | 1.272 |
| | CEI3 | I plan to work in the mining industry after graduation | 2.77 | 1.178 |

## Descriptive analysis

This study designed and distributed questionnaires through the Questionnaire Star website, with the respondents being college graduates or current students majoring in mining in Chongqing University. The teacher sent the questionnaire to the interviewees, and after screening, 222 valid questionnaires were finally collected. Among them, the distribution of age, grade, and other aspects is relatively similar to the distribution proportion of the major, which has good representativeness. The basic information of the interviewed college students is shown in Table 2.

**TABLE 2**

Basic information of interviewed college students.

<table>
<tr><th>Variable</th><th colspan="2">Value</th><th>Frequency</th><th>Percentage (%)</th></tr>
<tr><td rowspan="2">Gender</td><td colspan="2">Male</td><td>202</td><td>90.99</td></tr>
<tr><td colspan="2">Female</td><td>20</td><td>9.01</td></tr>
<tr><td rowspan="6">Learning status</td><td rowspan="3">In school</td><td>undergrad</td><td>132</td><td>68.39</td></tr>
<tr><td>postgraduate</td><td>37</td><td>19.17</td></tr>
<tr><td>PhD candidate</td><td>24</td><td>12.44</td></tr>
<tr><td rowspan="3">Graduated</td><td>Undergraduate course</td><td>12</td><td>41.38</td></tr>
<tr><td>Master</td><td>14</td><td>48.28</td></tr>
<tr><td>Learned scholar</td><td>3</td><td>10.34</td></tr>
</table>

The following sample characteristics are sorted out through the questionnaire: The proportion of males in the surveyed college students is higher than that of females, which is consistent with the male-female ratio of college students majoring in mining. In terms of learning status, undergraduate students are the main, accounting for 68.39 per cent of the students in school, and 41.38 per cent of graduates. This is in consistent with the proportion of undergraduates, masters and doctoral students in the school, indicating that the questionnaire is representative.

## Reliability and validity testing of the scale

By calculating the Cronbach's α value of each variable, we can know whether the reliability of the scale is up to the standard. The calculated results of Cronbach's α value of each variable in the questionnaire are shown in Table 3. The Cronbach's α value of each variable is greater than the general standard value 0.7, indicating that the reliability of the scale is high. By testing composite reliability (CR) and average variance extracted (AVE) of potential variables, the convergence validity of the scale can be tested to see whether it reaches the standard. According to Table 3, the CR values of the latent variables in the scale are all greater than 0.7, which is greater than the critical value of 0.6. The AVE values of each variable in the scale are all above the critical value of 0.5; And the factor loadings of the measured variables are all greater than 0.5, indicating good convergent validity of the scale. If the square root of AVE value of the measured construct is greater than the correlation coefficient between the construct and other constructs, that is, the differential validity of the scale is up to the standard. The differential validity indicators in this questionnaire are shown in Table 4, indicating that all indicators have met the standard. Therefore, the differential validity of each potential variables in this questionnaire is good.

**TABLE 3**

Reliability and validity test of measurement scales.

| Variable | Measurement question items | Factor load | AVE | CR | Cronbach's α |
|---|---|---|---|---|---|
| Attitude (AT) | I am very interested in employment in the mining industry | 0.887 | 0.842 | 0.941 | 0.939 |
| | I see a promising career in the mining industry | 0.913 | | | |
| | I think it is wise to work in the mining industry | 0.951 | | | |
| Subjective norms (SN) | I think my family and friends support me to work in the mining industry | 0.589 | 0.579 | 0.800 | 0.767 |
| | The school I attend actively encourages and supports us in choosing employment in the mining industry | 0.744 | | | |
| | The government actively supports us in choosing employment in the mining industry | 0.914 | | | |
| Perceived behavioural control (PBC) | I think I can adapt to the working and living environment of the mining industry | 0.891 | 0.783 | 0.915 | 0.916 |
| | I believe that the professional knowledge I have learned is competent for working in the mining industry | 0.892 | | | |
| | I think I can communicate well with my colleagues in the mining industry | 0.871 | | | |
| Perceived benefits (PB) | Employment in the mining industry can enjoy many preferential policies | 0.828 | 0.746 | 0.921 | 0.922 |
| | Employment in the mining industry can gain more social recognition and honours | 0.831 | | | |
| | Working in the mining industry will provide me with more opportunities to exercise and improve myself | 0.908 | | | |
| | Working in the mining industry will allow me to better realise my social value and contribute my youth to the country | 0.884 | | | |
| Perceived risks (PR) | Employment in the mining industry may face more difficult working and living conditions | 0.663 | 0.664 | 0.886 | 0.882 |
| | Employment in the mining industry may face lower salary and social security | 0.790 | | | |
| | Employment in the mining industry may face social and family pressures, which is considered to have a low level of employment and no face | 0.834 | | | |
| | Employment in the mining industry may face tedious and boring work, limited development space, and poor prospects | 0.947 | | | |
| Mine employment intention (MEI) | I am willing to work in the mining industry | 0.970 | 0.857 | 0.947 | 0.944 |
| | If given a good opportunity, I would choose to work in the mining industry | 0.876 | | | |
| | I plan to work in the mining industry after graduation | 0.928 | | | |

**TABLE 4**

Differential validity of various measurement variables.

| Variable | AT | SN | PBC | PB | PR | MEI |
|---|---|---|---|---|---|---|
| AT | 0.917 | | | | | |
| SN | 0.741*** | 0.761 | | | | |
| PBC | 0.821*** | 0.760*** | 0.885 | | | |
| PB | 0.811*** | 0.733*** | 0.814*** | 0.863 | | |
| PR | -0.114 | -0.029 | 0.116 | 0.008 | 0.814 | |
| MEI | 0.901*** | 0.696*** | 0.849*** | 0.857*** | -0.044 | 0.925 |

Note: The diagonal represents the arithmetic square root of AVE; *** represents P<0.001.

# DISCUSSION

## Model validation

This study used Amos 28.0 software to verify the fit of the model and explore the impact pathways of attitude, subjective norms, perceived behavioural control, perceived benefits, and perceived risks on mining employment intention. According to the hypothesis model (see Figure 1), the fitting index was not ideal. Therefore, based on the model correction index MI and the Theory of Planned Behaviour, the correlation path between the residuals of PB1 and PB2 was added. After model modification, the fitting indices obtained are shown in Table 5: The value of CMIN/DF is 2.808, the value of RMSEA is 0.090, the value of NFI is 0.905, the value of IFI is 0.937, the value of TLI is 0.922, and the value of CFI is 0.936. All relevant indices meet the requirements (Wen, Hou and Marsh, 2004), and the model fitting effect is good.

**TABLE 5**

Model validation indicators.

| Index | CMIN/DF | RMSEA | NFI | IFI | TLI | CFI |
|---|---|---|---|---|---|---|
| Initial model | 3.054 | 0.096 | 0.896 | 0.927 | 0.911 | 0.927 |
| Modified model | 2.808 | 0.090 | 0.905 | 0.937 | 0.922 | 0.936 |
| Adaptation value | <3 | <0.1 | >0.9 | >0.9 | >0.9 | >0.9 |

## Hypothesis testing

The revised hypothesis model was tested using Amos 28.0 software, and the standardised path coefficients between various measurement variables in the structural equation model were obtained. Based on this, the hypothesis model was tested and the test result model was compiled, as shown in Figure 2. By analysing Figure 2, it can be seen that the path coefficient of the influence of attitude on mining employment intention is 0.558, and P<0.001, indicating that attitude has a significant positive impact on mining employment intention, that is, H1 is established. Among the factors that directly affect the willingness to work in mines, the standardised path coefficient of attitude is the highest, indicating that attitude plays a crucial role in the mining employment intention of college students, that is, the more positive their attitude is, the more significantly their intention to work in mines is enhanced. However, the average values of the answers to the three questions in the questionnaire are only 2.90, 3.04, and 2.83, respectively, indicating that most mining major college students have a less positive attitude towards employment in mines. Therefore, improving the attitude of college students towards mining employment plays an important role in promoting their employment in mines. The path coefficient of the influence of subjective norms on attitude is -0.376, P<0.001, indicating that subjective norms have a significant negative impact on attitude, that is, H3 is not valid; The path coefficient of the impact of subjective norms on employment intention in the mining industry is -0.129, but the P=0.117, which is greater than 0.05, indicating that the impact is not significant, that is, H2 is not valid. Therefore, subjective norms mainly affect the attitude of mining graduates towards mining employment, and influence their intention to work in mining by influencing their attitudes. However, the path coefficients of the influence of subjective norms on attitude and mining employment intention are both negative, indicating that they are all negative impacts. The main reason is that in the three questions related to subjective norms in the questionnaire, family members, schools, and the government are asked whether they support them in going to mines for employment. As both schools and the government want college students to go to mines to strengthen their technical learning and enhance their own abilities, this is opposite to their attitude and inconsistent with their behaviour, so it has a negative impact on their attitude and intention to work in mines. The path coefficient of the impact of perceived behavioural control on mining employment intention is 0.278, P=0.01, less than 0.05, indicating that perceived behavioural control has a significant positive impact on mining employment intention, that is, H4 is established. The mean values of the three questions on perceived behavioural control in the questionnaire are 3.08, 3.35, and 3.37, respectively. It can be seen that college students lack confidence in adapting to the working and living environment of mines, as well as the professional knowledge and communication skills required for mining work. There is an urgent need to further enhance their abilities and confidence, and eliminate psychological obstacles.

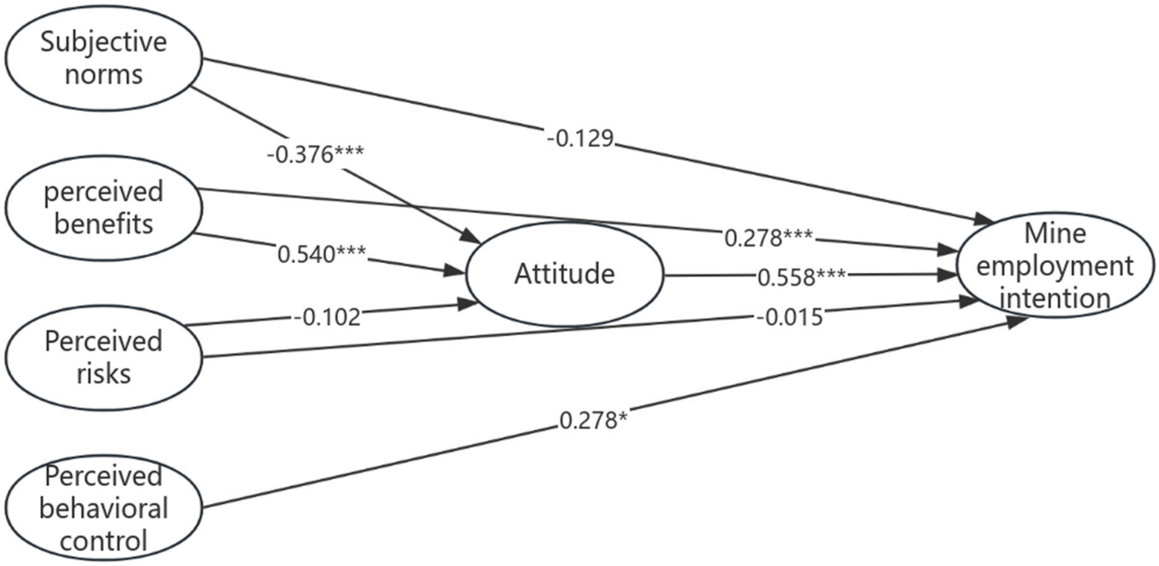


**FIG 2** – Model of research and verification results. Note: *** represents P<0.001; * represents P<0.05.

In addition, according to the hypothesis test results, the path coefficients of the impact of perceived benefits on mining employment attitude and mining employment intention are 0.540 and 0.278, respectively, and P<0.001, indicating that perceived benefits have a significant positive impact on mining employment attitude and mining employment intention, that is, H5 and H6 are valid. Among them, the path coefficients of the four perceived benefit observation indicators, personal preferential policies (PB1), social recognition (PB2), exercise opportunities (PB3), and social value (PB4), are 0.792, 0.796, 0.919, and 0.892, respectively. This indicates that the mining employment attitude of college students is mainly influenced by the emphasis on exercise and improvement opportunities, followed by the impact on the realisation of personal social value. The emphasis on preferential policies and social recognition is slightly lower than these two factors. The average values of the four answers of perceived benefits in the questionnaire are 3.09, 2.69, 3.13, and 3.20, respectively. It can be seen that college students generally believe that mining employment can provide opportunities for exercise and improvement, as well as a higher level of recognition for better realising their social value, while their perception of preferential policies and social recognition is still relatively low. The path coefficient of the impact of perceived risks on attitude is -0.102, and P=0.016, less than 0.05, indicating that perceived risks have a significant negative impact on mining employment attitude, that is, H7 is valid; The path coefficient of the impact of perceived risks on mining employment intention is -0.015, but P=0.653, which is greater than 0.05, indicating that the impact is not significant, that is, H8 is not valid. Therefore, perceived risks mainly affect attitudes towards mining employment, and influence their mining employment intention by influencing their attitude. It can be seen that for college students majoring in mining, their perceived risks of mining employment need to be comprehensively considered in order to affect their mining employment intention.

## CONCLUSION

On the basis of the Theory of Planned Behaviour (TPB), the theory is extended by introducing perceived benefits and perceived risks, constructing a theoretical model of the influencing factors of mining employment intention among mining major college students, and exploring the mining employment intention of mining major college students. The research results show that the intention of mining major college students to seek employment in mines is directly influenced by attitude, perceived behavioural control, and perceived benefits. The attitude has the greatest impact, but college students have a less positive attitude towards mining employment. Moreover, the perceived benefits of preferential policies and social recognition among college students are relatively low, which has not promoted their mining employment intention. In addition, the subjective norms and perceived risks of mining college students can indirectly affect their mining employment intention by influencing their attitude towards mining employment, and both have a negative impact on their attitude and mining employment intention. Moreover, predictable harsh working and living conditions and lower salaries are important obstacles to mining employment for college students.

## RECOMMENDATIONS

Based on the above conclusions, in order to enhance the employment intention of mining major among college students, the following suggestions are proposed:

Improve the employment environment and benefits, adopt a series of policy measures, improve the working environment in mines, increase salary levels, and increase various welfare benefits to enhance the attractiveness of college students to mining employment. Establish a sound incentive mechanism and provide certain rewards and honours to college students who are willing to engage in mining work to stimulate their enthusiasm and motivation.

Strengthen publicity and education, enhance the publicity of relevant policies, enhance the awareness and understanding of mining employment among college students, and make them more aware of the advantages and value of this choice. Strengthen psychological counselling and career planning guidance, help them establish correct employment concepts, enhance their confidence and enthusiasm in employment.

Provide more internship and training opportunities to enable college students to have earlier exposure to the mining industry, increase their practical experience of mining work, and thus enhance their employment intention. And promote the implementation of skill training programs for the mining industry, enhance the skill level of college students in related fields, and enhance their competitiveness in the job market.

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# Mine surveying degrees – internationalising the curriculum

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## ABSTRACT

In an increasingly interconnected world, where borders are becoming less significant and global collaboration is imperative, it is critical for institutions of higher learning to internationalise their curricula. This holds true for Mine Surveying degrees as well, which have traditionally focused on local practices and regulations. By embracing an international perspective in surveying education, students can acquire a broader understanding of the field, gain cross-cultural competencies, and be better prepared to contribute effectively to a globalised society. Surveying is not limited to a single country or region; its principles and techniques can be applied universally, yet the mining branch of surveying is still not studied as a standalone degree. By studying various international case studies, students can learn about different approaches to underground measurement, mapping technologies, and geospatial analysis methods. This paper explores how mine surveying programs are run in five selected universities across different countries. The selection of these programmes was based on the Webometrics Ranking of World Universities with a sub-criterion of the country's production or supply of mineral commodities in the world. The mine surveying programmes from these countries were compared for the purpose of finding synergy in curricula. The aim of such mutuality would prepare students for careers in a globalised world, addressing common challenges faced by mine surveyors worldwide. One such challenge, noted in this paper is the harmonisation of professional standards and regulations across countries. To successfully internationalise surveying degrees, this paper investigates several strategies that educational institutions can adopt, such as fostering collaborations with international universities and industry partners to facilitate faculty exchanges, joint research projects at final year of the undergraduate programmes and sharing of best practices.

## INTRODUCTION

In the era of globalisation and the Fourth Industrial Revolution, the demand for professionals who can operate seamlessly across international borders is escalating. Mine Surveying, a discipline essential to mineral resource management, is no exception. The growing complexity of global projects requires surveyors who are not only adept at technical skills but also possess a comprehensive understanding of international standards, regulations, and cultural nuances. As such, the internationalisation of surveying degree programs has become a critical focus for academic institutions worldwide. This paper examines the internationalisation of surveying degrees by conducting a comparative analysis of programs across five continents namely, North America, Europe, Asia, Africa, and Australia.

The significance of internationalising surveying curricula is multifaceted. Firstly, it provides graduates with the know-how to function well in a variety of regulatory and geographic contexts. Surveyors frequently work on projects that cross national borders and have unique legal and technical requirements. Maintaining the integrity of survey data and guaranteeing compliance require an understanding of these distinctions. Secondly, the exposure to other cultures strengthens graduates' cultural competencies, empowering them to function well in cross-cultural teams. Thirdly, innovation is encouraged, and the general standard of surveying practice and education is raised via the international sharing of best practices and knowledge.

A few essential elements are involved in the process of internationalising degree programmes in surveying, including industry relationships, faculty expertise, curriculum design, and student mobility. Global case studies and practices, as well as international standards like those established by the International Federation of Surveyors (FIG), must be covered in curriculum design. Faculty expertise is essential in providing students with insights into international surveying techniques and challenges. Student mobility, through exchange programs and internships, offers practical experience in diverse settings. Industry partnerships ensure that the curriculum remains relevant to the evolving needs of the global market and advances in technology.

A comparative analysis of surveying programs across different continents reveals both commonalities and unique approaches to internationalisation. In North America, particularly in the United States and Canada, surveying programs often emphasise a strong foundation in technology and geospatial information systems (GIS), combined with courses on international surveying standards. European programs, such as those in Germany and the United Kingdom, are noted for their integration of EU-wide standards and directives, promoting cross-border collaboration within the continent. Asian programs, exemplified by leading universities in China and India, are rapidly evolving to incorporate global best practices while addressing region-specific challenges. African programs, particularly in South Africa and Nigeria, focus on balancing traditional surveying methods with modern technology, addressing the continent's unique developmental needs. Australian programs, benefiting from the country's robust mining and land management sectors, emphasise practical experience and international partnerships.

Despite these efforts, challenges remain in fully realising the potential of internationalised surveying programs. Financial constraints, varying accreditation standards, and the logistical complexities of student and faculty exchanges can hinder progress. Additionally, aligning curricula with rapidly changing global standards requires continuous adaptation and collaboration among academic institutions and industry stakeholders.

This paper attempts to give a thorough review of the current state of mine surveying education across five continents, emphasising positive practices, pointing out problems, and suggesting approaches for increased internationalisation. The paper aims to provide important insights into how surveying programmes might better prepare graduates for the demands of a globalised profession by comparing the practices of various locations. In the end, it is important to seek to promote a more competent and connected professional community by adding to the ongoing conversation about improving the quality and relevance of surveying education globally through such a comparative research study.

## THE SCOPE OF SURVEYING AND ITS APPLICABILITY ACROSS COUNTRIES AND REGIONS

Surveying is a critical discipline in mining and underpins various stages in the mining value chain, including feasibility, development, and resource and inventory management, making it universally applicable across countries and regions. The principles and techniques of surveying are rooted in geometric measurements and spatial data collection, which are essential for accurately mapping and delineating land and structures. Fundamental techniques such as triangulation, trilateration, levelling, and the use of GIS are universally applicable, ensuring that surveyors can perform their tasks consistently and accurately, regardless of geographical location. Triangulation, for instance, involves measuring angles in a network of triangles to determine distances, a method that has been refined over centuries and remains integral to modern surveying practices. Similarly, leveling, which determines the height of points relative to a datum, is crucial for creating accurate topographical maps used in engineering, construction, and environmental management (Wolf and Ghilani, 2012).

GIS have revolutionised surveying by enabling the capture, storage, manipulation, and analysis of spatial data. This technology is universally adopted and allows for the integration of various data types, providing comprehensive spatial analyses that inform decision-making processes across multiple industries. The principles of using GIS in surveying involve data collection through remote sensing, total stations, and global positioning systems (GPS), followed by data processing and visualisation to create detailed maps and models. These techniques are globally recognised and applied, ensuring that surveyors from different regions can collaborate and share data seamlessly (Longley *et al,* 2015).

Despite the universal applicability of these principles and techniques, the scope of surveying as a standalone degree, particularly in the mining sector, is often limited. Mine surveying, a specialised branch, focuses on the measurement and mapping of underground and surface mines. This includes the precise calculation of ore volumes, monitoring of mine shafts, and ensuring the safety and efficiency of mining operations. While the core surveying techniques apply, mine surveying requires additional skills and knowledge specific to the mining industry, such as understanding geological formations, mineral extraction processes, and mine safety regulations (Stacey, 2018).

The demand for specialised mining surveyors is significant in countries with robust mining industries, such as Australia, Canada, South Africa, and Chile. These countries often incorporate mine surveying into broader surveying or mining engineering programs rather than offering it as a standalone degree. This approach ensures that graduates have a comprehensive education that includes both general surveying techniques and specialised mining knowledge. For instance, in Australia, institutions like the University of New South Wales offer integrated programs where students can specialise in surveying within a broader engineering framework, thereby enhancing their employability and versatility (UNSW, 2021).

However, in regions where mining plays a less central role in the economy, standalone mine surveying degrees are rare. Instead, general surveying programs may include modules on mining surveying, providing students with a basic understanding of the field. This model allows educational institutions to maintain flexibility and cater to a wider range of industries that require surveying expertise. It also reflects the interdisciplinary nature of surveying, where skills are transferable across various sectors, including urban planning, environmental management, and civil engineering.

## CASE STUDIES OF MINE SURVEYING PROGRAMS ACROSS SELECTED COUNTRIES

### Selection criteria

The selection of mine surveying programs for this analysis is based on two primary criteria, namely the Webometrics Ranking of World Universities and the country's significance in mineral commodities production and supply. The Webometrics Ranking provides a comprehensive assessment of university performance, considering aspects such as research output, academic reputation, and global impact. Countries with robust mineral production are chosen to ensure the relevance of the programs studied to the global mining industry. This selection process identifies leading institutions in key mining regions, including Australia, Canada, South Africa, and Chile (Table 1).

**TABLE 1**

Comparative analysis of curricula.

| | University of New South Wales (UNSW), Australia | University of British Columbia (UBC), Canada | University of the Witwatersrand (Wits), South Africa | Pontifical Catholic University of Chile (PUC), Chile |
|---|---|---|---|---|
| **Program Overview** | UNSW offers a specialised program in Mining Engineering with Surveying as a component of the Mine Planning module.<br>The curriculum integrates core surveying (from the school of Civil and Environmental Engineering) techniques with mining-specific courses. | UBC offers a Mining Engineering program that includes comprehensive mine surveying training as part of its curriculum. | Wits offers a Mining Engineering program with significant components dedicated to mine surveying. | PUC's Mining Engineering program incorporates mine surveying within a broader engineering framework. |
| **Key Courses** | Mine Planning<br>Geospatial Science for Mining<br>Mineral Resource Estimation<br>Environmental Management in Mining<br>Surveying Applications and Design | Surveying and Mapping for Mining<br>Mineral Exploration and Evaluation<br>Mine Planning and Design<br>GIS and Remote Sensing Applications | Mine Surveying Techniques<br>Geostatistics and Resource Estimation<br>Safety and Risk Management in Mining<br>Environmental Impact of Mining | Principles of Mine Surveying<br>Geospatial Data Analysis<br>Mine Ventilation and Safety<br>Sustainable Mining Practices |
| **Strengths** | Strong emphasis on practical skills through field trips and internships.<br>Integration of environmental and sustainability courses reflecting global trends. | Strong focus on technology integration, particularly GIS and remote sensing.<br>Collaboration with leading mining companies for internships and projects. | Strong industry connections providing ample practical exposure.<br>Emphasis on safety and risk management, crucial for the mining industry. | Focus on sustainable and responsible mining practices.<br>Collaboration with regional mining companies for hands-on training |
| **Challenges** | High cost of field trips and practical training.<br>Need to constantly update technology used in the curriculum | High demand for keeping up-to-date with rapidly evolving technology.<br>Balancing between academic rigour and practical exposure | Limited financial resources for cutting-edge technology and equipment.<br>Addressing diverse educational backgrounds of incoming students. | Limited access to advanced surveying technology.<br>Ensuring curriculum alignment with international standards |

## Synergy and common challenges

Synergy in curricula:

- All programs emphasise core surveying techniques, GIS, and geospatial analysis, ensuring that students are equipped with essential technical skills.
- Sustainability and environmental management are integral parts of the curriculum, reflecting the global shift towards responsible mining.
- Practical experience through field trips, internships, and industry collaboration is a common feature, highlighting the importance of hands-on training.

Common challenges:

- Keeping pace with technological advancements is a significant challenge across all programs. Rapid changes in surveying technology require continuous updates to the curriculum and access to modern equipment.
- Financial constraints affect the ability to provide comprehensive practical training and to integrate the latest technologies.
- Ensuring international standards and practices are consistently taught, particularly as mining operations become more globalised.
- Balancing theoretical knowledge with practical skills remains a critical challenge, necessitating innovative pedagogical approaches.

The comparative analysis of mine surveying programs at UNSW, UBC, Wits, and PUC reveals both common strengths and challenges. These institutions are leaders in integrating international standards, sustainability, and practical experience into their curricula. However, they face shared challenges such as keeping up with technological advancements, securing financial resources, and maintaining a balance between theory and practice. Addressing these challenges will be crucial in furthering the internationalisation of mine surveying education and preparing graduates for the global mining industry.

## CURRENT PRACTICES IN INTERNATIONALISATION OF SURVEYING CURRICULA

The internationalisation of surveying curricula is increasingly recognised as essential to preparing graduates for the demands of a globalised profession. The current practices in the internationalisation of surveying education, focusing on curriculum design, pedagogical strategies, and institutional collaborations were explored.

### Curriculum design and content integration

Curriculum design is a fundamental aspect of internationalising surveying programs. A common practice is the inclusion of international standards and best practices within the core curriculum. The International Federation of Surveyors (FIG), the International Society for Mine Surveying (ISM) and the International Organization for Standardization (ISO) provide frameworks and guidelines that are often integrated into coursework. For example, the ISO 19152 standard on the Land Administration Domain Model (LADM) is frequently taught to ensure students are familiar with global land management practices (Enemark, 2009).

Moreover, many programs incorporate case studies and examples from diverse geographical contexts to expose students to a variety of surveying challenges and solutions. According to Holden (2017), using international case studies enhances students' ability to apply theoretical knowledge to real-world situations, fostering a deeper understanding of global surveying practices. Additionally, curricula are increasingly emphasizing sustainability and ethical considerations, reflecting the global shift towards responsible and sustainable development.

### Pedagogical strategies and student mobility

Effective internationalisation also involves adopting pedagogical strategies that promote cross-cultural competencies. Collaborative online international learning (COIL) is one such strategy that has gained traction. COIL projects connect students from different countries through virtual teamwork on joint assignments, allowing them to engage in cross-cultural communication and problem-solving (Rubin, 2017).

Student mobility programs, including exchange programs, internships, and study tours, are another cornerstone of curriculum internationalisation. These programs provide students with firsthand experience in different cultural and professional settings. For instance, surveyors trained in one country may spend a semester studying abroad, participating in fieldwork, or interning with international firms. This exposure not only broadens their technical skills but also enhances their adaptability and cultural awareness (Giles, Elston and Johnston, 2020).

## Institutional collaborations and partnerships

Collaborative efforts between academic institutions and industry stakeholders are crucial for the successful internationalisation of surveying curricula. Partnerships with international universities facilitate student and faculty exchanges, joint research projects, and the sharing of educational resources. The Erasmus+ program in Europe is a good example that provides funding and support for mobility and cooperation among higher education institutions (European Commission, 2020).

Industry collaborations also play a significant role. Companies operating in the global surveying industry often partner with universities to offer practical training and internships. These partnerships ensure that the curriculum remains aligned with industry needs and emerging technologies. For example, the collaboration between the University of Cape Town and Esri, a global leader in GIS software, integrates cutting-edge technology and industry insights into the academic program (Kleinhans, van der Molen and de Vries, 2015).

## Challenges and opportunities

Despite the progress in internationalising surveying curricula, several challenges persist. Financial constraints can limit the availability of student mobility programs and the development of international partnerships. Additionally, differences in accreditation standards and professional licensure requirements across countries can complicate the integration of international content (Schulte, 2019).

Nonetheless, the ongoing digital transformation presents new opportunities for internationalisation. Online learning platforms and virtual reality (VR) technologies can simulate international fieldwork experiences, making global learning more accessible. As technology continues to evolve, so too does the potential for innovative approaches to internationalising surveying education.

Current practices in the internationalisation of surveying curricula reflect a comprehensive approach that includes integrating global standards, adopting innovative pedagogical strategies, and fostering institutional collaborations. While challenges remain, the continued emphasis on internationalisation is crucial for preparing surveying graduates to meet the complex demands of a globalised industry. Future research should explore the impact of these practices on student outcomes and professional success, as well as the potential of emerging technologies to further enhance internationalisation efforts.

# PROPOSED FRAMEWORK FOR INTERNATIONALISATION OF MINE SURVEY CURRICULA

To address the global demands of the surveying profession, a comprehensive framework for internationalising surveying curricula across five continents—North America, Europe, Asia, Africa, and Australia—has been developed. This proposal outlines a framework that emphasises a multifaceted approach which includes, integrating curriculum design, faculty development, student mobility, and industry partnerships to ensure graduates are well-equipped for international practice and to align with the current trends in curriculum internationalisation.

Integrating global standards and best practices:

- Incorporation of international standards:
  - Embed international standards such as the ISO 19152 (Land Administration Domain Model) and guidelines from the International Federation of Surveyors (FIG) into core courses (Enemark, 2009).
  - Ensure curricula cover international surveying regulations and protocols, enabling students to understand and apply these standards in various global contexts.
- Global case studies and projects:
  - Integrate case studies from different continents to provide students with a broad perspective on global surveying challenges and solutions (Holden, 2017).

    - Include projects that require students to collaborate on solving real-world international surveying problems.

Enhancing cross-cultural competencies:

- Collaborative online international learning (COIL):
    - Implement COIL projects that connect students from universities across different continents through virtual collaboration on joint assignments (Rubin, 2017).
    - Encourage the development of cross-cultural communication and teamwork skills through these online collaborative efforts.
- Cultural sensitivity training:
    - Offer workshops and courses focused on cultural sensitivity and global professional practices.
    - Include training in languages commonly used in international surveying projects, such as English, Spanish, and Mandarin.

Leveraging technological advancements:

- Virtual reality (VR) and simulation:
    - Utilise VR and simulation technologies to create virtual field trips and surveying scenarios from different parts of the world.
    - Provide students with immersive experiences that mimic international surveying environments without the need for physical travel (Giles, Elston and Johnston*,* 2020).
- Online learning platforms:
    - Develop online courses and modules in partnership with international institutions to offer specialised topics in global surveying practices.
    - Use platforms like Coursera and edX to provide access to a wider range of resources and expertise (Schulte, 2019).

Promoting student and faculty mobility:

- Exchange programs and internships:
    - Establish bilateral exchange programs with universities in different continents to facilitate student and faculty mobility.
    - Partner with global surveying firms to offer internships that provide practical international experience (Kleinhans, van der Molen and de Vries*,* 2015).
- Field trips and study tours:
    - Organise international field trips and study tours as part of the curriculum to give students firsthand exposure to surveying practices in different countries.
    - Secure funding and scholarships to support student participation in these programs.

Strengthening institutional collaborations:

- International partnerships:
    - Form partnerships with leading surveying institutions worldwide to share resources, conduct joint research, and co-develop curricula.
    - Engage in collaborative research projects that address global surveying challenges and innovate new solutions.
- Industry collaborations:
    - Collaborate with international surveying companies to ensure curricula remain relevant and aligned with industry needs.

- Involve industry experts in curriculum development and guest lectures to provide insights into current global trends and practices.

The proposed framework for internationalising surveying curricula across continents aims to create a holistic educational approach that integrates global standards, fosters cross-cultural competencies, leverages technology, and promotes institutional collaborations. By implementing this framework, surveying programs can better prepare graduates to navigate and succeed in the global market. Future research should focus on assessing the effectiveness of these strategies in enhancing student outcomes and professional readiness.

## CASE STUDY OF SUCCESSFUL INTERNATIONALISATION OF MINE SURVEYING CURRICULUM – UNIVERSITY OF JOHANNESBURG, SOUTH AFRICA

The University of Johannesburg (UJ) in South Africa has made significant strides in internationalising its Mine Surveying curriculum to meet the demands of the global mining industry. The paradigm shift is the offering of a unique Bachelor of Mine Surveying degree, unlike other institutions where mine surveying is a subsidiary to a mining engineering or a geotechnical major. Through strategic partnerships, innovative pedagogical approaches, and a focus on experiential learning, UJ has transformed its program to produce graduates who are equipped with the skills and knowledge needed to excel in diverse international settings.

### Key initiatives

- International partnerships: UJ has established partnerships with leading mining institutions and industry stakeholders worldwide. Collaborations with various universities and participation in international Mine Surveying bodies have facilitated student and faculty exchanges, joint research projects, and curriculum development initiatives. These partnerships provide students with exposure to international best practices and perspectives, enhancing their global competence.
- Global curriculum integration: The Mine Surveying curriculum at UJ has been redesigned to incorporate international standards such as those recommended by the ISM. Courses cover topics such as resource estimation, mine planning, and geospatial analysis, aligning with industry demands and global trends. The integration of GIS and remote sensing technologies ensures that students are proficient in modern surveying techniques used in international mining operations.
- Experiential learning opportunities: UJ places a strong emphasis on experiential learning through industry placements, fieldwork, and internships. Students can work on real-world projects with leading mining companies both locally and internationally. International field trips expose students to diverse mining environments and regulatory frameworks, broadening their understanding of global mining practices.
- Cross-cultural competency development: To prepare students for the challenges of working in multicultural teams, UJ incorporates cross-cultural competency development into its curriculum. Courses on intercultural communication, diversity, and leadership equip students with the skills needed to navigate cultural differences and collaborate effectively in international settings.

### Outcomes

The internationalisation efforts at UJ have yielded tangible outcomes, with graduates of the Mine Surveying program securing employment opportunities in leading mining companies worldwide. Alumni have demonstrated proficiency in applying their skills in diverse international contexts, contributing to the success of mining projects in regions such as Australia, Canada, and Latin America. The program’s reputation for producing globally competent surveyors has attracted students from across the globe, further enriching the diversity of the student body.

## Challenges and future directions

While UJ has made significant progress in internationalising its Mine Surveying curriculum, challenges remain. These include the need for continuous curriculum review to ensure alignment with evolving industry standards and technological advancements. Additionally, sustaining international partnerships and funding for student mobility programs requires ongoing efforts from the university and its stakeholders. Looking ahead, UJ aims to further enhance its internationalisation efforts by leveraging digital technologies and expanding its network of global partnerships.

The University of Johannesburg's Mine Surveying program serves as a compelling case study of successful curriculum internationalisation in the mining education sector. By prioritising international partnerships, integrating global perspectives into the curriculum, and providing experiential learning opportunities, UJ has positioned its graduates for success in the global mining industry. The program's commitment to excellence and innovation underscores its status as a leader in mining education on the African continent and beyond.

# CONCLUSION

The internationalisation of the curriculum for Mine Surveying degrees is essential in preparing graduates for the demands of the global mining industry. Through case studies, comparative analyses, and pedagogical literature reviews, it is evident that integrating international perspectives, standards, and experiences into mine surveying education enhances the competency and employability of graduates. Key findings highlight the significance of incorporating global standards, fostering cross-cultural competencies, and providing experiential learning opportunities. By exposing students to diverse mining practices, regulatory frameworks, and cultural contexts, internationalisation fosters adaptability, cross-cultural communication, and a global mindset. Moreover, it enhances the reputation and competitiveness of educational institutions, attracting students and faculty from around the world. Successful internationalisation initiatives have resulted in graduates who are well-equipped to navigate diverse international mining environments and contribute effectively to mining projects worldwide.

## Recommendations for educational institutions

Educational institutions play a pivotal role in internationalising the curriculum for Mine Surveying degrees. To adopt effective strategies for internationalisation, institutions should consider the following recommendations:

- Integrate global perspectives: Embed international standards, case studies, and examples into the curriculum to provide students with exposure to diverse mining practices and regulatory frameworks.
- Promote experiential learning: Offer opportunities for international internships, field trips, and industry placements to expose students to real-world mining environments and cultures.
- Foster cross-cultural competencies: Incorporate courses on intercultural communication, diversity, and leadership to develop students' ability to work effectively in multicultural teams.
- Establish international partnerships: Forge collaborations with leading mining institutions, industry stakeholders, and international organisations to facilitate student and faculty exchanges, joint research projects, and curriculum development initiatives.
- Leverage technology: Utilise digital technologies, online learning platforms, and virtual exchange programs to overcome geographical barriers and enhance global collaboration and learning opportunities.
- Continuously evaluate and update: Regularly review and update the curriculum to ensure alignment with evolving industry standards, technological advancements, and global trends.

By implementing these recommendations, educational institutions can effectively internationalise the curriculum for Mine Surveying degrees and produce graduates who are equipped to excel in the global mining industry.

An internationally standard curriculum for Mine Surveying is paramount in preparing graduates for the challenges and opportunities of the global mining industry. By embracing international perspectives and providing experiential learning opportunities, educational institutions can ensure that their graduates are well-prepared to navigate diverse mining environments and contribute to sustainable and responsible mining practices worldwide.

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# Understanding critical raw materials – insights from the AGEMERA online micro-credential European Critical Raw Materials for the Green and Digital Transition (ECRMs)

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## ABSTRACT

The international online micro-credential (MC) 'European Critical Raw Materials for the Green and Digital Transition (ECRMs)' available on the Opal online platform (also known as Bildungsplattform Sachsen) fills a gap in publicly accessible digital educational resources dealing with Critical Raw Materials (CRMs), in particular Rare Earth Elements (REEs) and Battery Raw Materials (BRMs), and their importance in everyday life at different stages of the value chain, thus contributing to the goals of the EU Digital Education Action Plan (2021–2027). The results of the online feedback questionnaire of the MC show that it increases knowledge about CRMs, although the majority of respondents are students in the late stages of their postgraduate programmes with a background in mineral raw materials. Several participants were introduced to CRMs for the first time during the course and many would take an online course similar to ECRMs again, even if it was not possible to obtain European Credit Transfer and Accumulation System (ECTS) credits. In particular, the content related to different technologies that are being applied and further developed within the Horizon Europe project AGEMERA (EU grant agreement ID: 101058178) is considered interesting and novel. The success of the MC is based on a close cooperation between industry partners of AGEMERA and its' university partners, where the latest information from the practical field complements the curricula of future engineers and scientists from TU Bergakademie Freiberg (TUBAF), Tallinn University of Technology (TT), University of Oulu (OU), University of Lapland (UL) and University of Zambia (UNZA). With 73 people registered, it serves as an early practical example of integrating MCs into TUBAF, the flexibilisation and expansion of course offerings, highlighting the great potential of MCs to introduce the mineral raw materials sector to a wide audience and attract potential prospects, while creating a place for lifelong learning.

## INTRODUCTION

Considering the growing demand for CRMs, particularly REEs and BRMs, which are crucial for achieving the vision of a green and digital future (Benchmark Mineral Intelligence Limited, 2022), as outlined in the EU Green Deal and the 17 United Nations Sustainable Development Goals (SDGs), the mineral raw materials sector requires future engineers and scientists with a comprehensive understanding of the entire system and its individual aspects. They need to comprehend the diverse needs of stakeholders in (future) exploration or mining, as well as the geopolitical mechanisms that are part of the sector. They must be prepared for an international work environment, capable of purposefully applying their expertise and effectively communicating with both those unfamiliar and familiar with the field. This applies to the entire value chain, from inception to completion and beyond (Meissner, Mischo and Islam, 2023).

The AGEMERA online lecture ECRMs responds to the industry's needs by enhancing the understanding of CRMs and their importance in everyday life while contributing the EU's plans to develop a digital higher education environment as outlined in the Digital Education Action Plan (2021–2027) (European Commission, nd-a). While ECRMs is targeted at aspiring professionals, it is open to the public and free to register, providing individuals from all backgrounds with an opportunity to understand an industry which sustains employment for over 30 million individuals in the EU and contributes to a total added value of €1.324 billion (European Commission, nd-b).

ECRMs is structured in the form of a MC and is an early practical example of integrating MCs into the educational system of TUBAF. A MC, also known as a micro-degree, compact course or micro-course and often referred to as a massive open online course (MOOC), is a specialised course, often stackable, to be combined or integrated into a larger educational programme, encompassing a relatively small volume of learning that addresses a certain skill or topic, evaluated transparently with clearly defined learning outcomes, resulting in a shareable and portable certificate owned by a successful participant (Council of the European Union, 2022). Unlike traditional degree programmes, MCs are shorter in duration, typically ranging from a few weeks to a few months. They can be completed on-site, online or in a blended (hybrid) format (University of Glasgow, nd).

Having expanded, developed and adjusted their study programs as part of the Bologna Process, MCs are not foreign to higher education institutions (HEIs). The ability to adapt study programs to the needs of diverse educational backgrounds without compromising quality and to create new learning environments that support lifelong learning are seen as important success factors for the future of higher education. As a result, MCs are becoming increasingly popular as a versatile and accessible approach to learn new skills in today's quickly changing economy (Dörr *et al*, 2023).

## THE CREATION OF THE MICRO-CREDENTIAL

Creating a MC involves a substantial workload for all participants and organisations involved. This begins with selecting the course type, if it will be conducted in-person, online, or hybrid, which is an important issue since it affects course dynamics, notably the interaction between instructors and participants. Since the course was initially aimed at students from various international academic partners of the AGEMERA project (TUBAF, TT, OU, UL, UNZA) it was essential to find a solution that granted easy access to all entities involved. Consequently, a fully online MC was created to facilitate participant mobility.

Beyond deciding on the format, several additional key challenges must be considered, when creating a MC. This starts with allocating sufficient time for communication and scheduling with collaborators from different geographical locations and time zones. It also involves determining which materials are already available, which can be combined and what needs to be created completely new for the course. The content should be based on educational gaps within the various course offerings of the partners and address the interest of the target groups and refined within a certain time frame. Additionally, the course must be effectively advertised to the target audience and performance assessments must be designed and conducted.

The course is conducted on the Opal online platform. People interested can find preliminary information on registration, course navigation and what to expect on the AGEMERA project website (https://agemera.eu/our-work/university-courses) and the Opal landing page (https://bildungsportal.sachsen.de/opal/auth/RepositoryEntry/42458447874/CourseNode/1701229034181662011?0).
Within Opal, users can register as either students or tutors. Course content, such as lecture files, literature and links, is stored and organised by chapter and presentation date. Students receive course updates via email through Opal and can view presentation times and dates in a dedicated section. Lectures are delivered in a virtual classroom, recorded and stored by TUBAF on the VIMP video platform, allowing registered participants to re-watch them. The course includes a certificate of attendance (COA) as a motivational reward for successful participants. To receive the COA, participants must complete an automated online pre-examination and provide feedback via an online questionnaire. As the live sessions are recorded and stored, participants can obtain the COA at any time. This COA is a prerequisite for taking a 90-min graded online written examination. Upon successful completion of the written examination and enrolment at TUBAF, participants are eligible to receive three ECTS credits.

## FEATURED TOPICS

Based on the requirements of the project and the individual HEIs, the course content was organised into eight chapters, as shown in Table 1. These chapters cover key areas of interest related to CRMs along the entire value chain, presented by different project partners according to their specific areas of expertise.

**TABLE 1**

Overview of addressed topics.

| # | Title |
|---|---|
| 1 | Geology and Exploration of CRMs |
| 2 | Geo-Politics and Challenges |
| 3 | Extraction of CRMs in a Global Environment |
| 4 | Social Assessment |
| 5 | Environmental Assessment |
| 6 | Mineral Economics |
| 7 | International Frameworks |
| 8 | Bonus Content |

The course begins with covering the geology and locations of CRMs, particularly REEs and BRMs in Europe and Zambia. Following this, various methods for collecting data and exploring underground resources are presented. This includes information on minimally invasive and innovative techniques for the exploration of mineral deposits. In particular, the technologies used and developed in the AGEMERA project for subsurface rock characterisation. These technologies include density characterisation using muons, drones combining magnetic, radiometric and electromagnetic sensing and passive seismic. In addition, the course discusses how to process, combine and visualise the collected data using a graphical user interface. Factors such as time, depth penetration, area coverage, volume, associated costs and the level of detail are regarded as well as the upsides and downsides compared to conventional alternatives (Joutsenvaara *et al*, 2024). Participants are not only introduced to the socio-economic, environmental and technical advantages and disadvantages of various underground exploration methods, but they also gain an understanding of the geopolitical landscape influencing the supply and demand of CRMs. They learn about the strategic approaches of major economies, such as the USA, EU and China and their key methods for addressing supply chain challenges and the increasing demand for CRMs. Given that CRMs are bound to a certain location, the importance of international collaboration and ethical sourcing in ensuring sustainable access to these materials is discussed. International projects related to the sourcing of mineral raw materials necessitate comprehensive planning and stakeholder involvement, particularly with regard to the local economic, environmental and social context, in order to mitigate potential risks that could have a negative effect on the projected outcome.

Business risk, in particular in the context of mineral exploration, extends beyond geological and financial aspects; among the most significant risks the sector faces are social issues. Although mineral exploration often does not have a significant impact on the environment, it can create uncertainty about the locality's future and may indirectly affect investments in tourism or housing. (Suopajärvi *et al*, 2023) Consequently, participants are introduced to concepts such as the Social Licence to Explore (SLE) and the Social Licence to Operate (SLO), environmental impact assessment (EIA) related EU legislation, such as the Water Framework Directive (WFD) and Natura 2000, which highlight the importance of environmental cultural sensitivity and showcase examples of good business practices. Furthermore, participants are provided with a historical overview of sustainability, which begins with the pre-industrial era and encompasses developments during the industrialisation period. This historical overview also covers the contributions of early consciousness-raisers such as Colbert, Evelyn and von Carlowitz, who laid the foundation for the modern understanding of sustainability. The lecture introduces frameworks that have further developed the idea what we understand of sustainable development, as the Brundtland Report and significant events like the Earth Summit, which paved the way for the adoption of the SDGs. The lecture explains the characteristics of the SDGs, their objectives, structure and the challenges associated with achieving them. In the latter part of the lecture, participants gain an understanding of the basics of mineral economics, resource evaluation, classification and resource management within the context of sustainable development, with practical examples from case studies. The lecture includes an overview of standards from the Committee for Mineral Reserves International Reporting Standards (CRIRSCO), which provides guidelines for disclosing reserves, resources and outcomes of mineral exploration to the public. Furthermore, the lecture explains the United Nations Framework Classification for Resources (UNFC) and its structure across different axes, as well as the United Nations Resource Management System (UNRMS), including its purpose, desired outcomes, key definitions and toolkit concepts. The course concludes with bonus presentations on AGEMERA's technologies, including the AGEMERA graphical user interface and muon-based density characterisation of rocks. Furthermore, a question-and-answer session was held on the subject of international reporting standards. Presentations were also delivered on the topic of multi-sensing drones, which combine magnetic, radiometric and electromagnetic sensing drones for the purpose of subsurface characterisation. Finally, a presentation was given by the Organisation for Economic Co-operation and Development (OECD) on their mining regions and cities initiative.

## COURSE EVALUATION

An interesting aspect for future iterations and improvements of the course lies in the conclusions drawn from its evaluation. The foundation for receiving feedback lays in the course structure, described previously and the issuance of rewards. The evaluation encompasses the results from the pre-examination and the feedback questionnaire required to receive the COA and the online written examination necessary to earn three ECTS credits.

### The pre-examination

The pre-examination, along with the feedback questionnaire and COA, was launched on April 22, 2024, on the Opal online platform. The pre-examination consists of 33 questions, each worth one point, for a total score of 33 points. In the first term of the course, 33 participants took the pre-examination, achieving an average score of 27.59 out of 33, which corresponds to 83.61 per cent. All participants passed the course, with a minimum of 13.2 points (40 per cent) required to pass the pre-examination. The pre-examination features questions on each chapter, developed in collaboration with the various presenters and is conducted in a multiple-choice format. The average time to fulfill the pre-examination was 24:02 mins, while participants have 45 mins for completion.

### The feedback questionnaire

The feedback questionnaire was designed with the intention to assess whether the course met its' goals to enhance the understanding about the importance of CRMs. Containing in total 37 questions, the questions (or subtopics) within the feedback questionnaire can be classified into eight different thematic purposes, labelled as 'topics' in Table 2. The questionnaire begins by collecting basic information about the participants, including their student status, university, study programme and level of education, to learn about their background (for example with mineral raw materials).

Within the questionnaire participants provide feedback on the course design, including their experience of enrolment, navigation and preferences for online, physical or hybrid formats, as well as attendance at live virtual lectures. Participant and tutor engagement is assessed through questions about participants' perceptions of teaching and engagement.

**TABLE 2**
Structure of the feedback questionnaire.

| # | Topic | Subtopic |
|---|---|---|
| 1 | Background Information About Participants | Q1.1: Respondent's Nationality<br>Q1.2: Enrolment at HEI<br>Q1.3: Name of HEI (Students Only)<br>Q1.4: Name of Study Program (Students Only)<br>Q1.5: Type of Study Program (Students Only)<br>Q1.6: Progress within Study Program (Students Only) |
| 2 | Course Experience | Q2.1: Registration Process<br>Q2.2: Course Navigation<br>Q2.3: Willingness to Attend Online Course Again<br>Q2.4: Ranking of Different Course Concepts<br>Q2.5: Attendance at Live Presentations (Chapters 1 to 7)<br>Q2.6: Attendance at Bonus Presentations (Chapter 8) |
| 3 | Participant Engagement | Q3.1: Opportunities for Engagement with Other Participants |
| 4 | Course Motivation and Expectations | Q4.1: Reasons for Attending the Course<br>Q4.2: Expectations for the Course |
| 5 | Content Evaluation | Q5.1: Interest in Presented Contents<br>Q5.2: Novelty of Presented Contents |
| 6 | Learning Outcomes | Q6.1: Time of First Introduction to CRMs<br>Q6.2: Enhancement of Understanding of CRMs<br>Q6.3: Additional Ways the Course Improved Knowledge |
| 7 | Marketing Data Collection | Q7.1: How Participants Heard About the Course<br>Q7.2: Willingness to Attend Without ECTS Credits<br>Q7.3 Suggestions for Course Improvement |
| 8 | Survey Conclusion | Q8.1: Missing Questions to be Included<br>Q8.2 Additional Comments and Feedback |

The questionnaire also assesses the expectations that people had when they enrolled in the course, to understand whether the course met those expectations. To find out whether the content presented is relevant to participants, the questionnaire asks about topics of interest to participants. Towards the end, data is collected on learning outcomes and whether the course was effective in raising awareness about CRMs. Lastly, it asks what attracted participants to the course.

The feedback questionnaire includes various questions, requesting participants to respond to statements by choosing a predefined answer. To quantify these responses, Likert scales were used, including values ranging from 1 to 5, or 1 to 7, as demonstrated in Table 3a. Based on the received mean values (MVs), different intervals were assigned to indicate trends and interpret the results. For instance, on a five-point scale, MVs between 3.5 and 5.0 are interpreted as positive, while MVs between 1.0 and 2.5 are seen as negative. MVs between 2.5 and 3.5 indicate a neutral stance.

According to recommendations from McGill University for course evaluations, for a five-point scale, MVs above 4.0 are considered strong, scores from 3.5 to 4.0 represent solid results and scores below 3.5 should raise concerns (Winer *et al*, 2012). Additionally, participants had the opportunity to comment on most questions to collect qualitative impressions. These qualitative answers were considered if a MV of 1.5, 2.5, 3.5, or 4.5 was received.

**TABLE 3A**

Interpretation of questionnaire results.

| Question | Answer possibility | | | | |
|---|---|---|---|---|---|
| **Q2.1; Q2.2; Q3.1; Q4.2; Q6.2** | Strongly disagree | Disagree | Neutral | Agree | Strongly agree |
| **Q2.3;** | Very unlikely | Unlikely | Neutral | Likely | Very likely |
| **Q5.1;** | Least interesting | Not interesting | Neutral | Interesting | Most interesting |
| **Q2.4** | Worst | Bad | Average | Good | Best |
| **Q5.2** | Nothing is new to me | The majority of content is known to me | The amount of new and known content is balanced | The majority of content is new to me | Completely new |
| **Code allocated to answer possibility** | 1 | 2 | 3 | 4 | 5 |
| **Interval of mean value** | [ 1; 1.5 [ | ] 1.5; 2.5 [ | ] 2.5; 3.5 [ | ] 3.5; 4.5 [ | ] 4.5; 5] |
| **Tendency** | Negative | | Neutral | Positive | |
| **Interpretation of mean values** | Of concern: 3.5 and lower | | | Solid results: 3.5 to 4:<br>Strong results: 4 < | |

Note: If a mean value ends with .5, a separate evaluation is necessary, considering qualitative info, if available.

The feedback questionnaire also includes various other question types, such as ‘yes/no’ questions. These were used to determine whether most participants were enrolled in a HEI or to gather information on whether respondents would attend the course if no ECTS credits were offered. The responses were coded, similar to Table 3a, to provide an overview of tendencies, displayed in Table 3b.

**TABLE 3B**

Interpretation of questionnaire results.

| Question | Answer possibility | | |
|---|---|---|---|
| **Q1.2; Q7.2** | No | Yes | - |
| **Q1.6** | Just starting out | Midway through | Near completion |
| **Allocated code** | 1 | 2 | 3 |
| **Interval of mean value** | Q1.2, Q1.6, Q7.2: [ 1; 1.5[ | Q1.2, Q7.2:] 1.5; 2]<br>Q1.6:] 1.5; 2 [ | Q1.6:] 2.5; 3] |
| **Tendency** | Q1.2: Not enrolled in a HEI<br>Q1.6: Beginning of studies<br>Q7.2: Would not attend again without ECTS | Q1.2: Enrolled in a HEI<br>Q1.6: Middle of studies<br>Q7.2: Would attend again without ECTS | Q1.6: Close to finishing studies |

When evaluating course results, the MV is an important indicator, but extreme scores or outliers do influence the MV, especially in circumstances where there are few replies. In this context, the standard deviation (SD) is used to evaluate the variation of respondents’ opinions around the MV. The SD typically falls within the range of 0 to 2, for questions featuring a five-point scale. A low SD suggests that responses are centred around the MV, while a high SD indicates significant variation. If the number of replies is small and/or the SD is high, the MV should not be relied on as a meaningful assessment tool of participants’ actual experiences. (Office of Institutional Data, nd) Therefore, in addition to the MV and SD, the median is also included because it is less influenced by extreme values and is a helpful indicator for small sample sizes (Ministry of Education New Zealand, nd). Next to the median, the margin of error (ME) aids in determining how good of an approximation the MV is as a measure of students’ actual reported experience in a course. The first step in calculating the ME is to estimate the standard error (SE). The SE of the mean represents the SD of the sampling distribution of the mean. It shows how great the variability is among samples from the same population. The SE is received by dividing the SD by the square root of the number of respondents (N) (Office of Institutional Data, nd):

$$Standard\ Error\ (SE) = \frac{Standard\ Deviation\ (SD)}{\sqrt{Number\ of\ Respondents\ (N)}}$$

A large SE suggests, that the MV from an individual sample might not be an exact representation of the population from which the sample was drawn. For samples (30 responses or more), it is expected that the samples MV follows a normal distribution. In this case, the 95 per cent confidence interval (CI) of the sample MV can be approximated, by using a critical value (Z) of 1.96 (Office of Institutional Data, nd):

$$Margin\ of\ Error\ (ME) = \pm\ Critical\ Value\ (Z) * Standard\ Error\ (SE)$$

$$\text{Confidence Interval (CI)} = Mean\ Value\ (MV) \pm Margin\ of\ Error\ (ME)$$

The 95 per cent confidence interval suggests that there is a 5 per cent possibility that the range excludes the MV (Faculty of Public Health, nd). With a 100 per cent response rate, the genuine experience of the entire course would be reflected, as it includes input from everyone. However, when the response rate is less than 100 per cent, the available data must be used to approximate the overall experience of the group. To draw conclusions from a course assessment, the Centre for Teaching Support and Innovation at the University of Toronto issued guidance on the required aspects, displayed in Table 4, necessary to ensure results can represent the collective experience. (Centre for Teaching Support and Innovation, 2018) A 'somewhat precise estimate' (SPE) or even a 'precise estimate' (PE) would be possible for Q1.2. However, to achieve a 'very precise estimate' (SP) of how well the responses to Q1.2 represent the overall course experience, the limiting factor is the number of respondents, as the maximum number of respondents ($N_{Max}$) of the feedback questionnaire represents approximately 45 per cent of all people registered, not more than 70 per cent.

**TABLE 4**

Response rate needed to create relevant statements (Centre for Teaching Support and Innovation, 2018).

| Interval around the mean | Recommended interpretation of the quality of the mean estimate | Course size and required response rate | | | | |
|---|---|---|---|---|---|---|
| | | 1–25 | 26–50 | 51–100 | 101–200 | 200+ |
| < ±0.1 | Very precise estimate (SP) | >90% | >80% | >80% | >60% | >50% |
| < ±0.2 | Precise estimate (PE) | >80% | >70% | >70% | >50% | >40% |
| < ±0.5 | Somewhat precise estimate (SPE) | >70% | >50% | >40% | >20% | >10% |
| < ±1.0 | General estimate (GE) | >60% | >20% | >10% | >10% | >10% |
| > 1.0+ | Very general estimate (VGE) | < 30% | <10% | <5% | <3% | <1% |

Note: Guidelines are based on a 95 per cent confidence interval around the mean with margin of errors ranging from ±0.1 to ±1.0, a standard deviation of 1.0, and correction for the use of a finite population.

The feedback questionnaire provided results that are able to make 'general', 'somewhat precise' and 'precise' estimates regarding the received MV to represent the genuine experience of the entire course according to the interpretation guide from the Centre for Teaching Support and Innovation at the University of Toronto. 'Somewhat precise' estimates (SPE) were possible for 77.55 per cent of the questions, 'precise' estimates (PE) for 18.37 per cent and 'general' estimates (GE) for 4.08 per cent.

### *Topic 1 – background information about participants*

In Q1.1, 33 participants from 21 different nations were identified. Among the 33 respondents, in Q1.2, almost all (93.94 per cent) indicated that they are enrolled to a HEI, while only a small proportion (6.06 per cent) are not. This is confirmed by a MV of 1.94 ± 0.08 and a median of 2 (Table 5).

**TABLE 5**

Evaluation of background information of respondents'.

| # | Respondents (N) | MV | SD | SE | ME | Median | Tendency | Estimate |
|---|---|---|---|---|---|---|---|---|
| Q1.2 | 33 (100%) | 1.94 | 0.24 | 0.04 | 0.08 | 2.00 | Enrolled at a HEI | SPE to PE |
| Q1.5 | 31 (93.94%) | 2.19 | 0.78 | 0.14 | 0.27 | 2.00 | Master's program | SPE |
| Q1.6 | 31 (93.94%) | 2.55 | 0.56 | 0.10 | 0.20 | 3.00 | Near completion | SPE to PE |

Note: $N_{Max}$= 33; Format is not applicable for Q1.1, Q1.3, Q1.4.

Of the 31 people enrolled in HEIs, the majority (80.65 per cent) mentioned in Q1.3 that they are enrolled at TUBAF. A total of 30 participants provided information about their study programs, as part of Q1.4. Almost all (96.67 per cent) are enrolled in programs related to geo-sciences. Nine individual study programs were mentioned. The largest group is enrolled in TUBAF's master's program in Sustainable Mining and Remediation Management (33.33 per cent), followed by 20.00 per cent in the master's program in Advanced Mineral Resource Development. Of the 31 participants enrolled to HEIs, most (74.19 per cent) are part of a master's program, for Q1.5. The remaining respondents are enrolled in PhD programs (12.90 per cent), bachelor's programs (9.68 per cent), or diploma programs (3.23 per cent), as indicated by a MV of 2.19 ± 0.27 and median of 2. This means that the majority (90.32 per cent) of respondents are part of postgraduate programs. Furthermore, a significant part (58.06 per cent) of the 31 participants in higher education are close to completing their studies, as indicated by a MV of 2.55 ± 0.20 and a median of 3 for Q1.6. Another 38.71 per cent are in the middle of their studies, while only a small portion (3.23 per cent) are at the beginning of their studies.

### *Topic 2 – course experience*

The results related to the course experience, as evaluated through questions Q2.1 to Q2.6, are shown in Table 6. The majority of 33 respondents (69.70 per cent) strongly agreed in Q2.1 with the statement that it was easy to register for the course. An additional 24.24 per cent agreed with the statement, while 6.06 per cent were neutral. No one disagreed or strongly disagreed. Overall, 93.94 per cent of respondents gave positive feedback (ie 'strongly agree' or 'agree'), representing the majority of respondents, with a MV of 4.64 ± 0.20 and a median of 5. The majority of respondents (72.73 per cent), also strongly agree that the course was easy to navigate in Q2.2. A further 15.15 per cent agreed, while 12.12 per cent were neutral. No one disagreed or strongly disagreed. Overall, 87.88 per cent of people gave positive feedback (equivalent to 'strongly agree' or 'agree'), representing most respondents, with a MV of 4.61 ± 0.24 and a median of 5. Approximately three quarters (75.76 per cent) of the 33 respondents selected in Q2.3 that they were very likely to take an online course again after having visited ECRMs. Another 24.24 per cent thought it was likely. None of the respondents said it was unlikely or very unlikely. In total, 100 per cent of people gave positive feedback (equivalent to answering 'very likely' or 'likely'). Respondents were asked to rate different course concepts in Q2.4. Among the 33 respondents, 51.52 per cent rated online lectures as the best concept and 42.42 per cent rated them as a good concept. In total, 93.94 per cent provided positive feedback (equivalent to answering 'best' or 'good'), supported by a MV of 4.42 ± 0.24 and a median of 5 in Q2.4 A. Regarding physical lectures, 33.33 per cent of the participants rated them as the best concept and 15.15 per cent rated them as a good concept. Overall, 48.48 per cent gave positive feedback ('best' or 'good'), while 36.36 per cent rated them as an average course concept. A small portion rated physical lectures as bad (3.03 per cent) or as the worst concept for teaching (6.06 per cent). For hybrid lectures, 33.33 per cent rated them as the best concept and 36.36 per cent rated them as a good concept. In total, 69.69 per cent of respondents provided positive feedback. More than a fifth (21.21 per cent) rated hybrid lectures as an average course concept and only a small portion (3.03 per cent) rated hybrid lectures as the worst teaching method. Both hybrid (Q2.4 C) and physical (Q2.4 B) lectures achieved a median of 4.

**TABLE 6**

Evaluation of the respondents' course experience.

| # | Respondents (N) | MV | SD | SE | ME | Median | Tendency | Estimate |
|---|---|---|---|---|---|---|---|---|
| Q2.1 | 33 (100%) | 4.64 | 0.59 | 0.10 | 0.20 | 5.00 | Strongly agree | SPE to PE |
| Q2.2 | 33 (100%) | 4.61 | 0.69 | 0.12 | 0.24 | 5.00 | Strongly agree | SPE |
| Q2.3 | 33 (100%) | 4.73 | 0.45 | 0.08 | 0.15 | 5.00 | Very likely | SPE to PE |
| Q2.4 A | 33 (100%) | 4.42 | 0.7 | 0.12 | 0.24 | 5.00 | Best | SPE |
| Q2.4 B | 31 (93.93%) | 3.71 | 1.17 | 0.22 | 0.41 | 4.00 | Good | SPE |
| Q2.4 C | 31 (93.93%) | 4.03 | 0.93 | 0.17 | 0.33 | 4.00 | Good | SPE to PE |
| Q2.5 | 33 (100%) | 5.48 | 1.64 | 0.28 | 0.56 | 6.00 | 76 ≤ 99 [%] | GE |
| Q2.6 | 33 (100%) | 3.21 | 1.95 | 0.34 | 0.67 | 2.00 | 0 ≤ 25 [%] | GE |

Note: $N_{Max}$= 33; **Q2.4 A:** Online, **B:** Physical, **C:** Hybrid.

Out of the 33 respondents, just over a quarter (27.27 per cent) reported attending 100 per cent of the lectures of Chapters 1 to 7 in Q2.5. A large part (42.42 per cent) attended between 76 per cent and 99 per cent of the lectures. A large SD of 1.64 indicates that the values are not evenly distributed around the MV of 5.48, as reflected by a median of 6 and a high ME of 0.56. Additionally, 12.12 per cent attended between 51 per cent and 75 per cent of the presentations, while 15.15 per cent attended less than 25 per cent of the sessions. Regarding the live presentations of the bonus content chapter in Q2.6, none of the respondents attended 100 per cent of them. Approximately 24.24 per cent watched between 76 per cent and 99 per cent of the presentations, 9.09 per cent watched between 51 per cent and 75 per cent, 6.06 per cent watched 50 per cent, 9.09 per cent watched between 25 per cent and 49 per cent, and 27.27 per cent watched less than 25 per cent. Additionally, 24.24 per cent indicated that they did not watch any of the bonus presentations. The wide variation in values is demonstrated by a MV of 3.21 (where 3.0 corresponds to an attendance rate of 25 per cent to 49 per cent), a high SD of 1.95 and a median of 2 (indicating an attendance rate of less than 25 per cent). This is further highlighted by a ME of 0.67, which is even greater than that of Q2.5.

### *Topic 3 – participant engagement*

Table 7 provides an overview of the evaluation of participants' opportunities to engage with others in the online course, their satisfaction with tutor engagement and their perception of the tutors' competence. Out of 33 respondents, 24.24 per cent strongly agree that participants have the opportunity to engage with other people in the online course, while 18.18 per cent agreed and 45.45 per cent were neutral. Additionally, 9.09 per cent disagreed. This results in a MV of 3.59 ± 0.33, with the median of 3 indicating a tendency towards a neutral position among the respondents for Q 3.1 A. Overall, respondents were satisfied with the engagement of the tutors, as indicated in Q 3.1 B. Out of 33 respondents, 57.58 per cent strongly agreed that the tutors were open to engagement, 27.27 per cent agreed, 9.09 per cent were neutral and 3.03 per cent disagreed. The MV is 4.44 ± 0.27 and the median is 5, indicating a trend towards a strong agreement. In Q3.1C, 60.61 per cent of respondents strongly agree that the tutors were competent, 27.27 per cent agree and 9.09 per cent are neutral. The MV is 4.53 ± 0.23 and the median is 5, indicating a trend as well towards strong agreement.

**TABLE 7**

Evaluation of engagement and competence.

| # | Respondents (N) | MV | SD | SE | ME | Median | Tendency | Estimate |
|---|---|---|---|---|---|---|---|---|
| Q3.1 A | 33 (100%) | 3.59 | 0.96 | 0.17 | 0.33 | 3.00 | Neutral | SPE |
| Q3.1 B | 33 (100%) | 4.44 | 0.79 | 0.14 | 0.27 | 5.00 | strongly agree | SPE |
| Q3.1 C | 33 (100%) | 4.53 | 0.66 | 0.12 | 0.23 | 5.00 | strongly agree | SPE |

Note: $N_{Max}$= 33; **Q3.1 A:** Engagement opportunities with others, **B:** Tutor engagement, **C:** Tutor competence.

### *Topic 4 – course motivation and expectations*

Respondents were asked why they attended the course through an open-ended question, in Q4.1. Responses range from personal interest and academic studies to professional development. Several participants mentioned that the course was a good opportunity to enhance their knowledge, gather new information and revise existing knowledge about CRMs and REEs. Master's and doctoral students mentioned that the course content was relevant to their thesis topics. One respondent, who works in the mineral raw materials sector, sees the course as an opportunity to learn more about the industry and the EU Critical Raw Materials Act. Another respondent appreciated the chance to learn from international speakers.

In Q4.2, participants were asked if the course met their expectations. The trend shown in Table 8 demonstrates that the course did meet respondents' expectations: out of 33 respondents, 57.58 per cent strongly agree and 42.42 per cent agree. No respondent selected 'neutral', 'disagree', or 'strongly disagree'. The MV of 4.58 in combination with a relatively small ME of 0.17 and the median of 5 show a trend towards strong agreement.

**TABLE 8**

Evaluation of respondents' motivation and expectations.

| # | Respondents (N) | MV | SD | SE | ME | Median | Tendency | Estimate |
|---|---|---|---|---|---|---|---|---|
| Q4.2 | 26 (78.79%) | 4.58 | 0.49 | 0.09 | 0.17 | 5.00 | Strongly agree | SPE to PE |

Note: $N_{Max}$= 33; Format is not applicable for Q4.1

### *Topic 5 – content evaluation*

Respondents were asked in Q5.1 to rate different presentations based on their personal interest, using a scale ranging from 'most interesting', 'interesting', 'neutral', 'not interesting' to 'least interesting'. The evaluation of the results from Q5.1 is presented in Tables 9A and 9B. While individual preferences varied, typical values for 'not interesting' are 0 per cent, 3.03 per cent, or 6.06 per cent and 'least interesting' does not exceed 3.03 per cent. The average value for 'neutral' is 13.13 per cent. The results indicate a positive trend towards the content being acknowledged as interesting by the respondents, with SDs ranging mostly around 1.0 and MEs around 0.33. The average sum of responses for 'most interesting' or 'interesting' made up approximately 80 per cent of responses, with MVs from 3.77 to 4.41 and medians ranging from 4 to 5. Among the contents which achieved a median of 5 is the lecture about drone surveys, applied and further developed within the AGEMERA project.

**TABLE 9A**

Evaluation of contents.

| # | Respondents (N) | MV | SD | SE | ME | Median | Tendency | Estimate |
|---|---|---|---|---|---|---|---|---|
| Q5.1 A | 33 (100%) | 4.41 | 0.82 | 0.14 | 0.28 | 5.00 | Most interesting | SPE |
| Q5.1 B | 33 (100%) | 4.21 | 1.01 | 0.18 | 0.34 | 5.00 | Most interesting | SPE |
| Q5.1 C | 32 (96.97%) | 4.31 | 0.92 | 0.16 | 0.32 | 5.00 | Most interesting | SPE |
| Q5.1 D | 33 (100%) | 4.42 | 0.65 | 0.11 | 0.22 | 5.00 | Most interesting | SPE |
| Q5.1 E | 33 (100%) | 4.21 | 0.98 | 0.17 | 0.33 | 4.00 | Interesting | SPE |
| Q5.1 F | 32 (96.97%) | 4.22 | 0.99 | 0.18 | 0.35 | 4.00 | Interesting | SPE |

Note: NMax= 33; **Q5.1 A:** Geology of CRMs in Europe; **B:** Mining in a Global Environment; **C:** Economic Resource Evaluation; **D:** Multi-Sensing Drones; **E:** Social Assessment in Mining and Exploration; **F:** Environmental Impact Assessment in the Extractive Sector.

**TABLE 9B**

Evaluation of contents.

| # | Respondents (N) | MV | SD | SE | ME | Median | Tendency | Estimate |
|---|---|---|---|---|---|---|---|---|
| Q5.1 G | 33 (100%) | 4.30 | 0.80 | 0.14 | 0.27 | 4.00 | Interesting | SPE |
| Q5.1 H | 32 (96.97%) | 4.22 | 0.96 | 0.17 | 0.33 | 4.00 | Interesting | SPE |
| Q5.1 I | 33 (100%) | 3.97 | 1.00 | 0.17 | 0.34 | 4.00 | Interesting | SPE |
| Q5.1 J | 32 (96.97%) | 3.94 | 1.00 | 0.18 | 0.35 | 4.00 | Interesting | SPE |
| Q5.1 K | 31 (93.93%) | 4.23 | 0.71 | 0.13 | 0.25 | 4.00 | Interesting | SPE |
| Q5.1 L | 32 (96.97%) | 3.94 | 1.00 | 0.18 | 0.35 | 4.00 | Interesting | SPE |
| Q5.1 M | 30 (90.90%) | 4.07 | 0.93 | 0.17 | 0.33 | 4.00 | Interesting | SPE |
| Q5.1 N | 33 (100%) | 4.03 | 0.80 | 0.14 | 0.27 | 4.00 | Interesting | SPE |
| Q5.1 O | 31 (93.93%) | 3.77 | 0.97 | 0.17 | 0.34 | 4.00 | Interesting | SPE |

Note: $N_{Max}$= 33; **Q5.1 G**: Muon-Based Density Characterization of Rocks; **H**: SDGs, UNRMS and UNFC; **I**: Passive Seismic Analysis for Subsurface Characterization; **J**: Q&A Session on International Reporting Standards; **K**: Conventional Exploration Technologies for CRMs; **L**: OECD Mining Regions and Cities initiative; **M**: The Green New Deal and CRMs; **N**: Geology of CRMs in Africa (Zambia); **O**: The AGEMERA Graphical User Interface.

In Q5.2, participants were also asked about the novelty of the content in the individual presentations. They could choose from ‘completely new’, ‘the majority of content is new to me’, ‘the amount of new and known content is balanced’, ‘the majority of content is known to me’ and ‘nothing is new to me’. The evaluation of the results from Q5.2 is summarised in Table 9C and Table 9D.

**TABLE 9C**

Evaluation of contents.

| # | Respondents (N) | MV | SD | SE | ME | Median | Tendency | Estimate |
|---|---|---|---|---|---|---|---|---|
| Q5.2 A | 32 (96.97%) | 3.68 | 1.20 | 0.22 | 0.42 | 4.00 | Majority is new | SPE |
| Q5.2 B | 32 (96.97%) | 3.19 | 1.10 | 0.19 | 0.38 | 3.00 | Balanced | SPE |
| Q5.2 C | 32 (96.97%) | 3.53 | 1.17 | 0.21 | 0.41 | 4.00 | Majority is new | SPE |
| Q5.2 D | 32 (96.97%) | 4.13 | 0.82 | 0.14 | 0.28 | 4.00 | Majority is new | SPE |
| Q5.2 E | 32 (96.97%) | 3.19 | 1.18 | 0.21 | 0.41 | 3.00 | Balanced | SPE |
| Q5.2 F | 32 (96.97%) | 3.31 | 1.36 | 0.24 | 0.47 | 4.00 | Majority is new | SPE |
| Q5.2 G | 32 (96.97%) | 4.44 | 0.93 | 0.16 | 0.32 | 5.00 | Completely new | SPE |
| Q5.2 H | 32 (96.97%) | 3.75 | 1.27 | 0.23 | 0.44 | 4.00 | Majority is new | SPE |

Note: $N_{Max}$= 33; **Q5.2 A:** Geology of CRMs in Europe; **B:** Mining in a Global Environment; **C:** Economic Resource Evaluation; **D:** Multi-Sensing Drones; **E:** Social Assessment in Mining and Exploration; **F:** Environmental Impact Assessment in the Extractive Sector; **G:** Muon-Based Density Characterization of Rocks; **H:** SDGs, UNRMS and UNFC.

**TABLE 9D**

Evaluation of contents.

| # | Respondents (N) | MV | SD | SE | ME | Median | Tendency | Estimate |
|---|---|---|---|---|---|---|---|---|
| Q5.2 I | 32 (96.97%) | 4.13 | 0.93 | 0.16 | 0.32 | 4.00 | Majority is new | SPE |
| Q5.2 J | 30 (90.90%) | 3.93 | 1.03 | 0.19 | 0.37 | 4.00 | Majority is new | SPE |
| Q5.2 K | 32 (96.97%) | 3.66 | 1.05 | 0.19 | 0.36 | 4.00 | Majority is new | SPE |
| Q5.2 L | 32 (96.97%) | 4.10 | 1.03 | 0.18 | 0.36 | 4.00 | Majority is new | SPE |
| Q5.2 M | 32 (96.97%) | 3.63 | 1.27 | 0.22 | 0.44 | 4.00 | Majority is new | SPE |
| Q5.2 N | 32 (96.97%) | 3.72 | 1.04 | 0.18 | 0.36 | 4.00 | Majority is new | SPE |
| Q5.2 O | 31 (93.93%) | 4.61 | 0.83 | 0.15 | 0.29 | 5.00 | Completely new | SPE |

Note: $N_{Max}$= 33; **Q5.2 I:** Passive Seismic Analysis for Subsurface Characterization; **J:** Q&A Session on International Reporting Standards; **K:** Conventional Exploration Technologies for CRMs; **L:** OECD Mining Regions and Cities initiative; **M:** The Green New Deal and CRMs; **N:** Geology of CRMs in Africa (Zambia); **O:** The AGEMERA Graphical User Interface.

The average responses show that participants think the material is new in general; on average 35 per cent of respondents say it was ‘completely new’ and 27.71 per cent selected ‘the majority of content is new to me’, resulting in a total of 62.71 per cent. Furthermore, according to an average of 22.71 per cent of respondents, ‘the amount of new and known content is balanced’. In the meanwhile, the combined average for the categories ‘nothing is new to me’ and ‘the majority of content is known to me’ is 8.12 per cent.

While MEs are relatively high ranging from 0.29 up to 0.44, the responses show overall a tendency in a positive direction towards the material being viewed as novel, with subjects related to the technologies used in the AGEMERA project receiving particular high ratings. Content on multi-sensing drones is rated as ‘completely new’ by 37.50 per cent and ‘the majority of content is new to me’ by 40.62 per cent, with a median rating of 4.

Similarly, with a median rating of 4, 37.50 per cent of respondents see the presentation on passive seismic analysis for subsurface characterisation as ‘completely new’, while 46.88 per cent say that ‘the majority of content is new to me’. The presentation on muon-based density characterisation of rocks received ‘completely new’ ratings from 62.50 per cent and ‘the majority of content is new to me’ from 28.12 per cent, with a median of 5.

### *Topic 6 – learning outcomes*

Respondents were asked in Q6.1 when they were first introduced to CRMs. Most respondents (71.43 per cent) had been introduced to CRMs before taking the course, with a relatively small ME of 0.17, a MV of 1.29 and a median of 1. Almost a third (28.57 per cent) heard about CRMs for the first time during the course.

Subsequently, respondents rated their level of agreement on whether the course enhanced their understanding of various CRM-related topics, as shown in Tables 10a and 10b during Q6.2. Respondents showed particularly positive agreement on questions 6.2 A, B, C, D, E and K, resulting in a median of 5 for these questions. Other questions achieved a median of 4, with acceptable SDs as well, not exceeding 1.0 and MV ranging from 0.20 to 0.30. Overall, 86.65 per cent of the feedback was positive (‘strongly agree’: 48.86 per cent; ‘agree’: 37.78 per cent). On average, 11.36 per cent of respondents were neutral and only 1.7 per cent provided negative feedback (‘strongly disagree’: 0 per cent; ‘disagree’: 1.87 per cent) regarding the course’s effectiveness in enhancing their understanding of various aspects related to CRMs.

**TABLE 10A**

Learning outcomes.

| # | Respondents (N) | MV | SD | SE | ME | Median | Tendency | Estimate |
|---|---|---|---|---|---|---|---|---|
| Q6.1 | 28 (84.85%) | 1.29 | 0.45 | 0.09 | 0.17 | 1.00 | Before | SPE to PE |
| Q6.2 A | 32 (96.97%) | 4.47 | 0.61 | 0.11 | 0.21 | 5.00 | Strongly agree | SPE |
| Q6.2 B | 31 (96.88%) | 4.42 | 0.66 | 0.12 | 0.23 | 5.00 | Strongly agree | SPE |
| Q6.2 C | 32 (96.97%) | 4.34 | 0.81 | 0.14 | 0.28 | 5.00 | Strongly agree | SPE |
| Q6.2 D | 32 (96.97%) | 4.38 | 0.86 | 0.15 | 0.30 | 5.00 | Strongly agree | SPE |

Note: $N_{Max}$= 33; Format is not applicable for Q6.3; Q6.2 This course enhanced my understanding of... **A:** rare earth elements; **B:** battery raw materials; **C:** wide spectrum of critical raw materials; **D:** critical raw materials and their significance in everyday life.

**TABLE 10B**

Learning outcomes.

| # | Respondents (N) | MV | SD | SE | ME | Median | Tendency | Estimate |
|---|---|---|---|---|---|---|---|---|
| Q6.2 E | 32 (96.97%) | 4.34 | 0.81 | 0.14 | 0.28 | 5.00 | Strongly agree | SPE |
| Q6.2 F | 32 (96.97%) | 4.16 | 0.87 | 0.15 | 0.30 | 4.00 | Agree | SPE |
| Q6.2 G | 32 (96.97%) | 4.22 | 0.70 | 0.12 | 0.24 | 4.00 | Agree | SPE |
| Q6.2 H | 32 (96.97%) | 4.25 | 0.87 | 0.15 | 0.30 | 4.00 | Agree | SPE |
| Q6.2 I | 32 (96.97%) | 4.31 | 0.63 | 0.11 | 0.22 | 4.00 | Agree | SPE |
| Q6.2 J | 32 (96.97%) | 4.31 | 0.58 | 0.10 | 0.20 | 4.00 | Agree | SPE to PE |
| Q6.2 K | 32 (96.97%) | 4.56 | 0.61 | 0.11 | 0.21 | 5.00 | Strongly agree | SPE |

Note: $N_{Max}$= 33; Format is not applicable for Q6.3; Q6.2 This course enhanced my understanding of... **E:** Europe's dependence on critical raw material imports; **F:** how our high-tech lifestyle relies on access to critical raw materials; **G:** the role of critical raw materials in the digital and green transition; **H:** international frameworks and regulations such as UNFC, UNRMS and the UNSDG; **I:** achieving a fair and justified supply of critical raw materials within the EU; **J:** the social license to operate in the raw materials sector; **K:** innovative non-invasive geophysical survey methods for sustainable and responsible exploration.

### *Topic 7 – marketing data collection*

Respondents were asked how they found out about the course. The largest part (50 per cent) heard about the course through their universities' internal communication channels, such as the daily email bulletin. The second largest group (25 per cent) were contacted directly by the course organisers or were recommended by university staff. In addition, 14.29 per cent were informed by colleagues and friends, while 10.71 per cent enrolled as a result of advertising on the AGEMERA account on the social media platform LinkedIn. The majority of respondents (84.85 per cent) indicated that they would attend the course regardless of the ECTS credits offered. A smaller percentage (15.15 per cent) selected that they would not attend the course if ECTS credits were not offered. The positive tendency is supported by a quite low SD of 0.36 and ME of 0.12, displayed in Table 11.

**TABLE 11**

Marketing data collection.

| # | Respondents (N) | MV | SD | SE | ME | Median | Tendency | Estimate |
|---|---|---|---|---|---|---|---|---|
| Q7.2 | 33 (100%) | 1.85 | 0.36 | 0.06 | 0.12 | 2.00 | Again | SPE to PE |

Note: $N_{Max}$= 33; Format is not applicable for Q7.3, Q8.1, Q8.2.

### *The written online examination*

The written online examination was held on May 03, 2024 and was open to all participants aiming to obtain 3 ECTS credits. Students were given the information regarding the prerequisites for participating in the examination, with plenty of time in advance. Successful completion of both the pre-examination and the feedback questionnaire by May 2, 2024, was required to qualify for the written online examination. Technical requirements included downloading the web browser Google Chrome, having a webcam positioned to display the participants' hands during the exam, access to a device for scanning results (eg a scanner or phone as a backup) and ensuring the ability to log in to the online platform on both a desktop computer or laptop and a mobile phone as a backup. Students were advised to ensure their ability to log in to Opal on their devices before the examination day, as coordinators are not able to address login issues on the day of the exam. The examination was conducted online in two distinct virtual meeting rooms separate from the virtual classroom used for lectures. Students were required to join 30 mins before the exam's start for the identification process and to ensure compliance with formal and technical requirements. Identification was performed using each person's student ID.

Participants could only see themselves in the virtual meeting room and were unable to send private messages or use the public chat function. All participants were muted upon entry, but it was possible to unmute and to ask questions to the coordinator. No external communication, assistance, or internet usage was permitted during the exam. After the identification process and explanation of rules, the coordinator made the PDF file of the exam available to students. Participants were instructed to handwrite their responses on paper, including their name and email address on each side of the sheets and then submit their results as a single file online in the designated upload folder. Uploaded files were named according to group, surname and version. Students had 90 mins to finish the examination and an additional 15 mins to upload their files. Similar to the pre-examination, questions from each chapter were included, developed in collaboration with different presenters.

## Discussion of scope for improvement and outlook for future courses

With an average attendance rate of 35.62 per cent among registered participants for the live lectures of chapters 1 to 7, the overall attendance is considered low. However, the attendance rate for the live presentations was relatively high among those who achieved the COA. Specifically, 69.69 per cent of the 33 respondents indicated that they attended 76 per cent to 100 per cent of all chapters 1 to 7 presentations.

The non-mandatory presentations had lower attendance rates than the presentations of chapters 1 to 7, with an average attendance rate of 10.41 per cent of the 73 registered participants. According to the feedback questionnaire results, only 24.24 per cent joined between 76 per cent and 99 per cent of the presentations in person, and 27.27 per cent of the respondents chose less than 25 per cent. Additionally, 24.24 per cent indicated that they did not join any of the live presentations of chapter 8. Different respondents to the feedback questionnaire mentioned that they missed the live presentations due to time differences or their option to combine the presentation with their studies or jobs. However, the recorded presentations (as of June 26, 2024) have shown that participants actively (re-)watched the recordings of live lectures, as 656 views were achieved. Since attendees come from various study programs and geographical locations, finding a schedule that suits everyone is impossible. However, since most registrants are from TUBAF, particularly the Sustainable Mining and Remediation Management Master's program, scheduling the courses to align with this program's timetable could help minimise conflicts and benefit the attendance rates of live lectures.

Out of 33 respondents to the feedback questionnaire, 24.24 per cent strongly agreed that participants have the opportunity to engage with other people in the online course, while 18.18 per cent agreed and 45.45 per cent were neutral. Compared to other answers to questions, the number of people who chose 'neutral' is comparably high. To improve engagement, satisfaction and attendance rates for live lectures and potentially increase student numbers, a hybrid lecture framework will be introduced in collaboration with partnering HEIs that have access to the required infrastructure. Conducting hybrid lectures allows people to join a real classroom while simultaneously livestreaming the session to a virtual classroom. While not all involved partners can fully implement this concept, it could be partially adopted by those that have access to the necessary technical equipment. This strategy would require additional effort, but it could satisfy those who provided negative or neutral feedback in the questionnaire regarding engagement possibilities. Tutors would benefit from direct interaction and quicker feedback and students who prefer in-person lectures might be more open to attend. Live events at partner universities could attract attention and increase the visibility of the courses, encouraging people who are unsure whether they should register for the courses and result in more registered students.

The feasibility of implementing a case study into the framework of a micro-credential, without compromising its ability to be scaled easily, to make the courses more interactive, will be explored. The integration of a case study could increase student interest and registration numbers. Since the COA is designed to be obtainable at any time of the year, the case study should be structured accordingly. The feasibility of integrating a case study will be examined before the second iteration of the courses.

More students could be reached by directly contacting them through announcements in lectures or messages from lecturers. Word-of-mouth was a passive method of attracting students, where students informed their colleagues about the course. Therefore, the dissemination strategy for future classes should include calls to action that encourage people to tell their friends about the courses offered via AGEMERA. The evaluation revealed that many respondents had learned about the courses through their universities' communication channels. This highlights the importance of all involved HEIs focusing on the dissemination channels/methods their students actively subscribe to. For example, platforms like LinkedIn may attract working professionals but university newsletters seem to be more effective in in the case of ECRMs to reach students.

## CONCLUSIONS

The feedback questionnaire provided results that, in most cases, can make 'somewhat precise' estimates regarding the ability of the received values to represent the genuine experience of the entire course.

Based on the feedback questionnaire results concerning the registration process, course navigation and structure and the positive indication by participants that they would be open to attend an online course like ECRMs again, no significant structural changes will be made for the next stage of the HEI courses. The content will focus on sessions mandatory for performance assessments, in line with the schedule of participants from the largest enrolled stakeholder group of the class of 2024. Hybrid courses or a case study might be introduced and communication efforts shall be improved.

The pilot launch of the AGEMERA university courses 'European Critical Raw Materials for the Green and Digital Transition (ECRMs)' effectively introduced the challenges and opportunities of the mineral raw materials sector, focusing on CRMs, to a broad audience from over 25 nations. Respondents to the feedback questionnaire were satisfied with attending ECRMs, as the course significantly increased their understanding and knowledge about CRMs. The positive feedback indicates that the courses can significantly increase participants' understanding and knowledge about CRMs, although most respondents of the feedback questionnaire were in the middle or advanced stages of postgraduate programs and had a background in mineral raw materials. The trends from the feedback questionnaire evaluation show that the course met the participant's expectations, including tutors' engagement and competencies, with most content rated as very interesting or novel. Subjects related to the technologies used in the AGEMERA project, such as multi-sensing drones, passive seismic analysis for subsurface characterisation, muon-based density characterisation and the graphical user interface, received exceptionally high ratings, filling educational gaps with the most recent information from the industry and research.

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# The Hub and Spokes approach, an industry-academia sustainable collaboration framework

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## INTRODUCTION

The digitalisation of industries has been moving forward providing numerous benefits and also challenges. These, represent not only a challenge to the industry but also to the academy since they are responsible for adapting the education and training of future mining professionals to the constant changes and new professional profiles required. It is due to the need for constant updating in the educational training of mining engineers that private companies must be active promoters of the approach to new trends and market needs. Since 2018, the Universidad Politécnica de Madrid (UPM) has implemented the Epiroc Industry-University Chair which involves the committed participation of Epiroc in an elective lecture in cooperation with the UPM which has increased the skills of the students and strengthen the relationship with the industry. In 2021, the Universidad Nacional Mayor de San Marcos adopted the Spanish model and since then a Hub and Spokes model of collaboration between industry and academy has been developed. Based on the initiative of Epiroc and with the aim to shape a sustainable collaboration model that can be replicated and transported to other universities, companies and industries, the authors have designed the 'Hub and spokes approach' which stands for an industry-academia sustainable collaboration framework. This presentation introduces the principles, highlights the required stages for success and builds on the strategy pursued when creating a replicable framework and aims to outline the relevance and impact of the collaboration, describe the initial model and its subsequent expansion, and detail the elements that foster a sustainable collaboration. Furthermore, it provides the reader with a list of general and specific objectives, and related indicators relevant for the conduction and assessment during and after the implementation of the approach.

## INDUSTRY-ACADEMIA COLLABORATION

The collaboration between industry and academia is not a new concept. Over the years, such partnerships have grown significantly, driven by mutual benefits and the evolving needs of both sectors. Furthermore, a partnership between industry and academia offers numerous benefits, including access to cutting-edge research, state-of-the-art of the technology, real-world applications for academic theories, and enhanced educational experiences. Such collaborations help bridge the gap between theoretical knowledge and practical application, preparing students for real-world challenges and providing industries with innovative solutions. Some of the prevalent collaboration practices include:

- Strategic Partnerships: Long-term agreements between companies and universities to work on specific research projects, technology developments, or innovation hubs. These partnerships often include shared funding, resources, and intellectual property rights.
- Collaboration Agreements/MoUs: Formal agreements that outline the terms and scope of collaboration. These agreements can range from academic collaboration and research projects to student internships and exchange programs.
- Industry-Funded Research: Companies provide funding for academic research projects that align with their strategic interests. This funding can support laboratories, scholarships, and specific research initiatives.

- Real-Case Scenarios in Lectures: Integrating practical industry challenges into academic curricula. This practice helps students apply theoretical knowledge to real case problems and prepares them for industry demands.
- Industry-Guided Thesis Work: Students undertake thesis projects under the guidance of industry experts, ensuring that their research has practical relevance and potential application in the industry.
- Guest Lectures/Honorary Professors: Industry professionals are invited to give lectures or teach courses, providing students with insights into current industry practices and trends.

Despite their benefits, contemporary collaboration practices face several challenges that impact their sustainability. Changes in company strategy, such as shifts in market focus, mergers, or leadership changes, can disrupt ongoing collaborations. High turnover in management positions within both industry and academia often leads to shifts in priorities and loss of continuity in collaborative efforts. Academic institutions may shift their research priorities based on funding availability, new faculty interests, or emerging scientific trends, which may not always align with industry needs. Differences in organisational cultures and objectives between academia and industry can lead to misalignment and conflicts. Personal changes, such as key personnel moving to different roles or organisations, cause a loss of knowledge and weaken the collaboration. Additionally, both sectors often face budget constraints and resource limitations, hindering the scope and progress of collaborative projects.

Epiroc, a leading OEM in the mining industry, identified the need for a structured and sustainable collaboration model to maintain a competitive edge and drive innovation. The initiative aimed to integrate educational efforts with industrial needs, promoting a continuous exchange of knowledge and expertise since, despite the benefits, many contemporary collaboration practices face challenges that affect their sustainability over time. The initial collaboration model was functional and successful, running for six years by the Universidad Politécnica de Madrid, with a variety of activities and positive assessments of results. This model involved strategic partnerships, mine visits to associated operations, and real-case scenarios integrated into lectures, which significantly benefited both the academic institutions and the industry partners. The enhanced presence of academia representatives in the visited mining operations has led also to additional collaborations with other stakeholders of the mining ecosystem bridging the gap between academia and industry.

## THE HUB AND SPOKES APPROACH

Building on the success of the initial model, Epiroc expanded the collaboration to Peru, conducting activities over three years. Later, as the network grew, the Ibero-American Hub and Spokes Approach was established to developed collaboration, covering four countries, Spain, Peru, Colombia and Ecuador. One of the major activities was the online lectures of the Epiroc-University Chair in 2023, involving 24 Peruvian universities, seven educational institutions, and ten global mining companies. The network positively impacted 993 students across seven Latin-American countries.

The Hub and Spokes model is a collaborative framework which principal advantage is that permits a rapid expansion for the collaboration between different universities and the company avoiding doubled efforts and optimising resources. The last is mostly relevant, when considering mining countries as Peru where the number of mining schools can be more than 20 universities. In this model, see Figure 1, a central hub university coordinates with various spoke universities, industry partners, and institutions to facilitate a wide range of activities. The model aims to combine educational and practical experiences through a structured approach that includes shared lectures, master classes, regional networks, research collaboration, champion programs, field trips, continuous professional training, webinars, and equipment donations. By establishing a central hub that serves as the nexus of coordination, the model ensures consistent quality and strategic alignment across all participating entities. The spoke universities and industry partners contribute to and benefit from the collaborative efforts, creating a dynamic network that fosters innovation, enhances educational outcomes, and ensures the sustainability of the partnership. This structure not only promotes effective knowledge transfer and resource sharing but also addresses regional needs, engages communities, and adapts to changing industry and academic landscapes. After the first round of activities conducted in 2023 of the Ibero-American network, a positive impact was identified addressing several stakeholders part of the mining ecosystem.

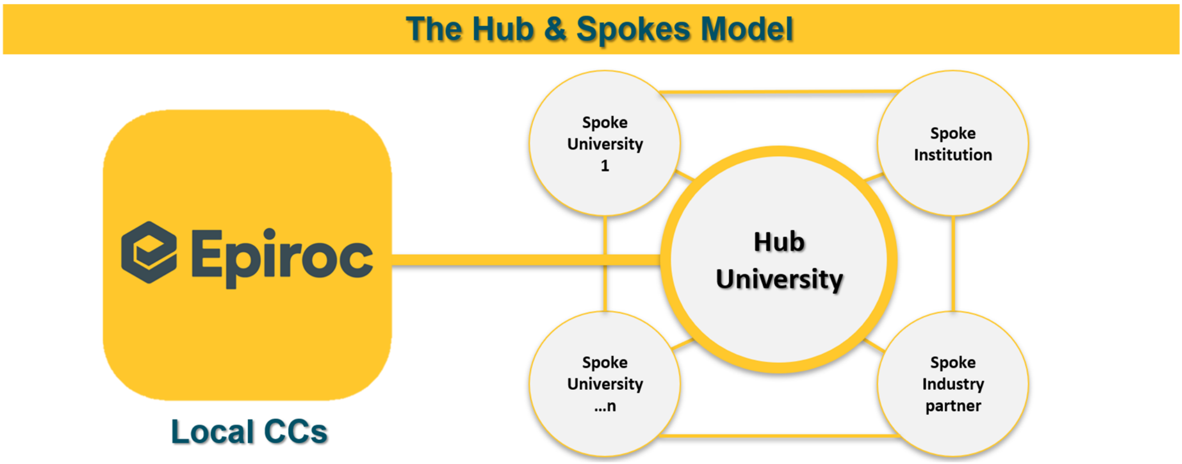


**FIG 1** – The Hub and Spokes Model.

Effective execution involved defining short and mid-term goals, deliverables, and KPIs. Communication strategies were essential for maintaining engagement with customer centres, general managers, and universities. Signing MoUs and partnership agreements is the starting point to formalise the collaboration and expand the network. Establishing contacts, having a direct communication with the OEM and the university, and setting the project along Epiroc' s strategy for quality education, were critical components in managing expectations and the success of the implementation. Issues such as intellectual property concerns and long-term relationship maintenance were identified as key challenges.

Project management principles were integrated to ensure clear objectives, key outputs, and continuous development and integration. To ensure the longevity and sustainability of the collaboration, Epiroc developed a model incorporating initiating, planning, stakeholder engagement, execution, and monitoring and controlling processes, as well as internal communication within the company. This approach aimed to create community engagement strategies, define regional needs, and allocate resources effectively. The model involved a central hub university coordinating with various spoke universities, industry partners, and institutions. This structure facilitated integrated lectures, master classes, regional networks, research collaboration, and continuous professional training. The robust project management framework underpins the sustainability of the proposed collaboration model described with the following steps:

- Initiating: Identifying stakeholders and defining the collaboration's purpose and scope.
- Planning: Developing detailed plans for project execution, including roadmaps, budgets, and resource allocations. Planning also involves risk management strategies and defining clear goals and objectives.
- Executing: Implementing the planned activities, ensuring all tasks are carried out as scheduled. This stage shall strength high standards of quality supported by a philosophy of continuous improvement.
- Monitoring and Controlling: Continuously tracking progress against the plan, managing changes, and addressing any issues that arise. This includes regular status updates, performance reviews, and adjustments to keep the project on track.
- Closing: Formalising the completion of the project or phase, ensuring all objectives are met, and conducting post-project evaluations to gather lessons learned.


**FIG 2** – Overview the stakeholders from the side of the OEM involved along the project development roadmap.

## OUTLOOK

The collaboration model led to significant achievements, including a rapid expansion and positive perception of the project from the mining ecosystem. The conduction of the first case, of the Ibero-American Network has led to further collaborations worldwide and additional initiatives in the industry, besides of the starting OEM. The Epiroc Industry-University Hub and Spokes model demonstrates a successful approach to industry-academia collaboration, fostering innovation, education, and sustainable partnerships. By addressing key challenges and balancing strategic frameworks, the model provides a blueprint for other organisations seeking to enhance their collaborative efforts in the mining industry and beyond. Moving forward, the focus will be on enhancing local and regional engagement, developing talent, and strengthening the brand positioning and marketing efforts of the project and all involved partners. Furthermore, the Society of Mining Professors (SOMP) has been an enthusiastic supportive forum of these efforts whereby yearly updates have been presented along the SOMP Annual General Meeting, for the last four years.

# Fostering competence-oriented teaching and learning by challenge-based learning in collaboration with industry

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## ABSTRACT

In their everyday work engineers need to solve uncertain, open-ended and complex problems. For tackling these problems, they do not only need fundamental (technical) knowledge, but also the necessary (soft-)skills. This requires the implementation of new teaching and learning methods supplementing traditional lecture formats. In line with this a challenge-based teaching and learning approach was developed and implemented in the M. Sc. Mineral Resources Engineering at RWTH Aachen University exposing the students to a real-world challenge from the mining industry. In winter term 2023/2024, the students were posed with a challenge by the K+S AG, an internationally oriented raw materials company and Europe's largest supplier of potash for fertilisers with production sites in Europe and North America. Their task was the control and optimisation of underground belt conveying in a specific mine site, the Zielitz mine. Over the course of the semester, the students were guided through the design thinking process, a systematic and iterative approach for developing innovative solutions for complex challenges based on user-centricity and multidisciplinary teams. Primarily, the students developed a deep understanding for the challenge. Therefore, they conducted research on different topics and pursued a semi-structured (online-)interview with selected employees from K+S AG. During a field trip to the Zielitz mine, the students had the opportunity to further analyse and observe the problem. Afterwards they intensively worked on developing and evaluating innovative ideas for the challenge resulting in a novel monitoring approach. The final solution was presented in front of K+S. The challenge itself not only exposed the students to a realistic engineering challenge, but also has given the mine operator a new perspective on the problem and innovative approaches supporting them in their efforts. For evaluating the effectiveness of this approach self-assessed acquisition of competences and students' motivation specific evaluation measurements were conducted.

## INTRODUCTION

In their everyday work engineers need to solve uncertain, open-ended problems (Chen, Kolmos and Du, 2021). Therefore, they do not only need fundamental (technical) knowledge, but also the (soft-) skills to do so. This requires the implementation of new teaching methods compared to traditional lectures for consequently following a competence-oriented teaching approach.

In line with this, a challenge-based teaching and learning approach was developed and implemented in the MSc Mineral Resources Engineering at RWTH Aachen University within the course 'Mine Equipment planning'. Over the course of the semester, the students were guided through the design thinking process to develop innovative solutions for a specific challenge. In the winter term 2023/2024, the students were posed with a challenge by the K+S AG, an internationally oriented raw materials company and Europe's largest supplier of potash for fertilisers with production sites in Europe and North America. For evaluating the effectiveness of this challenge-based teaching and learning approach self-assessed acquisition of competences and students' motivation specific evaluation measurements were conducted at the end of the semester.

This research aims to investigate if a challenge-based teaching and learning approach increases the students' skillset and therefore their ability to deal with complex, real-world problems and if dealing with real problems from research or industry can increase the students' interest and motivation. The following paper is structured as follows. Section two will provide relevant background information about the design-thinking process and the course, in which the challenge-based teaching and learning approach has been implemented. This is followed by an introduction into the methodology for evaluating the effectiveness of the challenge-based teaching and learning approach in section three. Sections four and five will present and discuss the findings of the accompanying study. Finally, this paper ends with a brief conclusion.

# BACKGROUND

This section aims to provide relevant background information about the design-thinking process and the master's course 'Mine Equipment Planning' in which the challenge-based teaching and learning approach has been implemented.

## The design thinking process

The design thinking process is a systematic and iterative approach for developing innovative solutions for complex challenges (Meinel, Weinberg and Krohn, 2015). The process is furthermore based on a user-centric approach and characterised by collaborating in multidisciplinary teams. The process is also characterised by constant dialogue between the developer of a solution and the user as well as early idea communication by means of prototypes. The design thinking process takes three key components into account: people, economy and technology. This means that solutions should be technologically feasible, economically viable and desirable from a social perspective. (Lewrick, Link and Leifer, 2020) Alongside working in multidisciplinary teams, the use of flexible spaces and the design thinking process are success factors for developing innovative solutions to complex problems (Meinel, Weinberg and Krohn, 2015).

The latter is characterised by iteratively going through six phases, with three assigned to a problem space and three assigned to a solution space. The whole design thinking process is illustrated in Figure 1.

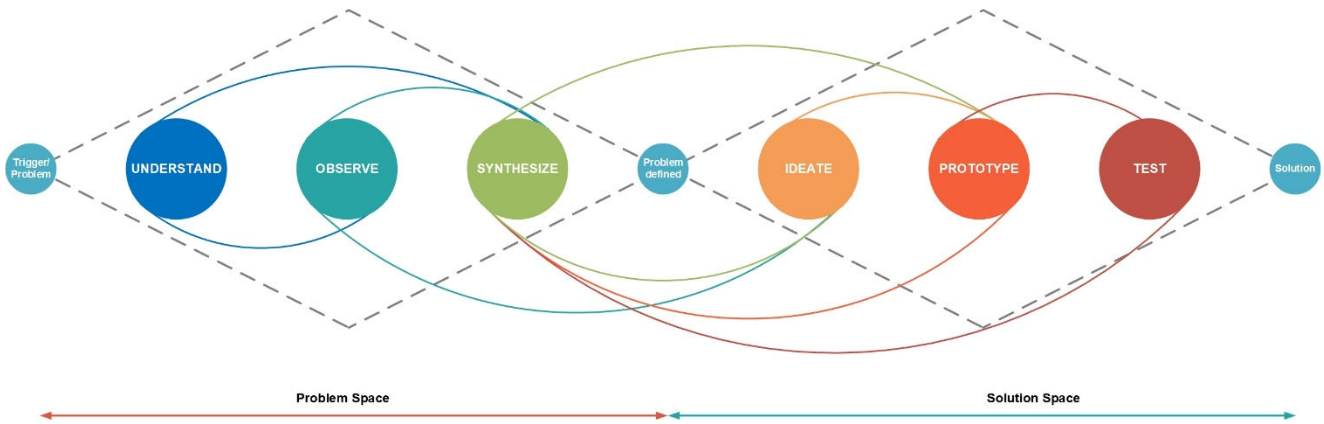


**FIG 1 –** Design Thinking Process (adapted from Hasso Plattner Institute for Digital Engineering gGmbH (2024)).

The problem space includes the following phases (Lewrick, Link and Leifer, 2020):

**Understand:** Defining und understanding the problem space.

**Observe:** Observing the current circumstances and establishing a relationship with the user.

**Synthesise:** Consolidating and summarising the findings.

The solution space includes the following phases (Lewrick, Link and Leifer, 2020):

**Ideate:** Developing ideas followed by prioritisation and elaboration.

**Prototype:** Elaborating concrete solutions and prototypical implementation.

**Test:** Testing the idea(s) on a target group using prototypes.

## Mine equipment planning

The challenge-based teaching and learning approach was developed and implemented in the M. Sc. Mineral Resources Engineering at RWTH Aachen University. In six bachelor's semesters, students initially learn the basics of engineering and mining disciplines. The four-semester master's programme builds consecutively on this with an in-depth specialisation and application focus. The course 'Mine Equipment Planning', in which the challenge-based approach was implemented, is anchored in the third semester of the master's degree programme. This means that students have already acquired relevant engineering and mining fundamentals as part of their studies. During the course, the objective is, that students work in teams on a complex problem with real and current application relevance from research or industry. Thus, the following learning objectives shall be achieved.

- Demonstrate a deep understanding and comprehensive knowledge of mine equipment design and planning of mining tasks based on a specific problem.
- Show the ability to develop mine equipment concepts for the extraction of mineral raw materials, taking into account relevant influencing factors and potential hazards.
- Proof of being able to carry out a project in a targeted and efficient manner based on a specific problem, including the necessary documentation, analysis, interpretation, and evaluation as well as presentation of the results.
- Demonstrate the ability to identify, analyse and solve engineering problems arising from the need for mine equipment planning and to apply this knowledge to develop, discuss and justify appropriate engineering solutions to these tasks and problems.
- Demonstrate the ability to work and communicate in a team and to shape team dynamics explicitly and actively.

In the winter term 2023/2024, the students were posed with a challenge by the K+S AG. Their task was the 'Control of the underground belt conveyor system in the Zielitz mine'.

Over the course of the semester, the students were guided through the design thinking process in a workshop format. Each workshop took 90–180 mins. At the end of the semester, the students' learning objectives were assessed in an oral exam. The detailed course structure was as follows:

**Week 1:** General course introduction and experiencing the design thinking process.

**Week 2:** Deepening knowledge about the design thinking process and introduction into team structures and processes.

**Week 3/4:** Understand phase of the design thinking process by analysing the challenge, preparing and giving short presentations on specific topics and preparing a semi-structured stakeholder interview.

**Week 5:** Observe and synthesise phase of the design thinking process by conducting the stakeholder interview with experts from K+S and evaluating the interview.

**Week 6:** Preliminary ideation and preparation of the solution phase.

**Week 7:** Three-day field trip, including the iterative step into the problem space, conducting the solution phase and prototyping of the results at the Zielitz mine of K+S AG.

**Week 8:** Course summary and evaluation at RWTH Aachen University.

# METHODOLOGY

For evaluating the effectiveness of this challenge-based teaching and learning approach self-assessed acquisition of competences and students' motivation specific evaluation measurements were conducted at the end of the semester. With this the following hypotheses were investigated:

- Using a challenge-based teaching and learning approach increases the students' skillset and therefore their ability to deal with complex, real-world problems.

- By working on real problems from research or industry, the students' interest and motivation is increased.

## BEvaKomp

For investigating the hypotheses, that a challenge-based teaching and learning approach increases the students' skillset and ability for dealing with complex and unstructured problems a test for evaluating the self- assessed student competencies has been performed.

This self-assessment survey based on the Berlin Evaluation Instrument for Self-Assessed Student Competencies (BEvaKomp) was pursued to assess the students' competences acquired throughout the course.

The original BEvaKomp survey is based on 27 questions that can be assigned to the following categories (Braun and Vervecken, 2009):

**Professional competences:** Focusing on students expanding their knowledge, understanding as well as their application of skills and analytical skills.

**Methodical competences:** Describing the ability of effectively planning and work scheduling.

**Presentation competences:** Focusing on effectively presenting papers, lectures and presentations considering the respective target group.

**Communication competences:** Describing the ability to articulate one's own opinion clearly and to constructively contribute to discussions.

**Cooperation competences:** Describing the ability to collaborate in groups and deal with tensions and conflicts.

**Personal competences:** Describing the students' positive attitude towards learning and self-development.

Within this study, questions addressing the professional competences, methodical competences, communication competences and personal competences were addressed. Examples of questions are given below:

**Professional competences:** As a result of this course, I am able to clearly explain complex issues.

**Methodical competences:** As a result of this course, I can better organise my personal work.

**Communication competences:** Because of this course, it is easier for me to articulate my own impressions/opinions.

**Personal competences:** As a result of this course, I enjoyed working on tasks that were assigned to me.

The survey comprised a total of 18 questions. The rating was based on a scale from 1 (I strongly disagree) to 7 (I strongly agree). The students also had the option of not answering.

## IMI

The Intrinsic Motivation Inventory (IMI) is designed to get a clear understanding of the students' motivation regarding a course. Initially designed for evaluating activities in laboratory experiments. (Deci and Ryan, 2024) IMI was adjusted to get a better understanding of the students' motivation regarding the course 'Mine Equipment Planning'. The questions can be assigned to different categories. Examples of questions are given below.

**Students' interest:** I really enjoyed working on a real problem from industry during the course.

**Perceived competence:** I am satisfied with my performance in the course.

**Pressure/tension:** I wasn't nervous when participating in the course.

**Effort/importance:** It was important for me to perform well during the course.

**Benefit/usefulness:** I think that working on a real-life challenge as part of the course will be useful for my future career.

The survey comprised 28 questions. The questions that can be assigned to the different categories were mixed. In addition, the survey contained both positive statements (eg *I really enjoyed working on a real problem from industry during the course.*) and negative statements (eg *I considered the course to be rather boring.*).

Again, the rating was based on a scale from 1 (I strongly disagree) to 7 (I strongly agree). The students also had the option of not answering.

## RESULTS

In the winter semester 2023/2024, a total of six students participated in the course 'Mine Equipment Planning'. One student did not complete the course, resulting in five students (four male, one female) taking part in the surveys.

## BEvaKomp

Figure 2 shows the results of the survey to assess the students' competences acquired throughout the course. Therefore, the results of all questions that can be assigned to one category have been summarised. It becomes clear, that the students perceived an increase in their competences in all areas. However, it is also apparent that there is a wide range of perceptions, particularly with regard to personal competences.

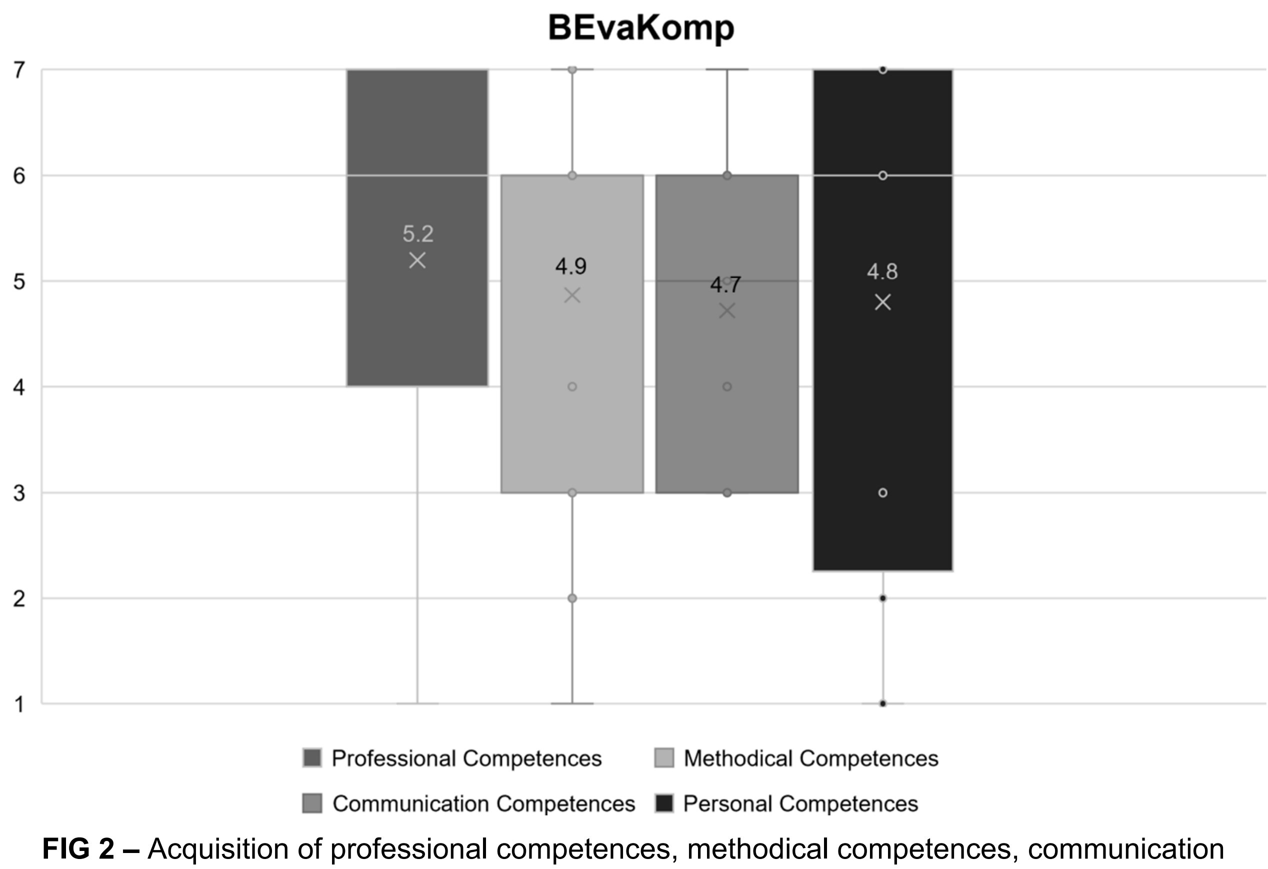


**FIG 2 –** Acquisition of professional competences, methodical competences, communication competences and personal competences from the students' perspective (n=5) from 1 = I strongly disagree to 7 = I strongly agree.

## IMI

Figure 3 shows the results of evaluating the students' intrinsic motivation when participating the course. Again, all results that can be assigned to one category have been summarised. Furthermore, the results of questions referring to negative statements have been inverted. The results indicate that the students liked in participating the course and that there was a strong interest.

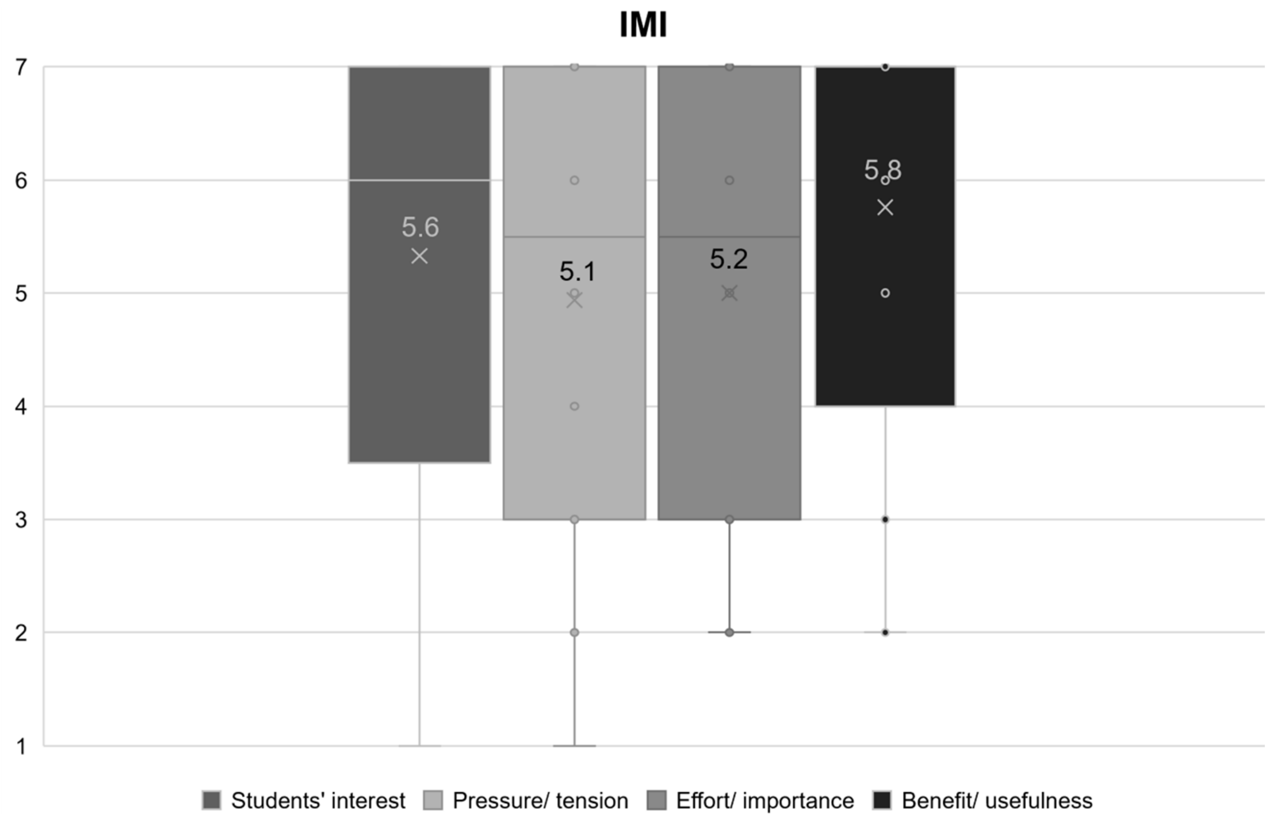


**FIG 3 –** Students' Interest participating the course (n=5) from 1 = I strongly disagree to 7 = I strongly agree. Note that the results referring to negative statements have been inverted.

## DISCUSSION

In order to evaluate the effectiveness of a challenge-based teaching and learning approach two hypotheses have been investigated to identify if this approach increases the students' skillset and therefore their ability to deal with complex, real-world problems and if dealing with real problems from research or industry increases the students' interest and motivation. In the following both hypotheses are discussed in detail.

In order to deal with complex problems, the students do not only need fundamental (technical) knowledge, but also the (soft-) skills to do so. This comprises professional competences, but also methodical, communication, presentation and personal competences as addressed in the BEvaKomp survey. An average greater than four was achieved for all questions, which indicates, that in this case the challenge-based teaching and learning approach increases the self-assessed students' skillset from their own perspective.

This is complemented and supported by several questions of the IMI survey that focus on the benefit and usefulness of this approach. Here an average greater than five indicates that the students see a certain benefit in this teaching and learning approach.

The students' interest and motivation were addressed by the IMI survey. For questions focusing on the students' interest an average greater than five was achieved Furthermore, the results show that it was important for the students to show a good performance throughout the course. Thus, this hypothesis can also be evaluated positively.

### Limitations

When evaluating the effectiveness of a challenge-based teaching and learning approach through self-assessed acquisition of competences and students' motivation specific evaluation measurements, it is also important to consider the limitations of this research.

In the winter semester 2023/2024, six students participated in the course and five took part in the survey. This results in a small number of outputs, which also show wide variation in some cases (eg questions from the IMI survey focusing on the students' interest, see Figure 3).

Yet this research only provides an initial impression of whether a challenge-based approach can contribute to an increase of the self-assessed students' skillset, their ability to deal with complex, real-world problems, their interest and motivation. A quantitative evaluation is not feasible so far, which is also due to the lack of a reference group. Further course-related studies need to be conducted for this.

## CONCLUSION

In their everyday work engineers need to solve uncertain, open-ended problems (Chen, Kolmos and Du, 2021). Therefore, they do not only need fundamental (technical) knowledge, but also the (soft-) skills to do so. This requires the implementation of new teaching methods compared to traditional lectures. In line with this a challenge-based teaching and learning approach has been implemented in the master's course 'Mine Equipment Planning' of the MSc Programme Mineral Resources Engineering at RWTH Aachen University.

For evaluating the effectiveness of this challenge-based teaching and learning approach self-assessed acquisition of competences and students' motivation specific evaluation measurements were conducted at the end of the semester using two surveys based on the BEVaKomp- and IMI-survey.

Thus, the following hypotheses were investigated and confirmed:

- Using a challenge-based teaching and learning approach increases the student's skillset and therefore their ability to deal with complex, real-world problems.
- By working on real problems from research or industry, the students' interest and motivation is increased.

Since the number of participants was limited, this research only provides an initial impression of the benefits of a challenge-based teaching and learning approach. For a deeper and profound understanding further investigations will be required in future. This study forms the basis for such investigations and further developing and implementing a challenge-based approach in engineering education.

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# European mining course and the TERRA initiative

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## ABSTRACT

Mineral raw materials are critical for renewable energy technologies and achieving the goals of the European Green Deal. The European Union wants to strengthen the sustainable and responsible domestic sourcing of mineral raw materials. To achieve this, the growing demand for experts in this field must be met. The TERRA (Tertiary Education in Sustainable Resource Extraction) project aims to address those challenges by bringing together key players of Europe's mining and mineral raw materials education and further strengthen the European Mining Course (EMC, www.emc-master.eu) as an international triple degree master program.

The TERRA consortium consists beside RWTH Aachen of the two EMC partners MU Leoben and Aalto University. Together, an Academic Expert Network with further important persons from the European mining education is to be founded, an academic conference will be organised and additionally the EMC will be further improved and adapted to current requirements.

As an overarching goal, TERRA is focusing on the fight against climate change, without responsible mineral raw materials there can be no clean energy transition. But the supply of mineral raw materials must be made more sustainable and responsible throughout Europe. To meet this challenge, the mining industry needs well-trained university graduates.

The European Mining Course is a triple-degree MSc program hosted by RWTH Aachen, Aalto University and Montanuniversitaet Leoben (MUL). Alongside with students of these three universities, there are numerous participants from Europe and all over the world. It is designed to provide a solid understanding of the global mining industry and takes a life cycle approach by covering the entire mining value chain. Sustainable mining is in the focus of the program (MUL, 2024).

The EMC aims to train professionals who will be the future decision-makers in the mineral resources and associated engineering trade, with a strong vision of future sustainable developments.

## INTRODUCTION

The need of mineral-based materials is growing globally, partly related to the new green technology. Applications such as windmills and electric vehicles need traditional metals, but also many high-tech metals that support the environmentally sustainable future (European Commission, 2024, Critical Raw Materials Act). Reuse of metals is important part in the materials cycle, but it will not satisfy the increasing demand of metals. Besides recycling, the extraction of minerals from the Earth's crust will remain a necessity well into the future. The European Mining Course (EMC) aims to train experts with a wide range of skills and abilities to meet the ongoing demand for metals and minerals (Figure 1).

**FIG 1** – Aalto University, September 1, 2023. Meeting of the new EMC students, the alumni of previous courses and the professors.

## EUROPEAN MINING COURSE

The safe, environmentally sustainable, and cost-efficient supply of raw materials is essential for a prosperous global society. This industrial sector must meet the challenges today and in the future with the help of research and development.

The purpose of the software program is to generate future decision-makers and game-changers in the field of mineral resources and associated engineering trade. The software program is based on the expertise of the participating universities within Resource Engineering. The focus is to provide state-of-the-art education by means of economically and environmentally sustainable systems and technologies (Aalto University, 2024).

The curriculum of the European Mining Course in detail (Figure 2):

- First semester in Aalto:
  - Minerals Engineering and Recycling
  - Rock Mechanics
  - Economic Geology and Mineral Economics
  - Fundamentals of Pyrometallurgy
  - Fundamentals of Hydrometallurgy
  - Field Experience and Project Communication.
- Second semester in Aachen:
  - Mine Design and Simulation
  - Mine Ventilation
  - Reserve Modelling and Estimation
  - Mine Waste
  - Feasibility Studies of Mining Projects
  - Case Study: Mining Project.
- Third semester in Leoben:
  - Continuous Mining Methods and Conveying
  - Underground Mining, Surface Mining
  - Occupational and Process Safety
  - Mineral Economics
  - Sustainable Development

    - Elective Studies.
- Fourth semester:
    - Master thesis, usually with industry cooperation.

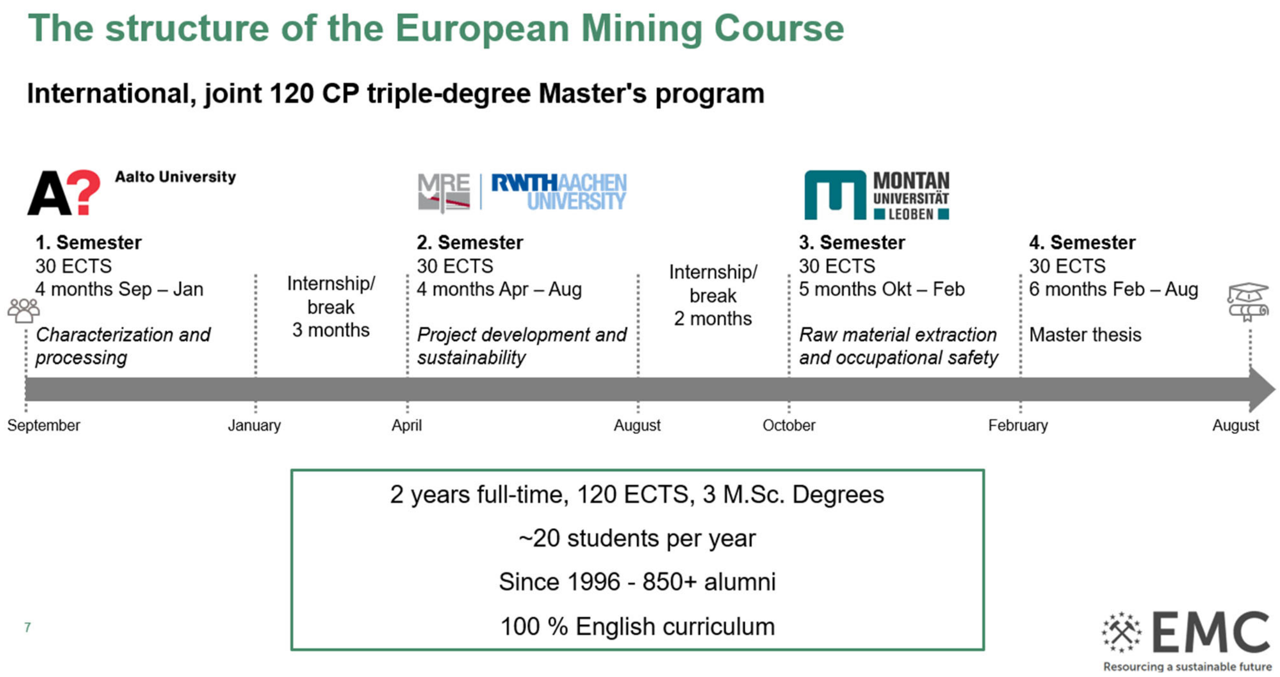


**FIG 2** – The structure of the European Mining Course.

An important part of the studies are practical excursions to operating mine sites (Figure 3) and the contact with industrial partners.

**FIG 3** – Visit with students to the underground Tungsten mine Wolfram/Mittersill in Austria (photo courtesy of: N A Sifferlinger).

The program is supported by the Federation of European Mineral Programs (FEMP). FEMP is a not-for-profit foundation established to support the education of Master of Science level students in the field of mineral engineering (FEMP, 2024).

Figure 4 shows the offering of the European Mining Course.

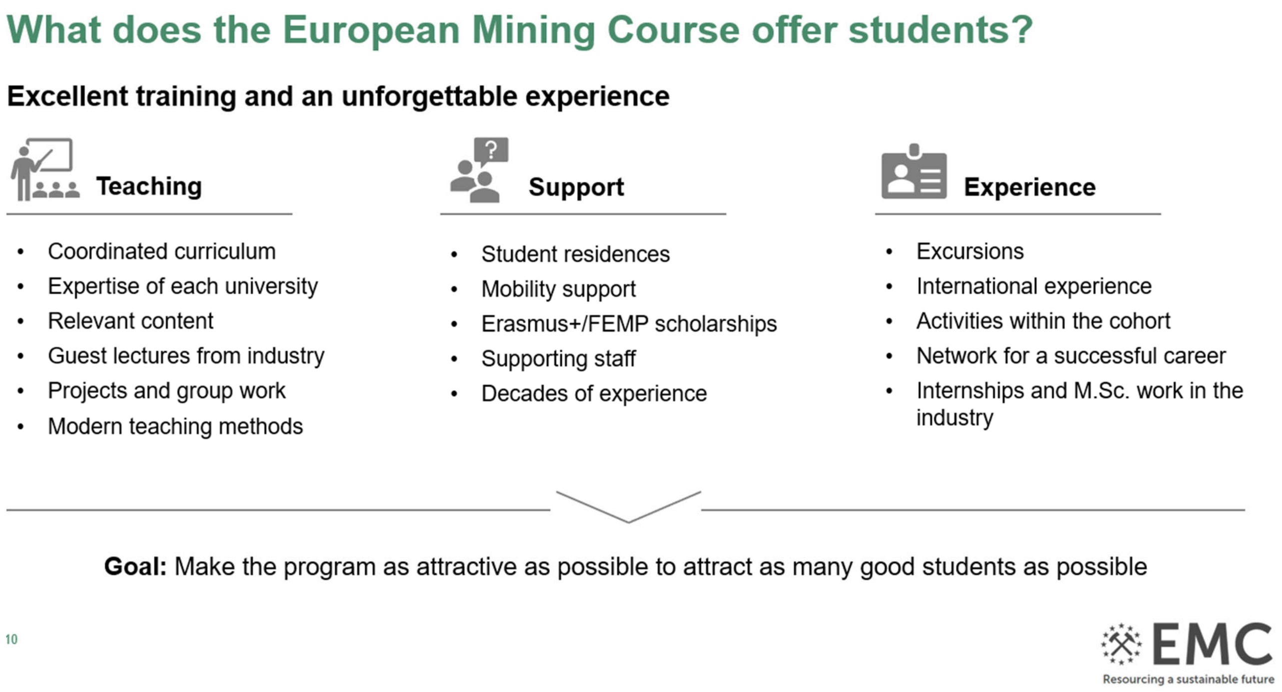


**FIG 4** – What does the European Mining Course offer students?

## TERRA (TERTIARY EDUCATION IN SUSTAINABLE RESOURCE EXTRACTION)

Mineral raw materials are critical for renewable energy technologies and achieving the goals of the European Green Deal. The European Union wants to strengthen the sustainable and responsible domestic sourcing of mineral raw materials. To achieve this, the growing demand for experts in this field must be met. The TERRA project aims to address those challenges by bringing together key players of Europe's mining and mineral raw materials education and further strengthen the European Mining Course (EMC, www.emc-master.eu) as an international triple degree master program.

The TERRA consortium consists beside the MRE of the two EMC partners MU Leoben and Aalto University. Together, an Academic Expert Network with further important persons from the European mining education is to be founded, an academic conference will be organised and additionally the EMC will be further improved and adapted to current requirements (MRE, RWTH Aachen University, 2024).

As an overarching goal, TERRA is focusing on the fight against climate change, without responsible mineral raw materials there can be no clean energy transition. But the supply of mineral raw materials must be made more sustainable and responsible throughout Europe. To meet this challenge, the mining industry needs well-trained university graduates. Mining programs across Europe face similar challenges with decreasing numbers of students and difficulties to offer the full range of relevant topics at their own university. To tackle those challenges, the TERRA project is working on modernising innovative learning and teaching methods and promoting cooperation between universities. The existing structures and experiences of the three project partners of the renowned European Mining Courses (EMC) and the Federation of European Mineral Programs (FEMP) serve as a sound basis for this.

The TERRA project envisages to achieve a number of results to address the challenges of European mining engineering education and thus supply Europe with sufficient and well educated future decision-makers:

- A database for students with information about personal career and educational opportunities across Europe.
- An Academic Expert Network, bringing together key players of the educational landscape and tackle common challenges together.
- An academic conference, facilitating the direct collaboration between key players in Europe's mining education. Figure 5 shows the participants of the TERRA conference in Boppard in September 2023.
- Benchmarking and improving the EMC curriculum with demands from industry, governmental bodies, educational institutions and students and thus further increase the quality of the triple degree program.
- Creating a summer school as a joint module between the three partner universities, opening up to participants outside of EMC.

**FIG 5** – TERRA Conference at Boppard, Germany in September 2023.

TERRA will have a major impact on the mineral raw material education landscape. The results of TERRA will have a lasting impact driven by the sound dissemination and perpetuation plan. TERRA will ultimately improve the sustainable supply of minerals and thus also fight climate change by sourcing a clean energy transition with responsible mineral raw materials.

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# Curriculum renewal and learning through doing – work-integrated learning in practice

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## ABSTRACT

In late 2018, Curtin University commissioned the independent Foresight Review of the Western Australian School of Mines: Minerals, Energy and Chemical Engineering (WASM: MECE) mining engineering curriculum. The review was conducted against a background of declining enrolments in mining engineering programmes across much of Australia and the Western world, including at Curtin.

A key recommendation of this review was that WASM: MECE should:

> *'Work with the resources sector to develop and implement a renewed curriculum that reflects the needs of the resources sector of the future and the new skills required, while maintaining the important core graduate attributes that define each discipline and the requirements of accreditation bodies (ie Engineers Australia)'.* (McGagh et al, 2018, p 9).

In 2020, WASM: MECE commenced staged implementation of a renewed undergraduate mining engineering course with the updated curriculum now including work-integrated learning, a pedagogical practice designed to provide students with diverse experiences that help them:

- understand how their theoretical knowledge applies in the real world
- gain much needed industry experience
- prepare them for their future as mining and metallurgical professionals.

This paper presents insights into some of the collaborative teaching models that have been piloted and developed as a part of the renewed curriculum's implementation (including results and feedback received), many of which cover a variety of themes including data analytics and digital applications, sustainability, the application of 'systems thinking' approaches, indigenous perspectives and safety and risk management. It is the authors' hope that, through sharing what they have 'learned through doing', they might help other colleagues seeking to do similar within their own organisations.

## INTRODUCTION

### Context

In late 2018, Curtin University (Curtin) commissioned the independent Foresight Review of the Western Australian School of Mines: Minerals, Energy and Chemical Engineering (WASM: MECE) mining engineering curriculum. The review was conducted against a background of declining enrolments in the mining engineering programmes across Australia and the Western world, including at Curtin. A key recommendation of this review is stated above.

Extensive consultation was undertaken with industry and community partners with Curtin identifying significant opportunity to differentiate itself from national and international universities by developing and promoting a distinctive mining engineering programme and student experience that takes advantage of the Kalgoorlie campus' co-location with an active mining industry (as well as Curtin's other, global locations), a strong WASM Alumni network and a high global rank of WASM: MECE in both the domestic and international tertiary education markets.

The renewed curriculum was designed to:

- deliver updated content to reflect the changing operating context and skill requirements of the resources sector (specifically in the digital age)
- utilise innovative teaching approaches
- incorporate industry and community immersion into the student learning experience
- provide students with flexibility regarding the depth and breadth of learning.

Furthermore, the renewed curriculum included new activities and programmes, and new units or additional lecture material to existing ones related to the following disciplines:

- mine automation and new technologies
- data analytics and digital applications
- sustainability, applications of 'systems thinking' approaches
- indigenous perspectives
- a strong focus on safety and risk management
- work-integrated learning (WIL)
- networking with industry and community.

Staged implementation of the renewed curriculum commenced in January 2020 with its successful embedding intended to ensure a steady supply of well-prepared mining engineering graduates, fit for employment in the modern mining industry. The first cohort graduated at the end of 2022, with two more groups completing their studies since then (mid-year and end of 2023). In addition, at the time of writing this manuscript, a fourth cohort are in their final weeks of study. Whilst understanding the full impact of the changes on all stakeholders (including student and graduate outcomes) is also a focus of WASM: MECE, this paper is intended to present insights into some of the collaborative teaching models that have been piloted and developed as a part of the renewed curriculum's implementation (including results and feedback received), and particularly in respect to the:

- utilisation of innovative teaching approaches
- incorporation of industry and community immersion in the learning experience
- embedding of WIL into the curriculum.

Subsequently (in late 2022), all of Curtin's undergraduate (UG) Bachelor of Engineering (Honours) majors (BEng) underwent a further structural renewal to incorporate space in each major for students to be able to take up breadth units or depth learning. Further work was undertaken to maximise efficiencies in teaching load across disciplines and a refreshing of all curricula to be relevant to the needs of modern graduates into industry. A focus on peer and project-based learning, embedding industry perspectives and incorporating the need to teach students about the ethics and use of artificial intelligence have been paramount. In addition, the reduction of traditional lecture delivery and emphasis on student-centred learning has been evident in each of the renewed curricula. Furthermore, a particular focus on more authentic assessment can be seen in each of the new courses.

## Exposure to professional engineering practices

Curtin's Kalgoorlie campus is currently accredited by Engineers Australia (EA) to deliver UG and postgraduate by coursework (PG) mining and metallurgical engineering programmes with the next general review in 2025 (Engineers Australia, 2024). Included in these programs is the requirement that students need to accumulate 480 hrs (12 wk) of 'work experience' or 'vacation work' to be eligible to graduate (Curtin University, 2017) which is in accordance with EA's 'strong [advocacy] that all engineering schools include a minimum of 12 weeks of exposure to professional engineering practices (EPEP).

In recent times, whilst WASM: MECE's mining engineering students have had little issue obtaining vacation work placements, given Bradley (2008) recommends that engineering schools offer a variety of options so that students can gain equivalent exposure in different ways, the 2018 Foresight Review identified the embedding of WIL into the mining engineering curricula as an opportunity to provide students with an alternative option to gain experience that could also count toward their EPEP and during the normal 12 week tuition pattern. Such a decision was thought to have the following benefits:

- confidence that the learning experiences that students participate in do provide them with valuable EPEP that enhances their graduate capabilities.
- opportunities for the academic team to directly connect the real-world learning experiences back to the theory the students are learning in the classroom.
- enhancement of the student experience.
- a contingency programme should the number and availability of vacation work positions for WASM: MECE students decrease (for example, due to a downturn in the sector).
- an alternative to vacation work should students wish to spend their summer break participating in other activities.
- peer-to-peer learning (the process of students learning with and from each other).
- increased number of opportunities for students to meet and engage with a range of industry professionals, both on-campus and off-campus at local and/or regional mining operations.

This last point is thought to be not only advantageous for students (as they consider where they would like to start their career) but also for industry partners as they can get greater insight into the student talent pool and use these opportunities to showcase their expertise to their future workforce. Furthermore, partners who engaged in learning activities that are scaffolded across the curriculum can use these opportunities to establish and nurture relationships with potential recruits for the duration of their studies.

## Work-integrated learning

WIL is a pedagogical practice with the phrase an umbrella term used to describe a range of approaches and strategies that blend theory with the practice of work. These can include work placements, fieldwork, industry-based projects, case studies, simulations, reflective journals, problem-based learning, mentoring from industry partners, work-related presentations, role plays, laboratories and capstone projects (Curtin University, 2015). From a tertiary perspective, the embedding and scaffolding of WIL across a curriculum (horizontally and vertically) has been shown to impact student work-readiness, contribute to employment capabilities and enhance the student experience (Smith *et al,* 2014). Core to this is the ability to provide students with real-world, authentic experiences. Thus, it is recommended that for WIL to be a positive experience, industry should take strong ownership of the practice and genuinely engage in collaboratively developing and strengthening the practice (Williams *et al,* 2012).

Therefore, as a part of WASM: MECE's mining engineering curriculum renewal process, the role of Industry Liaison Coordinator was created to work collaboratively with other internal stakeholders (eg Deputy Heads of School, unit coordinators and other members of the WASM: MECE Executive Team) to:

- Cement and manage offers from industry and community partners to participate in WIL activities.
- Develop a sustainable and innovate WIL programme across the new course that would go some way to meeting the EPEP requirements whilst also improving the student experience.

Whilst this has presented many opportunities, there have also been challenges and so it is the authors' hope that, through sharing what they have 'learned through doing', they might help other colleagues seeking to do similar within their own organisations.

# DISCUSSION

## Intensive WIL Weeks

Firstly, to assist in the provision of rich and immersive learning experiences that could count toward students' EPEP during Curtin's normal 12 week tuition pattern (per semester), WASM: MECE decided to dedicate two weeks of each semester as 'intensive WIL Weeks' (or 'WIL Weeks'). During WIL Weeks, there are no 'typical' learning activities (for example: lectures, workshops, laboratories, tutorials) scheduled for WASM: MECE coordinated units that are delivered out of Curtin's Kalgoorlie campus. The basis of setting aside two weeks each semester for years 2, 3 and 4 of the UG mining engineering degree was founded on the following equation:

$$480 \text{ h} / 3 \text{ yr} / 2 \text{ semesters yr}^{-1} / 2 \text{ wk semester}^{-1} = 40 \text{ h} / \text{wk} \quad (1)$$

Noting that there are challenges when individual study patterns include units taught by other Schools, this decision, overall, has afforded WASM: MECE's mining engineering students with the opportunity to participate in a variety of on-campus and off-campus experiences that expose them to several professional engineering practices that EA considers valuable (Bradley, 2008):

- practical experience in an engineering environment outside the teaching establishment
- use of guest presenters
- industry visits and inspections
- interviewing engineering professionals
- industry based investigatory assignments
- direct industry input of data and advice to problem-solving, projects and evaluation tasks
- case studies.

Several, relevant learning activities that WASM: MECE has designed, piloted and – where able – grown as a part of the four WIL Week programmes each year are described in the following, two sub-sections.

### *Site visits*

Since implementation of the renewed mining engineering curriculum commenced (except for Semester 1, 2020 due to COVID-19 restrictions), one of each semester's two WIL Weeks has been set aside as a week in which many site visits are offered. Most students who take up this opportunity have been those who have had limited exposure to the Australian mining context (ie third year UG students with no prior vacation work experience or newly enrolled PG students). Consequently, these learning experiences are typically structured to provide participants with an introduction to Australian mining with most itineraries including tours of the mining operations (underground and/or open pit), processing plant and any renewable energy infrastructure that may be on-site (eg solar and wind farms). In addition, industry partners are encouraged to focus tour talking points and technical presentations on topics aligned to relevant units of study so that, where possible, students can relate their experiences back to the course content being delivered through lectures, workshops, tutorials, laboratories and other on-campus activities. Recommended topics also include data analytics and digital applications, sustainability, the application of 'systems thinking' approaches, indigenous perspectives and safety and risk management.

The field-based experiences program is one example of where WASM: MECE has collaborated with industry to provide students with real-world learning experiences intended to assist them in better understanding the theory being taught in the classroom. For mining engineering students, the focus of these site visits is mine ventilation, with the information provided in Table 1 outlining some of the information provided in advance to industry partners to help them understand what learning experiences will be beneficial to the students and help them to demonstrate the learning outcomes for the unit **Mine Ventilation (MINE 3008)**. Where possible (whilst noting that renewal of WASM: MECE's metallurgical engineering courses were not included in the 2018 Foresight Review), opportunities for metallurgical engineering students to have similar experiences are also organised for the same time period (and locations) with suggested activities aligned with unit learning outcomes for **Hydrometallurgy (PRRE3005)** or **Advanced Mineral Processing (PRRE4004)**. This information is also provided in Table 1.

**TABLE 1**

Information given to industry partners hosting field-based experiences.

| Units | Activities and/or information to be shared |
|---|---|
| Mine Ventilation (MINE3008) | Demonstration of how a mine ventilation survey is completed at one location while underground. Students given the opportunity to use the instrumentation is also highly encouraged. |
| | Tour locations that help build understanding of primary and secondary ventilation systems. |
| | Engagement with the mining engineering team and learn about the environmental hazards found in your operation and what ventilation control measures are used to detect, monitor, minimise and manage them. |
| | How does the operation comply with mine ventilation legislative requirements? |
| | Does the operation use any simulation techniques and/modelling software? |
| Hydrometallurgy (PRRE3005); Advanced Mineral Processing (PRRE4004) | Students given the opportunity participate in a mill and/or plant survey. Where possible, students given the opportunity to review/workshop survey results. |
| | Background on why certain mineral beneficiation and hydrometallurgical techniques have been employed to treat the operation's orebody. |
| | What are the factors that influence each of the reactions taking place? |
| | Have the reactors been specially designed to facilitate the processes? |
| | What software do you use to model the processes used at the operation? |

Table 2 provides a summary of how the field-based experiences programme has grown since it was piloted in Semester 2, 2020. In 2020, due to the scope of the curriculum renewal pilot, the programme only focused on the UG mining engineering cohort. Given a successful pilot, the programme was expanded in 2021 to cater for demand from the PG mining engineering cohort, with four regional operations within a 2–4 hr drive of Kalgoorlie-Boulder also hosting a group of eight (seven students and one chaperone/driver) for one night. Noting that some industry partners can host larger group sizes, this group sizing was chosen as it was found that most partners were open to accommodating eight visitors underground at any one time (two light vehicles with four passenger seats and one industry partner employee driving each of these).

In 2022, the programme was further expanded to include metallurgical engineering students with groups of 12 proposed to visit regional sites (seven mining engineering students, three metallurgical engineering students, two chaperones). The time spent at camp was increased to two nights as this allowed for a full-day on-site, along with more opportunities for students to connect with the host partner and gain a greater insight into life at a fly-in fly-out mining camp. Automatic minibuses (12 seats, including the driver) were hired to transport the groups to site as they could be driven by members of staff with a C Class automatic driver's licence.

An example itinerary for a regional site visit is provided in Table 3.

**TABLE 2**
Growth of the field-based experiences programme.

| Units | 2020 | 2021 | 2022 | 2023 |
|---|---|---|---|---|
| Student cohort | UG | UG and PG | UG and PG | UG and PG |
| Discipline | Mining | Mining | Mining and metallurgy | Mining and metallurgy |
| Site locations | Local | Local and regional | Local and regional | Local and regional |
| Number of students | 26 | 53 | 61 | 62 |
| Number of locations | 2# | 8 | 10 | 8 |

# A single location visited three times.

**TABLE 3**
An example itinerary for a regional site visit.

| Time | Activity (mining) | Activity (metallurgy) |
|---|---|---|
| **Day 1** | | |
| 16:00 | Arrive at camp and greeted by site leadership:<br>• visit expectations<br>• site visitor induction<br>• collect crib packs<br>• collect room keys<br>Check into room and free time | |
| 18:30 | Welcome function with leadership team | |
| **Day 2** | | |
| Before 5:30 | Breakfast is available in dining room | |
| 05:30 | Meet managers and mining/processing overview<br>introductions<br>overview of day's schedule | |
| 6:00 | Mining meetings, eg pre-shift, daily production | Processing meetings, eg pre-shift, daily meetings |
| 08:30 | Underground and/or surface mining tours, technical presentations | Processing tour, technical presentations |
| 13:00 | Lunch | |
| 14:00 | Additional learning experiences, eg geology, environmental/community engagement, people and culture | |
| 17:00 | Return to camp | |
| 18:00 | Have dinner at your leisure in the mess | |
| **Day 3** | | |
| Before 07:00 | Breakfast in dining room, pack crib for return journey | |
| 07:30 | Pack up room, return keys and depart camp for Kalgoorlie | |

### *On-campus activities*

Apart from site visits, on-campus activities held during WIL Weeks include guest lectures and workshops on mine planning and design software, systems thinking, resource estimation, data analytics, haulage system simulation, mine automation and robotics, sustainability, and indigenous perspectives. These workshops are delivered through WASM: MECE's industry partners.

In the context of indigenous perspectives, community engagement leaders from various mining companies have conducted workshops on their corporate strategies for indigenous engagement and employment. Their success stories, particularly regarding the retention of indigenous employees, have greatly contributed to students' learning. We invite community elders to these workshops for a meaningful welcome to the country, followed by discussions with students. On occasion, participation in Aboriginal-led tours or guided experiences have also been included WIL Week programmes with these learning experiences also enriching and reinforcing student awareness of indigenous culture.

Furthermore, WASM: MECE is collaborating with the Australian Network of Mining Engineering Education Aboriginal and Torres Strait Islander subcommittee. This committee is focused on streamlining the design and delivery of content related to indigenous culture and education within the mining engineering curriculum.

## Normal tuition pattern

### *Indigenous perspectives*

The renewed mining engineering curriculum embeds the delivery of indigenous culture awareness through various unit offerings. For example, in **Mining Methods (MINE3012)**, students explore environmental and social governance (ESG) issues, focusing on land constraints, negotiations with landowners and local indigenous communities, and how these factors influence mining method selection and mine design and planning.

Similarly, **Resource Estimation (MINE3010)** enhances students' understanding of indigenous communities' spiritual connection to the land, which may include sites of significant artifacts. This knowledge impacts exploration and mining activities, as indigenous input can influence resource classification by highlighting areas where cultural heritage concerns may affect resource extraction. The unit also informs students about indigenous knowledge of local ecosystems and biodiversity, which can aid efforts to minimise environmental impacts associated with resource development. Integrating indigenous perspectives into resource classification processes leads to more inclusive, sustainable, and socially responsible outcomes in mineral resource estimation.

In **Mining and Sustainability (MINE3009)**, students delve deeper into the contrasting perspectives of indigenous peoples and non-indigenous peoples regarding land. For indigenous peoples, land holds sacred significance as the creator of life, whereas non-indigenous peoples often view land merely as a commodity. This fundamental difference in perception underscores the profound implications of mining activities. Loss of land due to mining operations and the influx of an external workforce disrupt indigenous societies, hindering their ability to maintain their traditional way of life. Therefore, securing agreements with indigenous peoples before commencing any mining activities is imperative.

**Mine Design and Feasibility (MINE4012)** requires students to apply their knowledge of indigenous cultures. In this unit, students work with an orebody (mineralisation) in a case study situated on indigenous peoples' lands. Consequently, students must include indigenous culture awareness and communication/negotiation with indigenous landowners and communities in their environmental impact assessments, risk assessments, and final feasibility studies.

### *Sustainability*

While covered to an extent in MINE3009, sustainability is a core component of the renewed curriculum, one that spans across disciplines and lends itself to deep discussion with a range of professionals. In 2023, a Sustainability Forum was held covering industry practice on decarbonising operations, heritage (including engagement with indigenous groups and enterprises) and tailings facilities. All of these have complex economic and social aspects in addition to the environmental and safety considerations around renewable energy and electric fleet implementation and management of waste storage. These provided an array of real-world case studies for discussion that provided both context for the content embedded in the curriculum and demonstrated the significance of these aspects of mining practice. A range of senior industry professionals spanning mining companies, service providers and community leaders presented or participated in panels to discuss challenges, disasters, opportunities and success stories to both share information and inspire broader thinking from the student group.

### *Specialisations*

Prior to the rollout of the latest version of the BEng curriculum for all majors in 2024, students obtained depth and breadth learning via electives or optional units. In the renewed version of the course, students have greater options and flexibility through the structural change that sets aside a set of four units alongside their major and pre-major.

Students can opt to widen their breadth of learning by taking a minor or cross-disciplinary specialisation in this slot, which is taken in years 2 and 3 (metallurgical engineering) or years 3 and 4 (mining engineering). These are pre-packaged sets of units offered across the university which could include study abroad, micro-credentials, participation in The Sustainability Challenge, or any other offering that is available to students based at the Kalgoorlie campus to broaden their learning. There are currently no extension specialisations offered at Kalgoorlie due to staffing constraints which was resulted from an explosion in student numbers. However, students can also deepen their learning in mining and/or metallurgy by taking up a ‘Flexible Minor’, which allows them to mix and match units across the university.

### *Final-year research projects*

As part of their final year of study, WASM: MECE’s mining engineering and metallurgical engineering students are required to complete a full-year engineering research project: **Engineering Industry Research Project 1 and 2 (ENGR4000 and 4001) or Professional Engineering Research Design Project 1 and 2 (ENGR6009 and 6010)** for UG and PG students, respectively. The provision of authentic topics by industry partners serves as an excellent opportunity for WASM: MECE’s students to apply their knowledge to solving a real-world challenge. Furthermore, it provides industry partners with the opportunity to establish (or build upon previously established) relationships with students and identify and nurture future talent.

Table 4 provides a summary of how the programme has performed since 2021, when proactive sourcing of projects via networks and connections established as a part of the curriculum renewal process (and, particularly, those made by staff participating in WIL Week activities) began. These are referred to as ‘WASM sourced’ projects and, whilst efforts are made by WASM: MECE to source projects prior to the commencement of each semester, the summer period has been the time in which most effort has been expended on this process. As such, most of these projects tend to be allocated to students in Semester 1 (ie Semester 2 conclusion). This is reflected in Table 4 with the percentage of projects being completed in partnership with industry for students concluding their studies in Semester 1 lower than their peers finalising their projects at the end of Semester 2. Most industry-based projects commenced in Semester 2 (9, 13 and 20 for 2022, 2023 and 2024, respectively) being sourced by students themselves, via their own networks, ie ‘student sourced’.

**TABLE 4**

Summary of the final-year research projects programme.

| | Semester concluded | | | | | |
|---|---|---|---|---|---|---|
| | 2021 S2 | 2022 S1 | 2022 S2 | 2023 S1 | 2023 S2 | 2024 S1 |
| Number of students | 57 | 14 | 39 | 30 | 66 | 58 |
| Number of industry projects | 38 | 9 | 29 | 13 | 39 | 20 |
| % of projects being completed in partnership with industry | 67% | 64% | 74% | 43% | 59% | 34% |
| Number of individual industry partners | 18 | 5 | 15 | 8 | 20 | 19 |

Given projects can be sourced via a variety of mechanisms, the following steps have been implemented to assist with streamlining the sourcing, review, and project allocation process:

- development of detailed flow charts that described the timelines (and deadlines) associated with the various project options available: student sourced, WASM sourced or academic allocated
- development of a proposal template that students can use to source projects through their own networks (a modified version is also sent to those within the WASM: MECE network)
- hosting student briefing sessions in which the flow charts and templates are explained.

In addition to following the above process, several industry partners set additional expectations from students seeking to complete or awarded projects that they propose, including:

- the signing of individual confidentiality agreements
- attending site during the winter vacation period to collect the data necessary for them to complete their research, and/or
- presenting their results to internal stakeholders at the conclusion of their studies.

## CONCLUSIONS AND FUTURE WORK

This paper has presented some insights into several collaborative teaching models that have been piloted and developed since WASM: MECE's renewed mining engineering curriculum commenced implementation.

The embedding of the intensive WIL Week programme into the tuition pattern at Curtin's Kalgoorlie campus (and the execution of these weeks) has presented significant logistical challenges; however, the enthusiasm of WASM: MECE's industry partners to contribute and actively engage in supporting the development of their future workforce has resulted in a large proportion of WASM: MECE's mining engineering and metallurgical engineering students having the opportunity to participate in these valuable learning experiences.

Examples of where the themes of sustainability and indigenous perspectives have been scaffolded into learning experiences conducted during the normal tuition pattern have also been provided. In response to the 2018 Foresight Review, breadth and depth learning was enhanced through the BEng mining engineering course through the inclusion of electives or optional units. With latest version of the BEng curriculum, students can now opt to do so by taking a minor or cross-disciplinary specialisation in this slot, which is taken in years 2 and 3 (metallurgical engineering) or years 3 and 4 (mining engineering).

Finally, the process by which industry has engaged with WASM: MECE's final-year research projects programme for both mining and metallurgical engineering students (through the provision of real-world challenges) has briefly been described.

To date, feedback on the work mentioned in this paper has mainly been sourced anecdotally with the Industry Liaison Coordinator routinely communicating with stakeholders to gather feedback so that WASM: MECE can identify areas of strength and weakness and explore opportunities to ensure activities remain vibrant, engaging and value-adding for all involved. In the future, so that full impacts of any changes can be measured, WASM: MECE is considering the collection of data in a systematic manner, from multiple stakeholders using a mixed methods research design (adopting both quantitative and qualitative methodologies).


## ACKNOWLEDGEMENTS

The authors would like to acknowledge WASM: MECE's industry and community partners, along with their academic colleagues based at Curtin Kalgoorlie. The authors also acknowledge the Minerals Council of Australia, the Keith Parry Foundation and the WASM Alumni for their financial support of the Industry Liaison Coordinator role during the period that it was piloted.


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# Trends in Australian mining education, recruitment and employee development

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## ABSTRACT

The Australian post-secondary education and training system is based on the ten level Australian Qualification Framework (AQF). It is divided into two major segments, higher education, mainly universities covering AQF levels 6 to 10 and VET, (vocational education and training) that includes the public providers, TAFE, (technical and further education) private for-profit providers and community not-for-profit providers covering AQF levels 1 to 6. There is an overlap at AQF level 6, associate degrees and advanced diplomas. This paper mainly focuses on the higher education/ university sector.

The Australian National Skills Council has identified the mining industry as having one of the most acute skills shortages amongst all industries (National Skills Council, 2023). Data gathered from surveys of the ten Australian universities delivering mining programs, (National Mining Engineering Academics Network E-Newsletter, 2023), and from the National Centre for Vocational Education Research (NCVER, 2023), have been analysed to demonstrate trends that are occurring.

The major trends show a stagnant level to decline in enrolments in the traditional core Bachelor of Mining Engineering program, whilst there has been a significant growth in both the participant numbers and breadth of alternative pathways for both entry into the industry and then ongoing employee development.

## INTRODUCTION

To address identified skills shortages in the minerals industry, in 2021–2022, the Australasian Institute of Mining and Metallurgy, (AusIMM), initiated a taskforce to identify issues involved and prepare a series of recommendations, or goals. Goal 4 shown in the AusIMM Collaboration Summit Report (AusIMM, 2022), outlined ‘Develop and expand educational pathways to diversify entry and progression options’. Key actions for consideration:

- Develop vision and targets for sustainable education.
- Generate a list of initiatives to be implemented to expand education pathways. Such initiatives can include:
  - Improve the connections between the education sectors and streamline pathways between sectors using a range of delivery options (online, face-to-face, blended).
  - Create mining training and information packages for schools to inform them of the ‘what, who, how and where’ and assisting Careers Counsellors in their role.
  - Enable training and upskilling opportunities for people who are already involved in the sector or who are transferring from another sector.
  - Establish and promote industry internships and work integrated learning.
  - Developing targeted scholarships at undergraduate and postgraduate coursework level.
- Determine time frames, individual roll out plans, and responsible parties.
- Put measures in place to determine the effectiveness of these initiatives.

## RECRUITMENT OF MINING ENGINEERING STUDENTS

There are significant differences between the Mining Industry core disciplines of Geology, Mining, Metallurgy/Materials/Chemical Engineering and Environmental Engineering/Science (these are the core disciplines outlined on the Australasian Institute of Mining and Metallurgy, (AusIMM), Course Recognition website (AusIMM, 2023).

With Geology, there are over 20 Australian universities delivering these programmes, with 18 universities having AusIMM Course recognised degrees (AusIMM, 2023). The number of geology graduates produced exceeds the mining industry's requirements and shortages may be able to be accommodated by increasing the percentage of graduates that enter the mining industry. At para-professional level, the only course at the sub-degree associate degree/advanced diploma/diploma level is the one at Central Queensland University and it has AusIMM Course Recognition.

The situation is similar with Environmental Engineering/Science. There are 25 Australian universities with AusIMM Course Recognised environmental programmes. So, again, if there is a shortage of graduates entering the mining industry, it could be resolved by increasing the percentage of graduates entering the industry.

Overwhelmingly, most metallurgical positions are now being filled by materials engineering, chemical engineering and process engineering graduates, as the supply of metallurgy graduates is restricted to small programs at just two Australian universities. There are at least 22 Australian universities conducting materials, chemical process engineering and materials degrees and nine of these have AusIMM Course Recognition. So, again, if there are shortages, this could be resolved by increasing the percentage of materials, chemical and process engineering graduates entering the mining industries.

However, Mining Engineering is in a quite different position. There are currently ten Australian universities that offer mining qualifications, although one is phasing them out, one is moving to offering masters degrees only, one rebadging their degree as a Bachelor of Resource Engineering rather than mining and one currently only offers associate degrees. At the advanced diploma/diploma level in mining, there are more annual completions, than those in Bachelor of Mining Engineering programs. There are 19 Australian Registered Training Organisations that have mining advanced diploma/diploma qualifications on their scope of registration, (NCVER, 2023), but it appears that only about half are delivering these qualifications. There are only three TAFE Institutes included and that is only for the quarrying Diploma in Extractive Industries. This means that with the recent Australian government's commitment to an extra 180 000 TAFE places annually, it is likely that none will be used for the coal or metals industries at the para-professional/technician level.

To recruit students into mining courses there are substantial differences between the Vocational Education and Training system, Certificates 2, 3 and 4, for operator to supervisor positions) and Diploma/Advanced Diploma para-professional positions, compared to recruiting students for university mining courses. Also, there are also significant differences between the universities in how they recruit students, depending upon their particular circumstances.

The content for all the vocational education and training qualifications are developed by national industry committees, with the outcomes being competency based, rather than knowledge based. These qualifications each focus on either metal mining, coal mining or quarrying, not a comprehensive approach across all types of mining that is the usual approach in university mining programs. It is also a requirement that the assessments of competency are performed within mining settings. The outcome for student recruitment is that intending mining vocational education and training students need to be employed in the mining industry to be able to do these qualifications, rather than doing the courses before entering the mining industry.

With the recruitment of mining students into university programmes, there are a wide range of diverse techniques used. Many of these techniques have been outlined by Professor Ismet Canbulat, (2024), showing the approaches used by the University of New South Wales. Five of the ten universities delivering mining programmes are part of the prestigious capital city 'Group of 8' universities with high matriculation scores required to gain entry. This means that many senior high school students that are interested in a mining engineering career are unable to gain direct entry into their mining programs. These intending students often gain entry into the regional universities offering mining engineering. Another difference is that while the capital city mining engineering programs are generally almost entirely based on full-time recent school leavers, the regional mining engineering programs, located in mining areas often have a mix of fulltime school leavers plus employed students doing their degree part-time. This can significantly increase the peer-to-peer student learning due to the part-time students' industry experience.

Another important source of mining engineering students is the ability for students to transfer between engineering disciplines in the early years of engineering degrees. It has become accepted practice for Australian Universities to offer a common first year across all the engineering disciplines. Students can simply enrol in an engineering degree and then before entering their second year they can choose their discipline. This provides the opportunity for mining engineering academic staff, the professional body and potential employers to influence the discipline that students choose. At the University of Wollongong, more than half of the Bachelor of Mining Engineering students choose mining during their common first year. Similarly, some universities offering mining engineering have formal transfer arrangements in place with other universities offering engineering degrees. This means that intending mining engineering students can do, say, the first two years of a civil engineering degree at one university and then transfer to another university for years 3 and 4 of a Bachelor of Mining Engineering degree. An example of this is students can do first and second-year civil engineering at Newcastle university, in a strong mining region and then there is a formal transfer agreement in place that enables them to do years 3 and 4 of a Bachelor of Mining Engineering degree at the University of New South Wales, or the University of Wollongong.

## EDUCATION AND TRAINING DURING COURSES

Due to the strong support of professional and industry associations, mining industry employers, equipment and technical services suppliers, most university mining programs are enriched by additional experiences beyond the traditional formal university classroom learning. This is demonstrated in Figure 1, the enhanced mining engineering curriculum model.

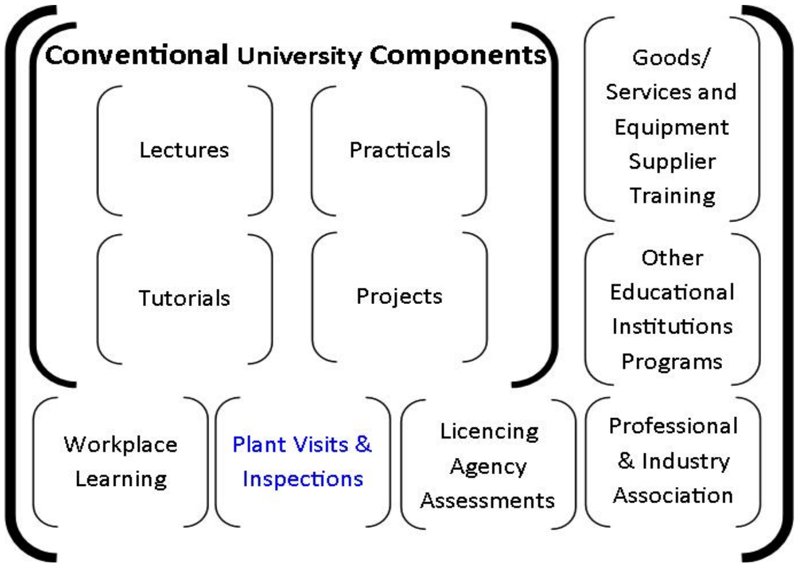


**FIG 1** – The enhanced mining engineering curriculum model.

As shown in Figure 1, university mining engineering qualifications include the formally lecturer led lectures, tutorials, practicals and projects common in any engineering degree qualification. However, this is enhanced by a broad range of activities, as shown, which tend to be jointly designed and implemented by academic staff, professional bodies, employers and the students themselves. These additional activities provide opportunities for students to gain independence and autonomy in their learning choices.

While the amount and range of these enhanced curriculum activities varies between universities, examples include the following.

Workplace Learning – Mining students are encouraged and supported to gain vacation employment in each year of their degree, including seeking a variety of positions across surface mining, underground soft rock, (coal mining) and underground hard-rock, (metal mining). This can provide guidance on the type of graduate employment and ongoing career that students prefer. The AusIMM has developed a series of three workshops on Employability Skills for the Minerals Industries, that students can do face-to-face, or by webinars, that assist with this process (AusIMM, 2017).

Plant Visits – A typical example is that at one university, mining engineering students can do three one-week field trips to other regions, plus visit local mines and associated facilities. During these visits students are likely to see up to 20 different mines, about half underground and half surface, plus around ten associated facilities, including coal, iron ore, gold, lead/zinc, copper, tin and construction mineral commodities.

Licencing Agency Assessments – In the major coal mining states, Queensland and New South Wales, it is compulsory for anyone wanting to work in an underground coalmine to have completed an approved underground coalmining induction course. Typically, this consists of seven competencies from the Certificate II in Underground Coalmining. With the assistance of some State Training Services, this qualification can be made available to university mining engineering students at no cost. Similarly, in some states, parts of surface mines are regarded as being construction sites and require a White Card to be eligible to enter these areas. Again, through some state training services, university mining engineering students can gain construction industry White Cards at no cost.

Professional and Industry Associations – AusIMM has established Student Chapters at each university running mining engineering programs. These Student Chapters work closely with local AusIMM branches to provide additional opportunities for students, particularly to attend technical talks, workshops, seminars and conferences. Other Industry Associations that provide support for mining engineering students are the Institute of Quarrying, Australia and the Australian Coal Preparation Society.

Other Educational Institutions Programs – Mining engineering students can also gain a wider range of accredited, nationally recognised skills and competencies by completing other educational institutions programs. For example, leadership and management, workplace health and safety, risk assessment, continuous improvement, quality assurance, hand and power tools, explosives (to gain a Powdeman’s Licence and/or a Shotfirer’s Permit), information technology and First Aid.

Goods/Services and Equipment Supplier training – Australia has an extensive range of goods, services and equipment suppliers for the mining industry. Mining equipment and technical services is one of the nation’s largest export industries. Many of these companies provide guest lecturers, or other development opportunities for mining engineering students. Austmine represents over 700 of these companies and they are a particularly useful source of information regarding the latest trends in equipment and services being introduced into the mining industry.

To a significant extent, the broad range of additional opportunities that surround most university mining engineering programs has resulted in many engineering students from other disciplines completing mining subjects as part of their degree. In some cases, if students from other engineering disciplines complete sufficient mining subjects their testamur can read ‘Bachelor of ………. Engineering with a minor study in Mining Engineering’. This aspect is significant when university executives review the viability of mining engineering programs. Often the number of students sitting in mining subjects is far more than the number enrolled in mining engineering degrees. In Australia, the Commonwealth government’s support for university students is funded at the subject level, similarly the university student charges, (the Higher Education Contribution Scheme, HECS), is also based on subjects the student has enrolled in, not the course. Thus, in practice, most mining engineering programs in universities are far more viable than the Bachelor of Mining Engineering degree enrolments indicate.

## MINING EMPLOYEE SKILLS DEVELOPMENT IN THE WORKFORCE

### The demand for mining professional and para-professional/technician staff

The National Skills Council (2023) and Professor Ismet Canbulat, (2022), from UNSW have estimated that there is a demand for around 300 mining engineering graduates/year and the demand for mining paraprofessionals (Under Managers, Metal Shift Supervisors etc) is likely to be at a similar level.

## The supply of mining professional and para-professional/technician staff from diverse programs

Table 1 outlines the number of mining graduates coming from Post-Graduate, Advanced Diploma/Diploma, Undergraduate Bachelor of Mining Engineering degrees and Mining Sub-degree programmes, in descending order of numbers, for 2020 and 2023. The source of this information is from the National Mining Engineering Academic E-Network 2020 and 2023 surveys, plus the National Centre for Vocational Education and Research (NCVER), Databuilders for Advanced Diploma/Diploma completions)

**TABLE 1**

The number of graduates from mining engineering programs 2020 and 2023.

| | 2020 | 2023 | % Growth 2020 to 2023 | % of total graduates 2020 | % of total graduates 2023 |
|---|---|---|---|---|---|
| Post-graduates (Masters, P/G Diploma, P/G Certificate) | 277 | 250 | -9.3% | 49.3 | 43.0 |
| Advanced Diploma, Diploma (Rounded to the nearest 5) | 150 | 155 | +3.3% | 26.6 | 26.7 |
| Bachelor of Mining Engineering | 104 | 102 | -1.9% | 18.1 | 17.6 |
| Mining Sub-degree (B Tech. Assoc Degree, Minor Studies) | 34 | 74 | +176% | 6.0 | 12.6 |

Care needs to be taken in determining the meaning of these statistics, as underlying information regarding the way in which the data has been collected can be important and the conclusions drawn can be based on perspectives. However, what this information indicates is:

- Bachelor of Mining Engineering graduates are less than 20 per cent of the pool of available talent for initial mining technical services and production positions and it is most unlikely that this source of mining talent alone will meet the requirements to overcome the mining industry's skills shortages.
- Post-graduate mining talent is the largest available group. However, care may be needed as this group includes substantial numbers of international students and some of the post-graduate mining programmes contain only a limited number of mining subjects that may not meet statutory requirements or the expectations of the industry.
- While the Advanced Diploma/Diploma graduates form the second largest group of available talent, these programs focus on three distinct different fields, coal, metal and quarrying, with the number of graduates in each field in the last three years being Coal 45, 30 and 20, Metal 5, 15 and 0, Quarrying 105, 105 and 135. So, while this is the second largest group overall, most of the graduates are in quarrying and there are relatively few in coal or metal mining.
- The Mining sub-degree group, while the smallest in numbers, has also been the fastest growing sector during the last three years. From just on a third of the numbers of the Bachelor of Mining Engineering graduates three years ago in 2020, this sector has grown to three quarters of the number of Bachelor of Mining Engineering graduates. One of the main reasons for the 176 per cent growth over the three-year period is the online external Associate Degrees in Mining Engineering conducted by Central Queensland University and the University of Southern Queensland. Both qualifications enable staff on-site at remote locations to gain, or upgrade, qualifications. These Associate degrees may also meet the requirements of the Commonwealth government's Industry 4.0 program for potential Advanced Apprenticeships or Cadetships, which have additional benefits for both employees and employers.

## Models of how the minerals industry employers tend to recruit and develop staff

To a significant extent, the minerals industries recruit and develop staff in four major columns, Technical, Production, Maintenance and Support, at three broad levels, Operational, Supervisory/Para-professional/Technician and Professional, as shown in Figure 2.

Minerals Workforce Planning and Development
Template Model

| | Technical | Production | Maintenance | Support |
|---|---|---|---|---|
| Professional | | | | |
| Supervisory/ Para-Professional/ Technician | | | | |
| Operational | | | | |

**FIG 2** – Minerals industry workforce template.

The Minerals industry tends to recruit these staff initially from three major sources, Universities, Vocational Education and Training, (VET), and Other sources, with, initially, after completing qualifications, these employees going into the Operational or Supervisory/para-professional/ Technician levels, as shown by the arrows in Figure 3.

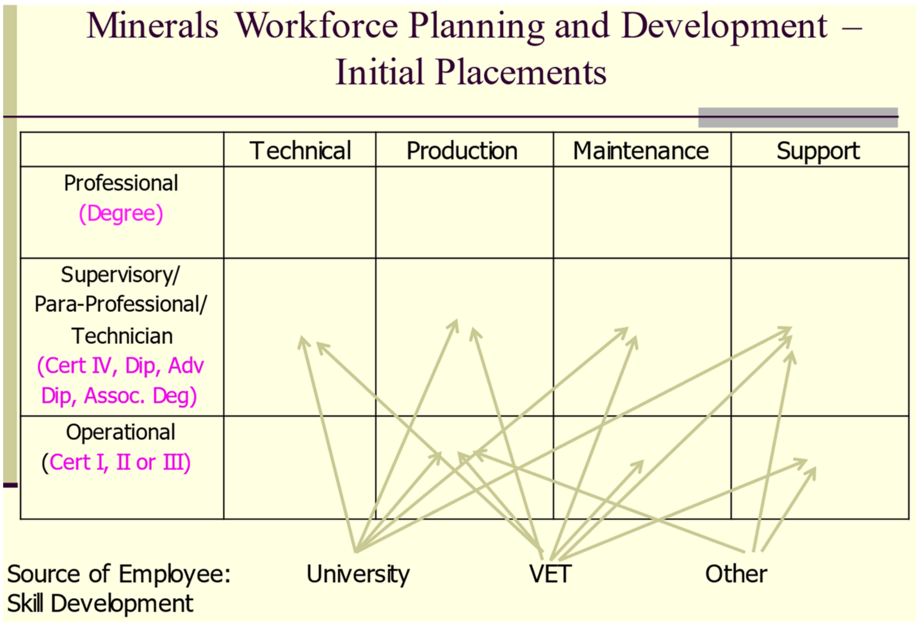


**FIG 3** – Initial employment in the mineral industries.

It is then through experience and development, as shown by the black arrows in Figure 4, that employees use a variety of pathways to become professionals.

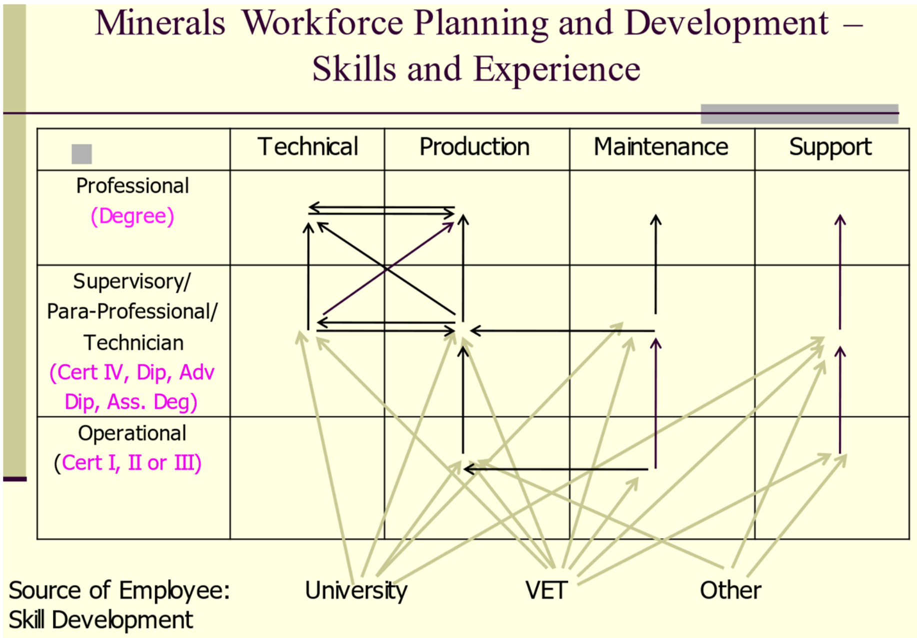


**FIG 4** – Ongoing development and pathways to becoming professionals.

There are a multitude of ways in which in which the development pathways operate. This can include university mining engineering post-graduate programs, such as post-graduate certificates, post graduate diplomas and masters of mining engineering degrees. Some universities, such as Curtin and Queensland offer micro-credentials which are often suitable for remote-based mining employees. Similarly, professional and industry bodies such as AusIMM, the Institute of Quarrying Australia and the Australian Coal Preparation Society offer development courses. In most states statutory positions and licences in mining also provide recognition of employee development and professional status. An example of this is the Graduate Diploma in Mine Ventilation (UNSW, 2024), that 'closely follows industry guidelines and incorporates a theoretical and operational perspective that's industry relevant. It's structured to meet the needs of both the metalliferous and coal mining sectors. On completion of this diploma, you'll gain accreditation as a Coalmine Ventilation Officer in NSW and Qld.'

Often employee development is a blend of individuals motivation and company or mine site workforce planning. It has become common for company and/or mine site human resource sections to use medium to long-term mine planning models as their basis for data into workforce planning and development software.

## CONCLUSIONS

Some of the main emerging issues with mining engineering education have been outlined and the following recommendations are made:

- The differences between the core industry disciplines, mining, geology, metallurgy/materials and environmental engineering should be recognised.
- The reasons why very few coal and metal mining national qualifications are being delivered by TAFE Institutes should be investigated, as this limits opportunities and the support that companies, employees and potential employees can receive.
- Just as there are advantages in developing effective long-term mine plans based on the use of appropriate software, as staffing costs are generally the largest cost driver, similar advantages can be gained by preparing effective workforce planning and development plans, using appropriate available software.
- Rather than basing available mining skills predominantly on graduates from Bachelor of Mining Engineering programs alone, it may be advantageous to consider the full range of mining

engineering pathways, thus diversifying and expanding entry and progression options, effectively overcoming some of the perceived barriers of skills shortages.

- However, care may be necessary in interpreting statistical data related to mining engineering educational programs, as the way in which the information has been collected and presented may be open to interpretation.

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# Member development

# Empowering early career academics for future excellence – insights from UNSW Engineering ECAN Initiative

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## ABSTRACT

Early Career Academics (ECAs) are the future academic leaders and the basis for UNSW Australia's future success and prestige. They are a source of research and teaching innovation, teaching support, and competitive grant funding for their faculties and the broader university. ECAs need support to reach their academic excellence, social engagement, and global impact goals. As an increasingly mobile population, ECAs face a range of challenges in establishing their academic careers.

Recognising the critical juncture at which ECAs find themselves, the Faculty of Engineering at UNSW pioneered a comprehensive support mechanism through the Engineering Early Career Academic Network (ENG ECAN). Since 2014, this initiative has underscored the Faculty's commitment to cultivating the next generation of academic leaders by addressing unique needs of ECAs in a rapidly evolving educational landscape. The ENG ECAN is comprised of ECAs from each School within the Engineering Faculty and works with existing UNSW organisations both within the Faculty and the wider university, including the Dean's unit and associated Faculty and School level boards to ensure all ECAs are aware of the events and resources available to them for achieving their academic and career goals. The ECAN aims to help ECAs improve their research and educational excellence, foster and encourage social engagement, and ultimately, support them in building their international reputation and in achieving the highest level of global impact. More specifically, the role of the committee is to promote, connect, enable, and represent the careers and interests of ECAs within the Faculty of Engineering. By providing a structured framework for support, ENG ECAN Committee facilitates the integration of ECAs into the academic community, fostering an environment where they can thrive and contribute significantly to their fields.

For universities looking to adopt and adapt such a framework as the ENG ECAN model, the approach involves a commitment to strategic planning and resource allocation tailored to the needs and aspirations of ECAs. This initiative emphasises the significance of creating effective communication channels, organising professional development opportunities, and promoting inclusivity within the academic ecosystem. Key to the success such a program is the engagement of stakeholders across the institution, ensuring that ECAs have a voice in decision-making processes and access to resources that support their progression. By implementing a feedback loop for continuous evaluation and adaption, institutions can create a dynamic support system that not only enhances the professional journey of ECAs but also enriches the academic culture and output of the university. Looking ahead, ENG ECAN's continued focus on inclusivity, diversity, and global engagement positions it as a role model for academic support initiatives worldwide. As the network grows and evolves, it will continue to empower, excel and evolve ECAs remain at the forefront supporting the next generation of academic leaders in education and research.

## INTRODUCTION

ECAs are essential to the future success and prestige of academia. They bring innovation in research and teaching, provide critical teaching support, and secure competitive grant funding, all of which contribute significantly to the advancement of their faculties and the university as a whole.

However, ECAs face a range of challenges in establishing their academic careers. These challenges include balancing the demands of research and teaching, securing funding, developing a professional network, and navigating the academic job market. Additionally, as an increasingly mobile population, ECAs often move between institutions and countries, which can complicate their career progression and integration into new academic communities (Gibson, 2004; Fisher and James, 2018). Figure 1 illustrates some of the themes of initiatives that are designed by some ECAs to promote open science and the help stakeholders support those ECAs working to facilitate change beyond their research


**FIG 1** – Themes of science reform work for ECA training and working conditions and incentives (Kent *et al,* 2022).

Recognising these challenges, the Faculty of Engineering at UNSW initiated the ENG ECAN in 2014 (UNSW ENG ECAN, 2023). This initiative underscores the Faculty's dedication to nurturing future academic leaders by addressing the unique needs of ECAs in a rapidly evolving educational landscape. ENG ECAN was established to provide a comprehensive support framework that helps ECAs navigate the complexities of their early academic careers and achieve their professional goals.

The ENG ECAN initiative aligns with UNSW's broader commitment to excellence in education and research. By focusing on the development and support of ECAs, ENG ECAN aims to foster a vibrant and inclusive academic community that promotes innovation, collaboration, and global engagement. The initiative's structured support framework ensures that ECAs have access to the resources, mentorship, and professional development opportunities they need to thrive in their roles and make significant contributions to their fields.

## THE ROLE AND STRUCTURE OF ENG ECAN

ENG ECAN comprises ECAs from each School within the Engineering Faculty. It collaborates with various UNSW entities, including the Dean's unit and Faculty and School-level boards, to ensure that ECAs are informed about the events and resources available to them. The committee's primary role is to promote, connect, enable, and represent the interests of ECAs within the Faculty of Engineering. By providing a structured support framework, ENG ECAN helps integrate ECAs into the academic community, fostering an environment where they can excel and significantly contribute to their fields.

ENG ECAN aims to help ECAs improve their research capabilities and educational excellence. It does so by organising professional development opportunities, facilitating access to resources, and creating effective communication channels. These efforts ensure that ECAs are well-equipped to achieve their academic and career goals. One example is the organisation of regular research seminars and workshops focused on grant writing, publishing, and effective teaching methods. These events provide ECAs with the necessary skills and knowledge to excel in their research and teaching roles. Additionally, ENG ECAN facilitates mentorship programs where experienced academics provide guidance and support to ECAs, helping them navigate the complexities of academia and develop their professional networks.

Social engagement is crucial for the professional growth of ECAs. ENG ECAN encourages this by organising networking events, fostering collaborations, and promoting inclusivity within the academic ecosystem. These activities help ECAs build strong professional networks and engage with the broader academic community. An example of this is the annual ENG ECAN Day, where ECAs from various disciplines come together to share their research, discuss challenges, and explore potential collaborations. This event not only helps ECAs expand their professional networks but also fosters a sense of community and belonging within the Faculty of Engineering. Additionally, ENG ECAN promotes social engagement through initiatives such as community outreach programs and volunteer opportunities, allowing ECAs to give back to society while enhancing their personal and professional development.

## ADAPTING THE ENG ECAN MODEL TO MINING ENGINEERING

Adapting the ENG ECAN model to the context of Mining Engineering involves a commitment to strategic planning and resource allocation to the specific needs of ECAs in this field. Mining Engineering schools must identify the unique challenges faced by ECAs and develop targeted strategies to address them. Schools should also develop strategic plans that outline their goals for supporting ECAs and the steps they will take to achieve these goals. Creating effective communication channels is crucial. Regular updates on available resources, events, and opportunities in the mining industry, education and research should be disseminated to ECAs through newsletters, emails, and dedicated platforms. This ensures that ECAs are well-informed and can take full advantage of the support available to them.

Organising professional development opportunities is essential for enhancing the skills and knowledge of ECAs. Workshops and seminars on topics such as time management and prioritisation, leadership, entrepreneurship, overcoming imposter syndrome, teaching, ECAs career paths, mentoring, grant writing, and networking should be tailored to the specific needs of Mining Engineering academics. Additionally, establishing mentorship programs where experienced mining engineers provide guidance and support to ECAs can help them navigate the complexities of the field and develop their professional networks.

Engaging stakeholders across the institution is key to the success of any ECA support initiative. Ensuring that ECAs have a voice in decision-making processes and access to the necessary resources requires the involvement of various stakeholders, including university leadership, faculty members, and administrative staff. Regular meetings between ENG ECAN representatives and university leadership could ensure that the needs and concerns of ECAs are heard and addressed.

## CONCLUSIONS

By adopting and adapting the ENG ECAN model, Mining Engineering schools could create dynamic support systems that empower ECAs to achieve their full potential, fostering a thriving academic community and ensuring a bright future for the mining engineering discipline. Integrating recommendations from recent research on empowering ECRs can further enhance these efforts, leading to systemic improvements in research culture and practice in the mining industry.

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# The role of international organisations and local commitment on gender equality

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## ABSTRACT

The implementation of the fifth Sustainable Development Goal of the United Nations 'Achieve gender equality and empower all women and girls' is more challenging in Mining compared to other areas. The male domination, cemented over centuries by legislative barriers that still exist in some countries, systematically excluded women and perpetuated the image of a male-dominated industry.

Despite, the changes in legislation and many forces to foster gender equality, challenges are still present: In Academia, Mining departments are often relatively small and geographically dispersed, resulting in limited visibility of diversity. Underrepresented groups, including women, first-generation academics, international professionals, different generations, and individuals balancing parenthood, often lack adequate representation. This scarcity of role models and minimal contact serves as a deterrent, diminishing the motivation for students and pupils from these diverse backgrounds to pursue careers in mining.

Drawing from personal perceptions and experiences within the Clausthal University of Technology and Germany, the contribution advocates for a dual-pronged approach to address these challenges. Firstly, it emphasises the role of international organisations in promoting gender equality by increasing visibility through their larger groups. Secondly, it highlights the importance of local commitment to the cause, urging smaller departments to actively engage in drawing a more inclusive picture of mining. The contribution provides insights into practical measures that can be implemented at both levels to dismantle systemic barriers and create a more equitable environment within the mining sector.

## INTRODUCTION

As part of the Agenda 2030 (United Nations 2015), the United Nations established 17 Sustainable Development Goals (SDGs) in 2015, setting forth a comprehensive action plan aimed at enhancing 'people, planet, and prosperity' and fostering 'universal peace in larger freedom.' These goals represent a collaborative vision that necessitates multi-stakeholder cooperation. To facilitate this, a Technology Facilitation Mechanism was defined, encompassing not only UN entities and member states but also civil society, the scientific community, and the private sector. These stakeholders are collectively focused on achieving the SDGs through various projects and initiatives at both global and local levels.

Among these goals, SDG 5 outlines nine specific targets to achieve gender equality and empower all women and girls. This goal emphasises the importance of women's effective participation and equal opportunities in political, economic, and public leadership, alongside supporting and strengthening policies that promote gender equality and empowerment.

For the mining sector, several actions to support SDG 5 are identified by (Columbia Center on Sustainable Investment, UNDP, UN Sustainable Development Solutions Network, World Economic Forum, July 2016). Promoting gender equality within core business operations is crucial, necessitating equal opportunities for women and the adoption of gender-inclusive practices. These actions span across human resources (HR) and community engagement, with additional collaborative and leverage-based strategies.

In HR, it is imperative to implement practices that not only recruit more women into the mining sector but also ensure equal pay and promote women to visible leadership positions. Adopting flexible schedules to accommodate childcare needs, providing gender-specific personal protective equipment (PPE), and offering gender-sensitive career development planning are essential steps towards creating a supportive and safe working environment for women.

Community-related actions are equally vital. These include incorporating the perspectives of women, men, and children in community decisions, making gender-inclusive social investments, and providing educational scholarships for women to empower them through education and open up new career opportunities.

Both HR and community-focused strategies should engage men and women in negotiations to ensure fair representation and comprehensively address gender-based concerns. Vigilance against gender-based violence and the establishment of gender-sensitive grievance mechanisms are crucial for creating a safe environment for all. Additionally, monitoring women's health within mining communities is essential for their well-being and access to necessary healthcare.

By implementing these measures, the mining industry can make significant contributions to achieving SDG 5, fostering an environment where gender equality is not only prioritised but integrated into every aspect of operations. This holistic approach ensures that both internal HR practices and external community engagements align with the goals of gender equality and women's empowerment.

This strategy, while focused on the mining and mineral industry, also holds implications for other stakeholders such as authorities, research institutions, and educational facilities, where HR-related actions and gender-specific aims must be considered. This paper will focus on the role of academia, initially presenting an academic view, providing some historical background, and discussing the challenges for women in academia based on the status quo. Using Clausthal University of Technology as a case study, it will describe a dual-pronged approach to supporting women in academia through a combination of local and global perspectives.

## CHALLENGES IN ACHIEVING GENDER EQUALITY IN MINING ACADEMIA

Challenges faced by women in the mining industry are widely recognised, though not comprehensively explored in the literature. Previous studies have systematically addressed several of these issues. For instance, a notable survey conducted in a South African mine (Benya, 2009) identified various obstacles, categorised into themes such as health and safety, workplace culture, career development, and infrastructure and facilities. These challenges include physical limitations, inadequate personal protective equipment (PPE), and employment restrictions related to pregnancy and breastfeeding. Additionally, prevalent prejudices, resistance from male coworkers, disparities in payment, and limited promotion opportunities due to lack of experience were highlighted.

Parallel issues in workplace culture are evident in mining engineering roles. Research conducted by (Kansake, Sakyi-Addo and Dumakor-Dupey, 2021) investigated the experiences of women working primarily in engineering and management within the mining sectors of Ghana and other African nations. This study highlighted widespread discrimination manifested through pay disparities and inequalities. Further compounding the issues are family-related challenges, such as inadequate maternity support, insufficient childcare provisions, and an unfavourable work-life balance. Moreover, the employment milieu often features ingrained gender ideologies including patriarchal and cultural biases, social prejudices, gender stereotypes, and a general lack of recognition for women's contributions. Additionally, harassment and sexism are markedly prevalent and correlate strongly with the prevailing work culture. Several career development hurdles are also identified, encompassing the 'glass ceiling' phenomenon, unconscious bias, deficient mentorship, unfavourable policies, inadequate inclusivity, limited empowerment opportunities for women, and a conspicuous scarcity of women in leadership roles.

Despite the limitations in the scope of the studies reviewed, these findings are corroborated by a broader analysis by (International Labour Organization, 2021), which offers a global perspective encompassing both small- and large-scale mining activities, thereby underscoring the pervasive and enduring nature of these challenges across diverse mining contexts.

From an academic perspective, the 'Mines of the Future' report by the Society of Mining Professors (Saydam *et al*, 2019) highlights the necessity of specific HR actions and the use of technology to create favourable working conditions for all employees. The report envisions inclusive working environments supported by mining networks and the promotion of successful female role models. The male dominance in the mining industry, historically justified by the physical nature of the work, as well as biases, cultural beliefs, and traditional role expectations, necessitates these actions. Moreover, historical working bans and associated study restrictions have reinforced this male dominance. These bans, still present in some countries, must be lifted to gradually increase the proportion of women in mining, as illustrated by the case of Germany.

Internationally, the International Labour Organization (ILO) prohibited women from working underground in 1935 (International Labour Organization, 1935), a convention ratified by 98 countries, including West Germany in 1954. In contrast, East Germany permitted women to work underground until the reunification of Germany in 1990, when the legal framework of West Germany, including the prohibition of women working underground, was extended to the former East Germany (Treaty, 1990). This prohibition was in place until a 2005 ruling by the European Court of Justice declared that such bans violated the principle of gender equality (Europäischer Gerichtshof, 2005). Consequently, Germany denounced the ILO convention in May 2008, allowing women to work underground and pursue relevant educational programs without restriction.

The legacy of more than 70 years of occupational bans, compounded by the positioning of mining within the STEM fields, continues to influence the culture of the profession. Female mining engineers remain a rarity and are underrepresented in higher positions, with progress towards greater inclusion being slow. The exceptional nature of women in such roles is often highlighted in media reports when women manage mines, assume professorships in mining, or are elected to executive boards of mining companies (see Engel, 2012; Toussaint, 2019; Fritze, 2020).

Worldwide, the situation varies significantly by country. As of now, 68 countries still adhere to the ILO convention, systematically excluding women from working underground and, in some cases, from studying mining (International Labour Organisation). This restriction extends to prohibiting female visitors from mine sites, preventing international female students from gaining underground experience and representing a clear case of intersectional discrimination.

In addition to the established legal frameworks, the current representation of women in the mining sector warrants attention. Evidence from various contexts reveals a consistent pattern of gender underrepresentation. In Artisanal and Small-Scale Mining (ASM) activities, prevalent in numerous developing nations, mining initially presents itself as a viable economic opportunity. However, these endeavours frequently expose women to myriad challenges already discussed in previous sections. Particularly in these domains, obstacles associated with entrenched gender roles and the marginalisation of women are pronounced, yet there simultaneously exists a notable potential for female empowerment (Baddianaah, 2023; Buor and Ayim, 2019; Mendes *et al*, 2022).

Moving up the corporate ladder, despite the reduced physical demands in higher echelons such as mining engineering positions, female participation remains disproportionately low. For example, a study within a Brazilian mining corporation, which has been actively trying to increase its female workforce, reports that women constitute only 16 per cent of its workforce. Similarly, in the Swedish mining industry, which is notably male-dominated, women comprise only 14 per cent of all mining engineers and a mere 2 per cent of the production workforce. Overall, 77 per cent of employees in this sector are male, ranking it as the fourth most male-dominated industry in the nation (International Labour Organisation, 2021; Johanson, 2022).

These statistics underscore the pervasive gender disparities within various segments of the mining industry. Despite legal advancements and growing awareness, the participation of women in mining, particularly at higher levels of responsibility, remains critically limited. This ongoing gender imbalance highlights the need for sustained and effective interventions aimed at bridging the gap and fostering a more inclusive mining work environment.

Despite legal advancements and growing recognition of gender disparities, the representation of women in the mining sector remains disproportionately low, affecting all areas of the industry including mining companies, equipment manufacturers, consulting firms, regulatory bodies, and academic institutions. These statistics underscore the pervasive underrepresentation, impacting various levels of operations and corporate echelons.

The scarcity of women in mining is symptomatic of broader recruitment challenges faced across the sector. Organisations within this field typically draw from a similar talent pool which is predominantly defined by the existing workforce and graduates from STEM disciplines. The representation of women in these areas mirrors their underrepresentation in mining, indicating a systemic issue across related fields. Thus, expanding this workforce pool to include more women appears daunting, as efforts by one employer to increase female recruitment can inadvertently limit the availability of female candidates for other organisations.

To address these challenges, enhancing the attractiveness of mining careers is critical. To achieve a more equitable gender representation, the entire sector must collectively focus on making mining careers more appealing. This includes enriching the pool by targeting career changers, although their impact might be limited given their similar origins from other STEM fields. For mining academia specifically, these efforts align closely with promoting academic programs and gaining broader appeal among potential students. This necessitates collaborative strategies across different sectors to yield substantial improvements.

In addition to the proposed collaborative efforts, it is imperative for individual employers within the mining sector to enhance their own attractiveness to prospective female employees. This is crucial in drawing more women from the limited existing pool. Specifically, the academic segment of the mining industry needs to adopt practices that make it distinctly appealing to women. For mining academia to lead in gender inclusivity, it must embody an environment that not merely attracts but also supports, retains, and nurtures female talent. Further elaboration on these strategies will be provided in the subsequent sections of this discussion.

The representation of marginalised groups within academia is particularly significant, as prospective and current students often first interact with academic figures before encountering industry professionals. These individuals serve as foundational role models, playing a crucial role in influencing career choices and professional development (Gibson, 2004). However, when there is a pronounced underrepresentation of certain groups, potential students, current students, and aspiring academics face a scarcity of role models.

Mining, as it stands academically, is a niche discipline. Not many institutions host dedicated Mining Departments, and those that do tend to be small and geographically dispersed. This structure limits the pool of visible role models for prospective students, current students, and aspiring researchers. When representation of marginalised groups, such as women and first-generation academics, is low, there are few, if any, role models available. This limitation hampers career development because role models not only inspire but also provide guidance, advice, and access to professional networks. The scarcity of diverse role models in mining academia can limit professional perspectives and perpetuate a cycle of underrepresentation.

## CASE STUDY – MINING ACADEMIA AT CLAUSTHAL UNIVERSITY OF TECHNOLOGY

This case study focuses on Clausthal University of Technology (CUT), comparing its mining academia to two other German universities with similar departments. The analysis is based on data from university web pages as of June 1, 2024; and includes only active, non-emeritus professorships directly related to mining.

Under state legislation, universities are mandated to promote gender equality and enhance opportunities for women in academia. This commitment is embedded within the legal frameworks governing higher education institutions, as stipulated in various educational laws, which emphasise the objective to counteract the underrepresentation of women, particularly in fields where they are not equally represented (Section 3 (4) (Niedersächsischer Landtag, 1 Jan. 2007/2007), Section 5 (3) (Sächsischer Landtag, 31 May. 2023/2023), Section 3 (4) NRW (Landtag Nordrhein-Westfalen, 16 Sep. 2014/2014)).

CUT has evolved over its 250-year history from a mining school to a university of technology with strong ties to the mining and minerals sectors. The Institute of Mining, part of the Faculty of Energy and Economic Science, is a key component of CUT's focus on the Advanced Circular Economy. The institute is divided into departments focusing on surface and underground mining, each led by a male professor with support from a female assistant. Notably, the underground mining department exclusively employs female scientific research assistants, making up 60 per cent of the institute's scientific staff.

Technical support within the institute is predominantly male, with the technical workshop crew consisting entirely of men. The department also includes seven external lecturers, all male, some of whom hold honorary professorships.

When compared to university-wide metrics from 2021, the proportion of female scientific staff at the Institute of Mining is significantly higher (university average: 25 per cent). However, only 13 per cent of CUT's professors are female, reflecting a broader trend of underrepresentation at senior academic levels. Administrative roles are generally filled by females, whereas technical staff positions are predominantly male.

In comparison to other universities, professorial positions are predominantly held by men, with the exception of one female professor in the Advanced Mining Technology department at RWTH Aachen University. The proportion of female scientific research assistants at CUT is notably higher (Freiberg: 29 per cent, Aachen: 28 per cent). Additionally, no department at these universities reports having any female honorary professors or external lecturers. In summary, Clausthal distinguishes itself with a higher representation of female researchers, particularly within its underground mining department, relative to both the university itself and other mining departments. However, there remains a notable underrepresentation of females in senior academic roles.

Local recruitment primarily targets students from CUT's Master's program in Mining Engineering. Recent data show that female enrolment in this program fluctuates between 10 per cent and 15 per cent, which is below the university's overall female student percentage of 27 per cent as shown in FIG **1**. The associated Bachelor program has shown improvement with the introduction of a new program, increasing female participation to 22 per cent and 35 per cent, respectively.

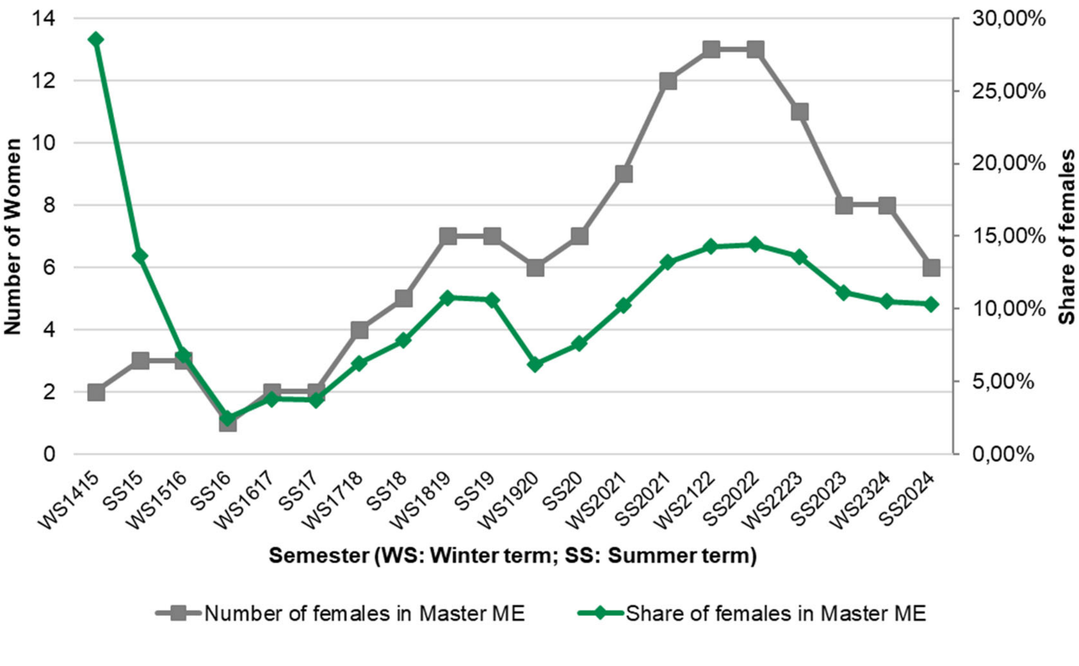


**FIG 1** – Development of female students in Master Mining Engineering.

Asked for a description of their situation, the scientific research assistants in the underground department, all co-authoring this publication provided a range of characterisations that collectively depict a diverse and complex workplace environment. The assistants described their day-to-day work as physically strenuous and emotionally lonely despite being within a socially conservative milieu. Yet, they perceive their interactions as being on equal footing, suggesting a level of respect and collegiality amongst peers that fosters an innovative climate.

Descriptions like 'few but many' and 'freaky' suggest a small group that feels distinct within the broader department, perhaps due to unique or unconventional roles or perspectives they bring. Their confidence and role as initiators indicate a proactive involvement in shaping their work environment, reflecting their status not only as outliers but also as trendsetters and potentially inspirational figures.

This duality is further captured in their self-view as 'exceptional and standard' and 'diverse,' illustrating their awareness of being both typical researchers and exceptional in their capacity to navigate and influence a traditionally conservative field. They express a sense of pride and purpose in representing a new generation of female mining professionals, thereby challenging and broadening the conventional roles and expectations assigned to them. Their experiences underscore the transforming dynamics within mining academia, marked by a blend of traditional challenges and progressive changes.

These insights set the stage for exploring initiatives aimed at attracting and supporting female students at CUT, including the department's active engagement in the Society of Mining Professors, which facilitates global exchange. The subsequent sections will delve into both local and global measures designed to enhance the inclusivity and diversity of the mining academic community.

## SUPPORTING MORE DIVERSITY – A DUAL PRONGED APPROACH

The pursuit of enhanced diversity within mining academia requires a nuanced understanding of both local and global interventions to make substantive progress. Locally, the unique specificities of each department often necessitate tailored, individual-based support. However, the typically small size of these departments results in fewer role models and limited networking opportunities. This situation highlights the need for integrating local and global initiatives to create a more robust mechanism for fostering diversity.

At the local level, the commitment and targeted actions within individual departments can significantly impact the professional landscape for underrepresented groups. These actions might include targeted recruitment, mentorship programs, and the development of supportive policies that encourage diversity and inclusion.

Conversely, a global perspective involves leveraging networks and collaborative partnerships that extend beyond immediate academic or professional environments. This can include forming alliances with international organisations, participating in global conferences, and engaging in cross-border research initiatives. Such efforts not only broaden the scope of academic and professional opportunities but also enrich the educational environment by introducing diverse perspectives and practices.

The interplay between these local and global strategies is crucial. The following sections will explore how institutions like Clausthal University of Technology (CUT) and global organisations such as the Society of Mining Professors (SOMP) implement these collaborative approaches to promote diversity, with a particular focus on gender equality within mining academia. Through this dual-pronged strategy, it is possible to achieve a comprehensive and inclusive approach that not only addresses immediate disparities but also fosters a sustained cultural shift towards greater diversity in the field.

### Local actions and commitment

Local departments within mining academia face unique challenges and opportunities shaped by the specific context of their local mining industry, prevailing legislation, and cultural norms. Factors such as legal restrictions in certain countries, where women may only be allowed to work in specific areas of mining, significantly influence how departments can operate and promote diversity. Additionally, the historical background, demographics of students, employees, and professors, along with existing organisational policies and structures within a university, play pivotal roles in shaping strategies for enhancing gender inclusivity.

While no single strategy fits all situations, overarching objectives can guide efforts to promote diversity and gender equality. These objectives can be tailored to the distinct roles of departments:

As **Educational Entities**: Departments should focus on actively recruiting a diverse student body, particularly targeting underrepresented groups such as women in mining. The goal extends beyond increasing their numbers; it also involves ensuring these students receive the necessary support to thrive academically and professionally. This includes creating supportive frameworks that enable female students and other minority groups to pursue and sustain careers in mining. Additionally, integrating competencies in the curriculum that foster leadership and teamwork in diverse teams is crucial.

As **Organisations within Mining**: Departments should aim to project a gender-inclusive image that resonates beyond the academic community to influence public perception and attract a broader demographic to the mining field. This portrayal helps dismantle longstanding stereotypes and builds a more progressive and inviting image of mining as a viable career option for women.

As **Employers**: Departments are tasked with creating and sustaining an equitable work environment. This role is not only about being an attractive employer but also about serving as a role model for other stakeholders in the industry.

To effectively meet these objectives, mining departments must select from a vast array of potential actions that are ideally suited to achieve their goals. These measures should align with established objectives and be carefully tailored to resonate with the target groups, adapt to local circumstances, and utilise available resources effectively.

Given that mining departments generally do not possess in-depth expertise or extensive networks in fields directly related to gender equality efforts, such as equal opportunity employment practices, strategic marketing, or human resource development, forging partnerships with the central units of the university is crucial. By leveraging the expertise and resources of these central administrative units, mining departments can more effectively implement a diverse range of gender-focused actions. Such collaboration not only streamlines the execution of these initiatives but also ensures that gender equality measures are sustainably integrated within the department's structures and align with the broader objectives of the university.

In the ensuing discussion, specific actions that mining departments can undertake, in synergy with central university services, to promote gender equality will be presented. These measures are designed to cater to both immediate and long-term needs, pushing for a transformative shift towards a more inclusive and diverse mining academic and professional environment. In the next section, the general approaches are discussed followed by specific examples from CUT that illustrate these strategies in action.

### *Educational outreach*

Engaging potential students from an early age is a cornerstone of effective educational outreach, particularly for promoting gender diversity in fields traditionally dominated by men. Activities tailored for various educational levels—from kindergarten through to high school summer programs—are instrumental in sparking interest in mining careers. Specifically designed initiatives aimed at girls, such as special trial study programs, play a crucial role in this outreach strategy. Beyond targeting children and adolescents, it is equally vital to include older demographic groups through tailored workshops, informative presentations, and strategic media campaigns. These efforts collectively serve not only to educate but also to reshape societal perceptions about the mining industry, making it an attractive and viable option for a diverse workforce.

At Clausthal University of Technology (CUT), the Institute of Mining has actively supported a robust series of outreach activities over the past year, aligned with its commitment to fostering a diverse mining sector. These initiatives have included educational programs for different age groups such as Kindergarten Class, Pre-School Class, and Children-Holiday-University, alongside targeted events like Girls-Day, Trial-studies for Girls, School-Information Days, and Orientation-Studies for girls. These programs are specifically designed to appeal to young female students and promote the field of mining as a gender-inclusive and progressive career choice.

In addition to direct educational activities, the Institute has also developed various presentations and media content aimed at broadening societal understanding and appeal of the mining profession. All these outreach efforts are meticulously crafted as interactive teaching-and-learning experiences, focusing heavily on student participation and engagement. This approach not only educates but also actively involves students in the learning process, thereby promoting a modern and inclusive perspective of mining engineering education. Through these multifaceted outreach efforts, CUT continuously works to challenge traditional stereotypes and cultivate a welcoming environment for all aspiring.

### *Support for current students*

In the context of mining education, it is essential to carefully curate support actions tailored to different student demographics, particularly focusing on individual support for female students alongside the design of general educational activities. Departments must foster a gender-sensitive environment, ensuring that support mechanisms are equitably accessible to all students, devoid of any discrimination. This commitment to diversity can be further enhanced through workshops aimed at addressing unconscious biases, thereby cultivating a more inclusive academic culture.

Staff members should be well-informed central units responsible for student support to ensure that individuals receive the necessary guidance and assistance tailored to their specific needs. Moreover, universities can significantly boost individual development through structured support programs that include workshops, professional networks, and mentoring specifically designed to uplift female students. Departments play a critical role in actively promoting, recommending, and facilitating these offerings to ensure they reach the intended participants.

Moreover, the design and implementation of all courses should inherently consider and integrate principles of diversity. This approach involves creating a supportive classroom environment that encourages participation from all students and minimises barriers to learning but also including diversity-sensitive behaviour as a skill. Faculty members should actively assist marginalised groups in establishing industry connections and emphatically communicate to broader stakeholders that discrimination has no place in mining, advocating strongly for equality and rights within the sector. Through these comprehensive strategies, departments can ensure that education in mining not only equips students with technical skills but also instils a profound respect for diversity and inclusion.

At CUT, the mining department actively promotes and supports central programs designed specifically to assist female students. Recognising the diverse backgrounds of its student body, the department has advocated for the inclusion of English-language programs to better support international students, reflecting the university's global outlook.

Additionally, CUT is committed to ensuring that education is accessible to all. This commitment is evident in the concerted efforts to cultivate an inclusive educational environment that minimises barriers to learning. These efforts include adapting educational materials, enhancing accessibility within classroom settings, and ensuring that diverse learning needs are met.

In line with this, during the accreditation process for study programs, CUT mandates the inclusion of explicit statements concerning gender equality and diversity. This not only reinforces the university's dedication to these principles but also holds academic programs accountable for upholding and promoting these values within their curricula. Such measures ensure that students receive an education that not only enriches them academically but also instils a deep respect for diversity and equality, preparing them to be both skilled professionals and conscientious members of the mining community.

### *Post-graduation engagement*

Maintaining robust contact with alumni is essential not only for nurturing a continuing relationship but also for levering these connections to inspire current and prospective students. Highlighting successful female role models among alumni can particularly motivate and encourage women considering careers in historically male-dominated fields like mining.

At CUT, the Department of Mining holds strong relation with the alumni management. The department not only keeps in touch with former students but also facilitates platforms for ongoing engagement. One key initiative is the hosting of annual conferences that serve also as a forum for alumni. These events allow recent graduates to interact with seasoned professionals, fostering a network that supports career development and continues the educational mission of the university. Through these interactions, alumni can share their career experiences and achievements, underscoring the possibilities that lie in mining careers for future generations, especially women, thereby enhancing the inclusivity and diversity of the mining community.

### *Universities as employer*

Creating a supportive and inclusive working environment is foundational to promoting gender equality within academic settings. It is essential to implement targeted employment practices that facilitate women's advancement. This includes establishing mentoring programs, forming professional networks within STEM or engineering sectors, and providing advising services that address family support, such as parental guidance and child-care facilities. Furthermore, active recruitment strategies are crucial, especially for higher academic and administrative roles such as professorships, to ensure that more women can ascend to senior positions. These efforts not only contribute to achieving gender parity but also foster a work culture that values diversity, inclusion, and equal opportunity.

At CUT, the commitment to equal opportunities is prominently endorsed by the presidential board and supported by a dedicated Office of Equal Opportunities. This office is tasked with overseeing diversity management and family services, thereby ensuring comprehensive support for all pertinent target groups within the university community. To continually assess and enhance its strategies, CUT periodically — every three years — develops a new equal opportunities plan (Gleichstellungsplan). This plan methodically reviews current conditions, sets new objectives, and defines actionable measures to advance gender equality across the campus.

In addition to these central efforts, CUT has implemented a decentralised system of equal opportunities officers across various faculties and units. These officers are elected from the female staff of their respective areas, integrating insights and experiences from those who understand firsthand the challenges and needs specific to their sectors. Currently, the first author serves as the equal opportunity officer for the Faculty of Energy and Economic Science. This dual role not only highlights the individual's dedication to fostering an inclusive academic environment but also illustrates the university's broader commitment to integrating equal opportunities into every aspect of its institutional framework. Through these layered and interconnected efforts, CUT strives to create a workplace culture that truly values and promotes gender equality, setting a benchmark for inclusivity within the academic realm.

### *Visibility of women*

While the inclusion of women in outreach and other activities is crucial for increasing the visibility of female role models within academia, it is essential to acknowledge that such responsibilities can inadvertently impose an additional burden on the few women who are already part of these departments. While these roles offer valuable opportunities for personal and professional growth, they can also lead to overcommitment and potential disadvantages if not managed properly. Consequently, the university needs to critically address compensation and support mechanisms for women actively engaging in these roles to ensure their efforts are sustainable and recognised.

To alleviate the pressures on women and to extend inclusivity strategies in departments with low diversity, several approaches can be implemented that do not exclusively rely on the participation of women. For instance, inviting external guests who are diverse role models can provide varied perspectives and inspire all students and staff. Moreover, careful management of imagery in promotional materials and the active showcase of diversity can reinforce the importance of inclusivity. Additionally, fostering an environment where all employees are encouraged to actively partake in and endorse inclusivity measures can significantly amplify the impact of these efforts.

Ultimately, every member of the academic community should be engaged in these initiatives, demonstrating commitment and allyship. By sharing the responsibility and actively participating in inclusivity practices, departments can cultivate a supportive environment that advances gender diversity while minimising the risk of overburdening a limited number of individuals.

## International networking and collaborations

In addition to local initiatives, international organisations play a critical role by broadening the reach and enhancing the impact of gender equality efforts within academia. These organisations offer what is often unachievable at a local scale, providing platforms that increase visibility, influence, and networking opportunities. This global perspective is particularly crucial in specialised fields such as mining academia, where specific challenges require distinct solutions.

The Society of Mining Professors (SOMP) exemplifies such an organisation. It aspires to be recognised as the leading international society for mining university professionals, with its vision clearly articulated:

'The vision of The Society of Mining Professors/Societät der Bergbaukunde is to be the leading international society for mining university professionals, recognised for effective networking; fostering collaboration and innovation in research, teaching and learning practices; relevance and impact for the global mining sector and society at large' (Society of Mining Professors, 2019). Based on the articulated key areas, specific actions can be identified that actively promote gender equality.

### *Networking and mentoring*

The presence of approximately 50 female members within the Society significantly enhances the visibility and accessibility of role models for emerging professionals in the mining academia. This larger group not only serves as an inspiration but also actively participates in structured and informal mentoring programs. These programs are crucial in providing guidance, sharing experiences, and offering support, thereby nurturing the next generation of female mining professors. Such initiatives exemplify the practical application of the Society's commitment to 'effective networking' and fostering collaboration, especially in enhancing the career trajectories of women in mining.

Through these efforts, the Society ensures that female members are not just participants but contributors to the mining academia community, thereby enriching the entire community with diverse perspectives and experiences. The visibility of these role models plays a critical role in motivating and empowering women, illustrating the profession's potential and the inclusive nature of the mining.

### *Collaboration and capacity building*

Collaboration is key in the Society of Mining Professors' efforts to promote gender equality within the mining industry. Through the Society smaller-scale projects that focus on gender equity are initiated. Furthermore, the enhancement of mobility and connection among professional enable growth of its members. These collaborative activities are crucial for challenging existing gender norms and fostering an environment of equality and joint effort, enriching the society with diverse perspectives.

Further, the Society strongly emphasises capacity building through the support of new schools and departments specialising in mining. By cultivating these new institutions with a modern outlook that inclusively accommodates and promotes diversity, the Society ensures that the forthcoming generations of mining professionals are educated with a pronounced focus on equity. This approach not only develops the educational framework within the field but also ensures that these entities consider progressive values, contributing to a broader cultural shift towards a more inclusive and sustainable mining sector.

### *Innovation support through best practices sharing*

Innovation is an essential aspect of the Society of Mining Professors' strategy, particularly through the sharing of best practices in research and education. Through this approach also innovations in gender equality and diversity are supported. Key to this effort are the approaches employed across various institutions. By openly sharing and discussing these methodologies, members of the Society developed them further and use them as a repository of effective strategies that enhance inclusivity in mining education.

This process allows institutions from different geographical and cultural backgrounds to learn from each other, enhancing their own educational practices by adapting these proven strategies to fit local conditions. The discussions and exchanges facilitated by the Society not only foster innovation but also ensure that the best practices in gender equality and diversity are continuously refined and widely implemented. This collaborative approach to innovation empowers all members to contribute to and benefit from collective advancements in creating a more inclusive mining academic environment.

### *Relevance and impact*

Beyond networking and collaboration, the Society actively advocates for a transformation in mining culture, promoting modern, sustainable practices that transcend traditional industry norms. Through strategic partnerships and political advocacy, it aims to elevate the mining sector's role in sustainable development. Additionally, the annual meetings of the Society serve as a crucial forum for discussing challenges, sharing innovative ideas, and formulating collective responses. In terms of Diversity and the skill development in academia, the initiatives of SOMPs Member Development Committee (MDC) have contributed mainly to the discussion. The MDC conducted a series of discussion rounds and surveys initiated to deepen insights and perspectives of women from various countries and academic positions. A panel discussion 'Supporting Women in Mining – A Brief Insight into Our Experiences and Perspectives' provided a platform for female role models and reflected on the support they have received in their career paths, identified what was particularly beneficial, and shared their desires for future forms of support.

Overall, organisations like the Society of Mining Professors play a essential role in international efforts to advance gender equity in mining, showcasing the profound impact that well-coordinated international networks and collaborations can have in fostering significant societal and professional advancements.

## Transfer and development – interlocking levels

The interlocking of local initiatives with the efforts of a global organisation like the Society of Mining Professors (SOMP) can significantly amplify success on both levels. Such integration offers substantial benefits for individual development and the collective efficacy of gender equality measures in mining academia.

A key strategy to facilitate this connection involves actively engaging young emerging scholars within the SOMP. Allowing them to participate as Junior Members not only provides them with access to the mentioned benefits of membership but also fosters their early professional development. By expanding the membership criteria of the Society to include not just professors but other academics Junior Members, the organisation offers these young talents a platform to influence and shape their careers from an early stage.

Active participation in SOMP enables members to contribute on both an individual and institutional level. Members can present developments and best practices they have trialled at their home institutions. This sharing and integration of proven approaches not only supports the professional growth of individual members but also enriches the entire organisation with fresh perspectives and strategies for promoting gender equality and diversity.

This synergistic relationship between local endeavours and global collaboration optimises the effectiveness of efforts aimed at enhancing gender equity in the mining sector. It highlights the critical role that global networks and collaborations play in shaping the future of mining academia. Through this strategic interconnection, sustainable changes are fostered that benefit both the academics involved and the broader industry.

# PRACTICAL MEASURES AND RECOMMENDATIONS

To effectively enhance diversity within mining academia, it is crucial to adopt a dual-pronged approach that encompasses both local and global strategies. This section provides concise recommendations aimed at fostering an inclusive academic environment.

At the departmental level, targeted recruitment and support initiatives are essential. Proactive strategies to attract and retain students from underrepresented groups should be complemented by curriculum revisions that integrate diversity, equity, and inclusion principles. Additionally, fostering an inclusive work culture through regular workshops for faculty and staff is vital.

Globally, forming partnerships with international institutions can enrich educational experiences and broaden perspectives. Participation in global networks also facilitates access to diverse mentors and role models, enhancing professional development and cultural competence.

Community engagement initiatives are crucial for demystifying the mining profession and promoting it as a viable career option across diverse populations. On this level, a global collaboration for the development of Open Education Resources that can are adapted implemented for local settings effectively supports the formation of better image of mining. Effective use of digital platforms can amplify the success stories of diverse individuals in the field, thereby inspiring future generations.

Inclusive support services, such as scholarships and dedicated career counseling for underrepresented students, can mitigate barriers to success. Establishing safe spaces and support groups within academic settings further ensures that all students receive the encouragement and resources needed to thrive. Starting on a local level, an early global connection of students let them benefit from the global networks such as SOMP.

On all this stages, interdisciplinary approach and collaboration with experts can increase the quality of measures and outcomes. Openness for experts and the partnership eg with gender studies or diversity can enrich the dialogue and foster the development towards reaching the SDG 5 in mining.

## CONCLUSION

Mining has long been a male-dominated field within STEM, presenting substantial challenges in achieving gender equality. The pursuit of Sustainable Development Goal (SDG) 5, which calls for gender equality, demands comprehensive actions from the mining sector to engage communities effectively and create workplaces that are modern and inclusive of all genders. Despite enduring challenges in today's mining environment, various initiatives are gradually advancing toward this goal.

One significant issue in achieving workforce equality is the limited pool of potential female employees, which constrains hiring opportunities and intensifies competition among employers. Addressing this requires collective efforts to broaden this pool. Mining academia is uniquely positioned in this respect, acting both as educators and employers. Increasing the visibility of women in mining not only helps to reshape the sector's image but also promotes it as a forward-thinking and inclusive field.

The commitment to gender equality in mining academia is supported by strong local initiatives and global collaborations, such as those facilitated by organisations like the Society of Mining Professors (SOMP). The example of Clausthal University of Technology (CUT) illustrates best practices at various levels of action, demonstrating a firm commitment to supporting women and enhancing collaboration with central units. Notably, CUT has achieved a distinctive milestone with an all-female team of scientific research assistants in an underground mining department. Moreover, SOMP has played a crucial role in providing a broad network of diverse role models and promoting development through international collaboration.

Despite these advancements, ongoing efforts from all stakeholders in the mining sector are necessary to promote gender equality and establish a discrimination-free environment. The competition for female talent should not prevent collaborative solutions but rather inspire the creation of an inclusive culture that benefits other minority groups as well. Ultimately, enhancing diversity within the mining sector will not only address equity issues but also improve the overall health and sustainability of the industry.

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# Attracting Gen Z into careers in the mining industry – new models, messages and means of delivery

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## ABSTRACT

A recent study concluded that 73 per cent of the Australian Gen Z community who were born from 1995 to 2015 believe that mining does more harm than it does good. Encouraging Gen Z students to think about careers in mining is fraught with difficulty. Universities, mining companies and peak body industry groups have collaborated in a variety of initiatives to enhance student numbers into geology, mining and metallurgical programs. These initiatives, however, have enjoyed marginal success. Most of these initiatives are 'bottom-up' initiatives that challenge school leavers and first year university students to view mining differently. This paper examines a number of ways that we might consider to 'influence' the same cohort of students via the indirect influence of friends, parents and popular media driven by international recognition for the importance of critical mineral supply. Such approaches aim to add 'top down' and 'sideways' influences to the traditional bottom up approach. The combined effect is to build a '360 degree' strategy for influencing prospective Gen Z students.

## INTRODUCTION

The last decade has witnessed dramatic changes in the mining industry. Chief amongst these has been the deterioration of public perception of the industry, galvanised by failed tailings dams in Brasil, destruction of Indigenous heritage sites in Australia and violent anti-mining demonstrations in Peru and other parts of the world.

There are four forces affecting the mining industry (Figure 1). These are: climate change and energy transition; the rise of Environmental, Social and Governance (ESG) issues influencing mining projects and operating mines; the relentless march of automation and digitalisation technologies through the industry and, in developed countries, acute skills shortages and mining companies compete with other industries for talent. One could also add to this list current geo-political concerns as wealthy developed countries attempt to reclaim production processes that they were previously relinquished to developing countries.

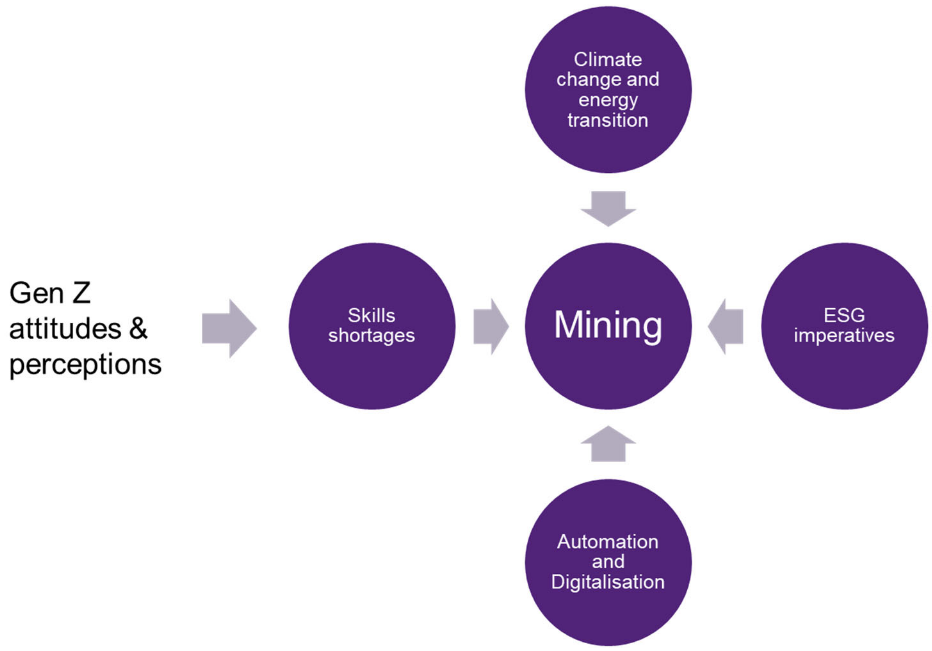



**FIG 1** – The four forces affecting the mining industry.

This paper sets out to explore the factors that are influencing Gen Z away from mining careers and presents what this means to the mining industry in the form of declining graduate numbers. It then explores the messaging that we (universities, industry and government) are employing to try and attract younger people to consider mining careers. It suggests that these messages are not aligned with the beliefs of Gen Z and suggests a '360 degree' model to better shape and sell messages.

## CURRENT STATE

BHP (2023) attributes the decline in Gen Z interest in mining careers to three factors:

1. Limited earth science and mineral resources education and career exposure in schools
2. Perceived resources industry reputation and global environmental concerns
3. Media misrepresentation

In Australia, the traditional four-year mining engineering degree relies on recruiting students as they leave secondary schooling. In these models, we are essentially requesting students to commit and 'get married' to the mining industry straight out of school (Figure 2). The exception to this involves those universities having a general first year engineering program. In this case, we have an additional year of 'courtship' in which to convince students to commit to a mining specialty.

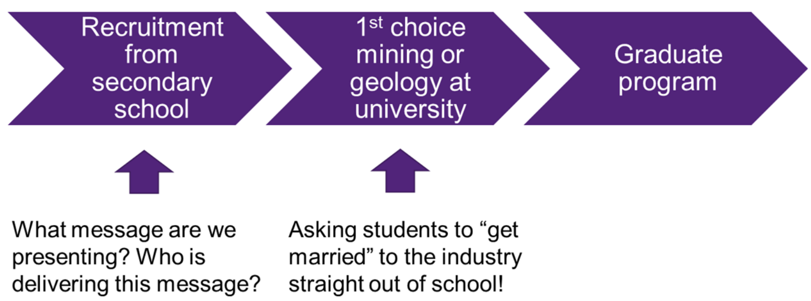
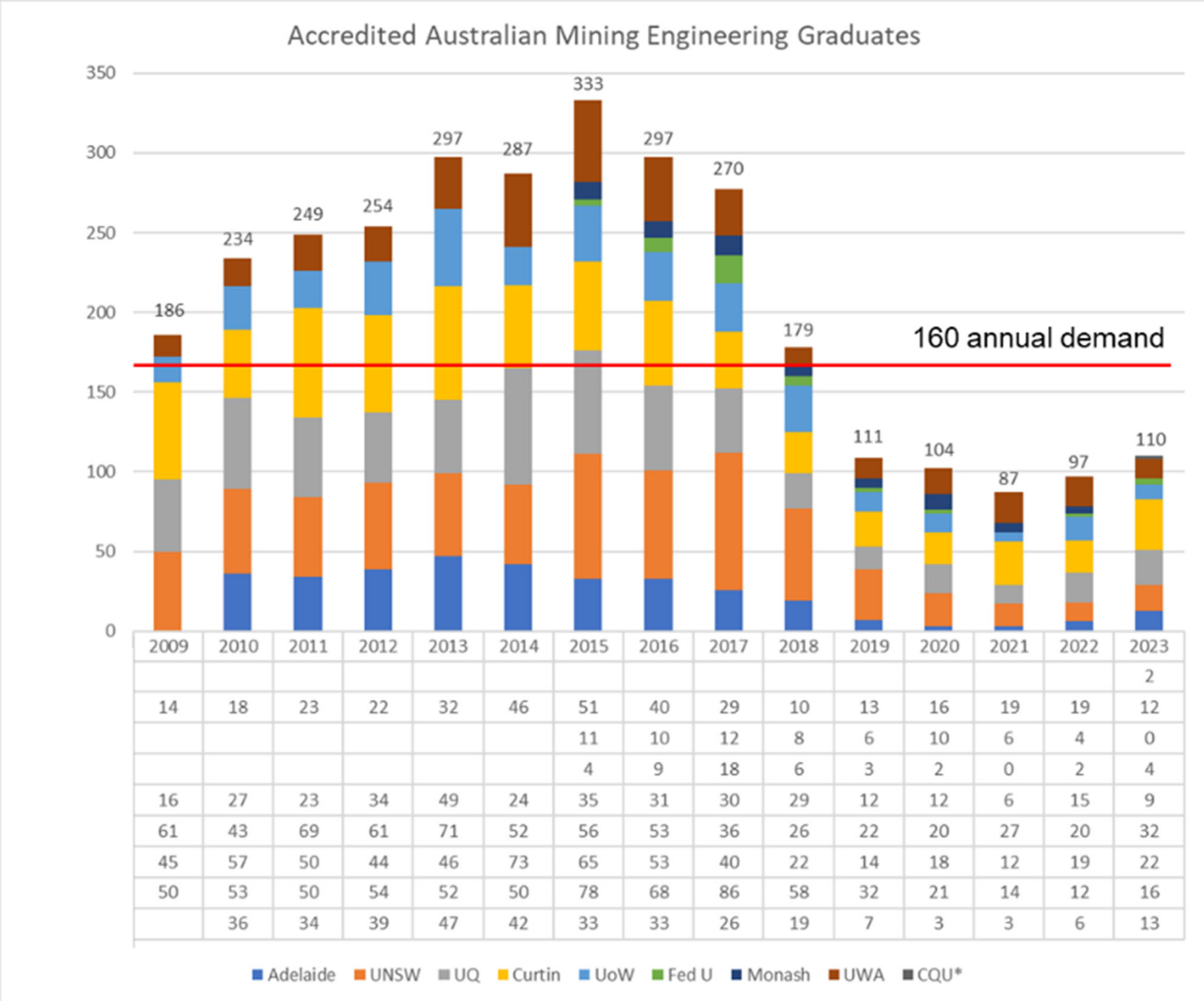



**FIG 2** – The traditional university recruitment model.

Unsurprisingly, this model has resulted in declining enrolments, particularly amongst the east coast Universities of Australia where the politics of coal is a prevalent factor in determining student career choices. Figure 3 illustrates the roller coaster ride of graduate mining engineers across Australia over the last decade and a half. Graduate numbers peaked in 2015, three years post the peak in mining investment. Since then, it has all been downhill until 2021. There has been a gradual recovery, thanks in large part to the two Western Australian universities, Curtin and UWA, however numbers are significantly below the 160 sustainable annual demand estimated by Knights (2019).




| | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | | 2 |
| | 14 | 18 | 23 | 22 | 32 | 46 | 51 | 40 | 29 | 10 | 13 | 16 | 19 | 19 | 12 |
| | | | | | | | 11 | 10 | 12 | 8 | 6 | 10 | 6 | 4 | 0 |
| | | | | | | | 4 | 9 | 18 | 6 | 3 | 2 | 0 | 2 | 4 |
| | 16 | 27 | 23 | 34 | 49 | 24 | 35 | 31 | 30 | 29 | 12 | 12 | 6 | 15 | 9 |
| | 61 | 43 | 69 | 61 | 71 | 52 | 56 | 53 | 36 | 26 | 22 | 20 | 27 | 20 | 32 |
| | 45 | 57 | 50 | 44 | 46 | 73 | 65 | 53 | 40 | 22 | 14 | 18 | 12 | 19 | 22 |
| | 50 | 53 | 50 | 54 | 52 | 50 | 78 | 68 | 86 | 58 | 32 | 21 | 14 | 12 | 16 |
| | | 36 | 34 | 39 | 47 | 42 | 33 | 33 | 26 | 19 | 7 | 3 | 3 | 6 | 13 |

**FIG 3** – Australian mining engineering graduates 2009–2023.

## FUTURE DESIRED STATE

As a result of a sustained decline in student numbers entering the mining engineering program at The University of Queensland, in 2021 the University ceased enrolments into the four-year bachelors of Engineering (Mining) program. This decision was taken following extensive consultation with industry and government stakeholders invited to a one-day workshop at Customs House in Brisbane in 2019. At this workshop, a new model was proposed involving an eight-course Mining Major, to be offered as part of the Mechanical, Mechatronics and Civil Engineering specialties (Figure 4).

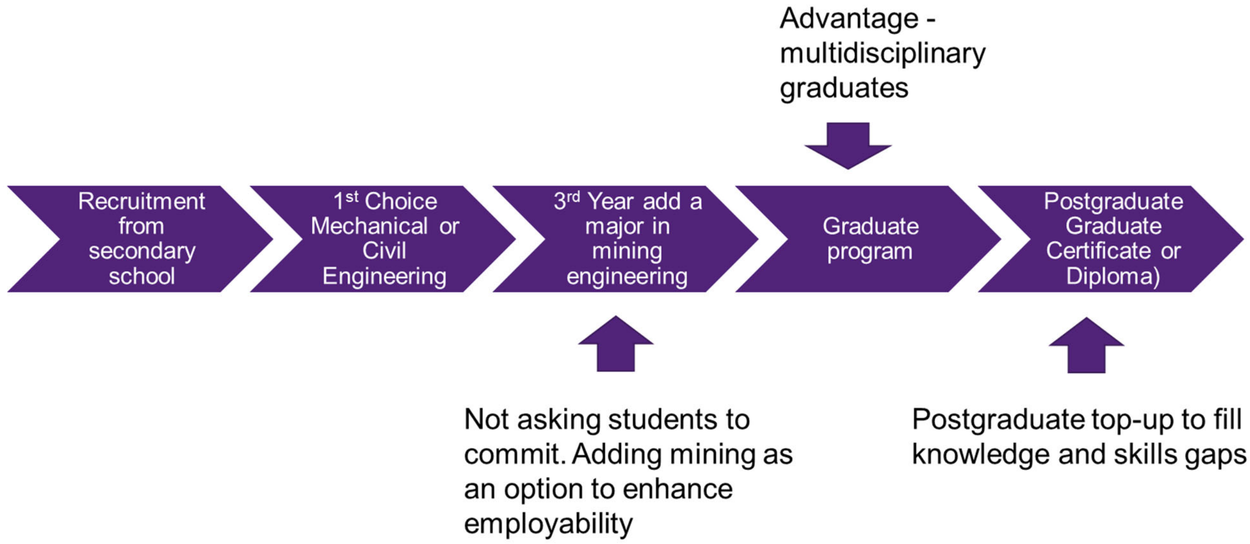



**FIG 4** – Future facing recruitment model.

## SHIFTING THE DIAL

### New models

The new Mining Major considers the essential knowledge and capabilities required by a mining engineer (Figure 5). It provides a suite of foundation courses plus a set of courses aimed at imparting knowledge across the mining value chain. It includes a capstone mine design and feasibility study. The new Mining Major is not intended to provide an accredited pathway to a mining engineering degree. Should a graduate find themselves working in the mining industry, UQ is working towards introducing a number of postgraduate offerings (Graduate Certificate, Graduate Diploma and Integrated Masters) designed to progressively address knowledge gaps.

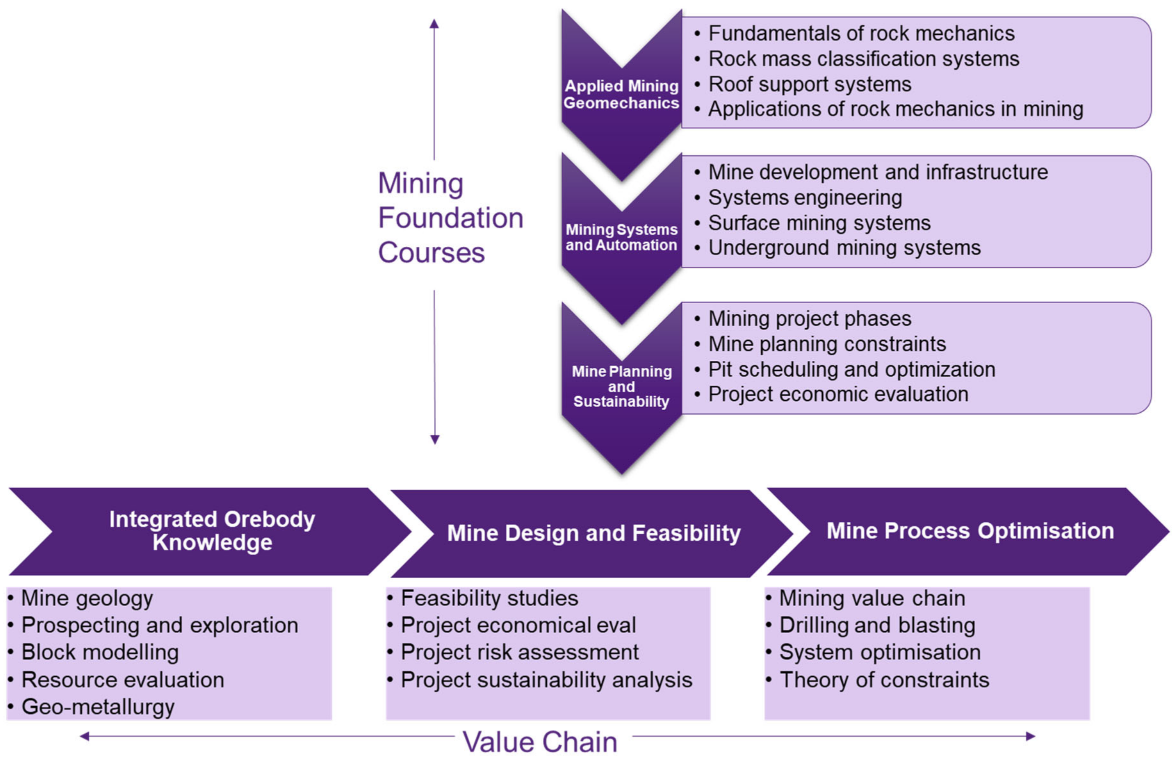



**FIG 5** – Structure of new UQ Mining Major.

## New messages

Gen Z describes the generation of people born between 1995 and 2015. They are characterised by (Betts, 2024):

- Having pride in the organisation in which they work.
- Needing a purpose that is socially responsible, human-centred and ethical.
- Contributing to and change human beings' lives.
- They are not motivated by acquiring and achieving things, they are motivated by fulfilling a purpose.
- Meaningful work is described as positive, purposeful and significant'.
- They emphasise mental well-being and health.

Common communication mistakes with Gen Z include (Betts, 2024):

- Spelling things out in minute detail (eg Here is the list of tasks that a mining engineer does).
- Adopting a 'sky is falling' message (eg the world will stop without mining, there is no energy transition without mineral resources etc).
- Adopting a 'you should be grateful' message (eg 'Every Australian has a stake in Australian Minerals' (Minerals Council of Australia (MCA), 2024).

In an address to the Geological Society of Australia, Professor Peter Betts (2024) contrasts the advertising used by the Meat and Livestock Association (MLA) of Australia with that employed by the Minerals Council of Australia (MCA). In the MLA advertisements, you see lots of contented cows in paddocks and then happy families enjoying roast dinners. The public are not shown the intermediate process – the abattoir – for obvious reasons! Contrast this with MCA advertisements, where big machines are everywhere to be seen!

The point here is that messaging from the mining industry must align with the Gen Z values. How is mining contributing to making the world a better place from a Gen Z perspective. How is it contributing to: alleviating poverty; improving health care; providing employment opportunities for Indigenous peoples; ensuring more affordable housing etc? Mining has a positive story to tell. It's just that we are not messaging it well!

## New means of delivery

A further thought, once we get the message right, is who is best placed to be presenting the message. This is the role of an advocate, a person who publicly supports, recommends or argues for a particular cause or policy. Consider the following equation (adapted from Betts, 2024):

$$Trust = \frac{competence + experience + transparency}{Self\ interest}$$

People trust sources that are credible (competent and experienced), transparent and unaffected by self-interest. Unfortunately, the mining industry is very self-interested, and so often it is not the right vehicle to be 'selling the message'. BHP's message (Figure 6) is an advance in that it puts people first, however it cannot disentangle itself from the self-interest charge!


**FIG 6 –** BHP's message to the world (people, not processes).

## A 360 DEGREE VIEW OF GEN Z

Figure 7 proposes a 360 degree model in which Gen Z is surrounded by influencers positive to mining. Coordinated leadership at the top level is required, involving collaboration between industry, government and universities. All entities need to be aligned around a positive message supporting mining.

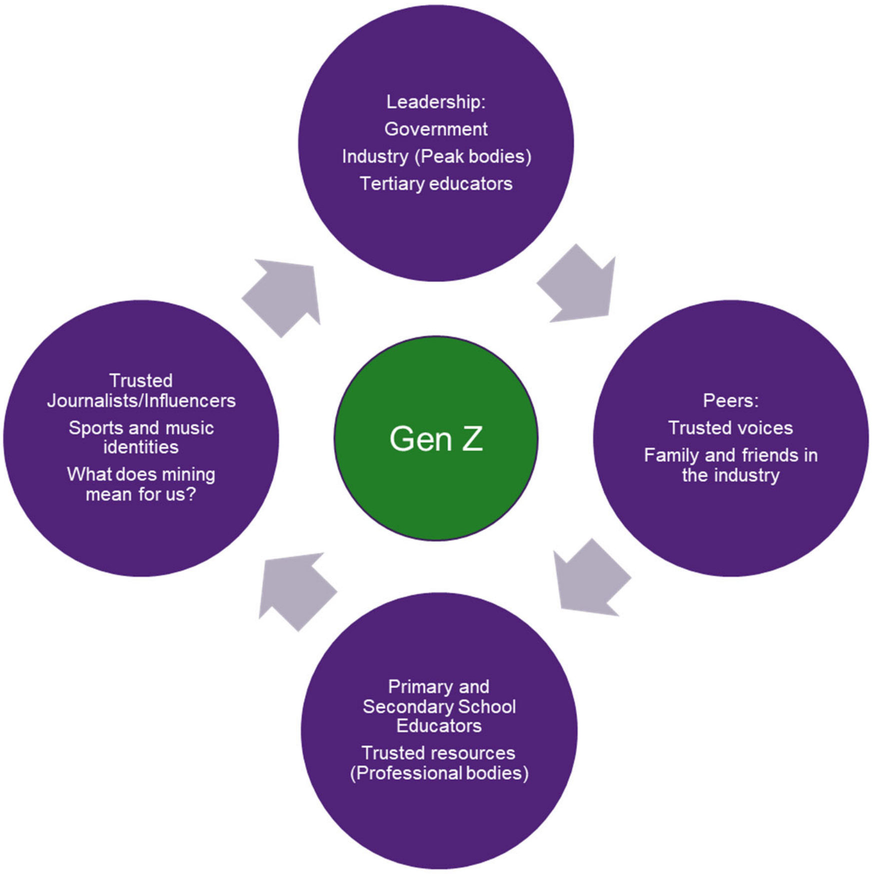



**FIG 7** – 360 degree approach to influencing Gen Z.

Educational institutes, school teachers and academic staff form a nurturing role as Gen Z develops. Therefore, primary and secondary school teachers need unbiased materials related to the origin of things (for instance, where does make-up come from? What about construction materials?) Universities can assist with the development of such materials.

Side influences consists of family and friends with exposure to the mining industry. A recent survey of 1000 young Australians between the ages of 15 and 24 conducted by the Australian Mining and Automotive Skills Alliance (Barndon, 2024) showed that, in Western Australia, 64 per cent of those surveyed who had family members working in the mining industry viewed mining more positively. Everybody working in the Mining and METS industries needs to be an ambassador!

Both Gen Z and Millennials continue to pull back trust in any and all institutions (government, banks, and even brands). An Influencer Marketing Hub survey found that 63 per cent of consumers trust influencers more than they trust what brands say about themselves, and Gen Z and Millennials are twice as likely to trust them (Methods+Mastery, 2024). Another strategy, therefor, is to identify influencers (sports players and creatives) receptive to a positive message around mining and to encourage them to promote their positive opinions.

## CONCLUSIONS

The mining industry is facing a crisis of perception, particularly amongst Gen Z demographic. This 'crisis' has been a long time coming. To attract workers into the next decade the industry needs to find:

- new models
- new messages
- new means of delivering these messages.

The industry cannot do this alone. It requires a coordinated response with leadership from government, universities and professional bodies.

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# The career development of an international student in Australian universities – lessons and advice based on case studies

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## ABSTRACT

Australian tertiary education sector has been attracting a significant number of international students owing to the good resource quality and high ranking globally of Australian universities. In 2023, the total number of international students is 786 891, which is 27 per cent more than that in 2022. Once they all finish the degrees, the career development becomes significantly important as almost all students would want to pursue a career in here. This paper presents a true story of the career development of an international student in the Australian tertiary education sector. The student started his undergraduate studies at UNSW Sydney in 2010 and after 14 years he is a senior lecturer at WA School of Mines, Curtin University in 2024. Taking his story as a case study, lessons and advice along the journey will be shared in this paper to assist potential international students in pursuing their careers in Australia, particularly academic careers.

## INTRODUCTION

There has been an apparent surge in the number of the international students studying in Australia, especially after the COVID-19 (see in Figure 1) evidenced by the published data by Department of Education (2024). Although the number dropped slightly in the wake of the COVID in 2021–2022, it rebounded back and reached a record high in 2024. Among all sectors, the higher education or tertiary education sector contributes the most of the number. There are many factors propelling the surge of international students applying for universities in Australia, including the wide spectrum of course choices, availability of scholarships and research fellowships, post-study work rights and work opportunities, and a multicultural society. Such a big community generates undoubtedly tremendous business and hence revenue to Australia. According to Lucas (2022), Australia's total economic benefit from its 'education exports' was A$$37.6 billion in 2018–2019, making higher education the country's third-largest export earner, second only to coal and iron ore.

| Categories | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 |
|---|---|---|---|---|---|---|
| Higher Education | 321,616 | 330,602 | 287,982 | 271,344 | 308,228 | 377,139 |
| VET | 151,023 | 178,983 | 179,795 | 156,218 | 176,642 | 223,969 |
| Schools | 20,338 | 18,791 | 12,558 | 8,246 | 10,914 | 15,307 |
| ELICOS | 59,930 | 57,551 | 19,764 | 11,070 | 59,874 | 68,093 |
| Non-Award | 26,023 | 24,447 | 9,154 | 7,280 | 16,212 | 18,737 |
| **Total** | **578,930** | **610,374** | **509,253** | **454,158** | **571,870** | **703,245** |

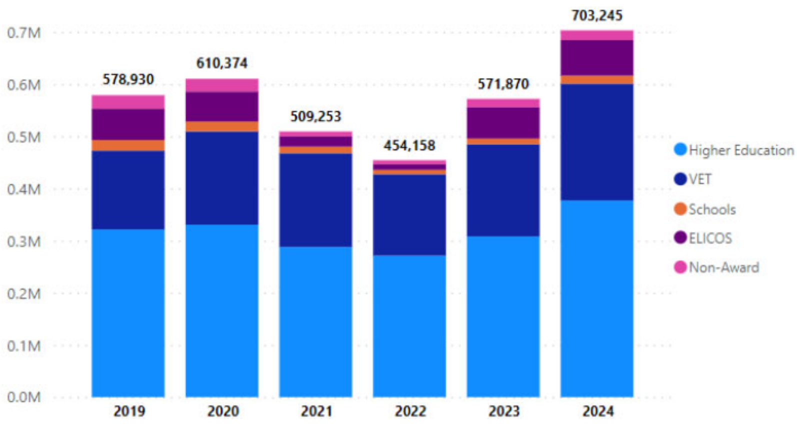


**FIG 1** – International students' enrolment in different sectors in the past five years.

All these solid facts indicate that the community of the international students would stay strong and will become bigger in the long-term if Australia has no sovereign risks or geopolitical issues with other contributing countries (eg China, India etc). One of the ultimate goals of majority international students is to find a job and start their career in Australia once they complete their studies in the higher education institutions. As such, assisting the international students in their career initiation and development is significantly important both for the students themselves as well as Australia, as Australia would eventually benefit from the new migrants with different invaluable skill-sets. It has been noted that each university would have a career centre or as such helping international students with the career subjects but those activities are limited to the general paper work advices, for instance, resume advice, job information, cover letter advice, interview skills, work rights, etc. Although some career forums are occasionally held with some successful alumni from multi-cultures sharing their experiences, the advice from the forums are still limited and sometimes ambiguous, because the advice for one sector might not necessarily apply to others. Therefore, the author of this extended abstract aims at sharing some lessons and advice of the academic career development in Australia for international students based on the author's true story.

## EDUCATION BACKGROUND

The author came to Sydney, Australia, in February 2010 for studying in the foundation year at UNSW Foundation before entering university. Foundation year is the only channel for international students who have not studied in Australian high schools to enter Australian universities for bachelor degree. It is one year program offering a range of fundamental courses including math, chemistry, physics, computing and English etc, if the candidate wants to study science or engineering in the university. It has its own examination program at the end of the study and based on the exam's mark, the student could choose the major and the university he wants to study in. The author achieved 9.7/10 at the end of the foundation year and chose mining engineering as the major for bachelor at UNSW. During the four years' undergraduate study, the author consistently achieved and maintained the excellent performance in the meantime worked part-time in various occupations including restaurant, delivery, newsagency and logistics. At the end of the underground study in 2014, the author achieved over 80/100 overall and hence graduated with the first class honour degree.

Owing to the outstanding academic performance during the undergraduate period, the author was offered a full scholarship to pursue his PhD degree in 2015 under the joint supervision of Professor Paul Hagan, Professor Serkan Saydam and Dr Hossein Masoumi at School of Mining Engineering UNSW. The research topic is analytical and experimental investigation into the failure mechanisms of the cable bolt under axial loading. That was the time the author started getting to know academic life and hence gradually developed his interests in scientific research. The author officially finished his PhD in February 2019.

## WORKING HISTORY

Although the author officially finished the PhD in February 2019, he started working as a course conveyor and research associate at the same school in UNSW from July 2018. Once he got the completion letter in February 2019, he joined Department of Civil Engineering at Monash University as an Associate Lecturer starting his academic career. He was teaching three courses there and in the meantime continued carrying out more in-depth research extended from his PhD.

Owing to his excellent teaching and research track records, he was appointed as a Lecturer at WA School of Mines (WASM), Curtin University, in 2021. Then he was promoted to Senior Lecturer in 2023. At WASM, he has been teaching rock mechanics courses and trying to expand his research areas to a broader spectrum.

## LESSONS AND ADVICE

If looking at the academic community in Australia, it is rare to see anyone initially coming to Australia as an international student at the undergraduate levels and end up as a faculty staff in universities. The author's experience is unique and as such, sharing his true stories and experiences might be helpful for those international students to broaden their career options and breakdown their stereotypes on academic career and even PhD.

## PhD and academic stereotypes

It seems people not only limited to the international students always have stereotypes on the PhD and academic career by overthinking the difficulties of the degree and the complexities of the working contents. This is partly true. However, that doesn't necessarily mean PhD is not doable. Indeed, different candidates might have different research areas that would suit them. In author's opinion, research in general can be classified into two categories including hard skill-set and soft skill-set. Finding the most suitable research topic or area is significantly important to any candidates wanting to pursue a PhD. Please bear in mind that all roads lead to Rome. The author chose the mine rock mechanics as the research area owing to his interests and enthusiasms in mathematics and physics. It turns out to be a wise decision as he has been enjoying the journey of his PhD and academic career.

## Don't knock off any opportunities

Every opportunity is a potential pathway to growth, learning, and success. Whether big or small, each opportunity presents a chance to explore new avenues, develop skills, and expand horizons. Sometimes, the opportunity might be challenging and that is when most people would re-consider the opportunity before deciding to take it. But it is noteworthy that longer time in the decision-making process might lead to the potential loss of the opportunity especially when the opportunity is competitive. So as a junior person who needs experience and growth, grasp everyone opportunity present to you as quickly as possible. Before the author received the completion letter of his PhD in 2018, due to one school staff's resignation, he was contacted by the HoS for delivering an undergraduate unit with only two weeks early notice. Apparently, it is an excellent opportunity but very challenging. The author made a decision accepting the offer right on-site. A similar occasion also occurred in 2021 when one staff in WA School of Mines resigned. The author was contacted by Curtin's HR about a lecturer position which requires an immediate teaching upon arriving in the school. He took it although this opportunity is challenging. These challenging opportunities turn out to be the best opportunities for growing the candidate and advancing his career path.

## Always work to the best of your capability

Working to the best of your capability in each task is essential. It ensures that you give your all, deliver high-quality results, and maintain a standard of excellence. Whether it's a simple task or a complex project, putting forth your best effort demonstrates dedication, professionalism, and a commitment to success. It's about striving for excellence and continuously improving to achieve better outcomes. Please rest assured that your excellent performance and achievement will be picked up by your line manager or supervisor or potential employer and eventually your hard work will very likely pay-off. Owing to the author's teaching experience gained in UNSW, he was appointed as an associate Lecturer in Monash University in 2019. He was mainly responsible for teaching the UG units without too much research workload expectation. Nevertheless, he still pushed himself to carry on extensive research and as a result, he successfully published at least two Q1 papers each year. The hard work eventually paid off when he was appointed as a lecturer in WA School of Mines owing to his teaching and research track record.

## Stay curious

Curiosity is a powerful force that drives discovery, innovation, and personal growth. It fuels a desire to learn and explore new ideas, concepts, and experiences. It keeps your mind active and engaged, fostering a lifelong love of learning. This is particularly more important in academic occupation as we have to never stop learning to acquire edge cutting skill-sets and improve our knowledge. In addition, curiosity also sparks creativity by encouraging you to question the status quo, think outside the box, and seek unconventional solutions to problems. It's the foundation of innovation and progress in all fields, which is significantly important to all researchers. My research area and expertise is rock mechanics and geotechnical engineering with a focus on ground support. All my research experience is with coalmines before joining WASM. After moving to Kalgoorlie, I managed to find a vocational mining engineer opportunity in Silver Lake Resources and spent three months on-site to get to know hard rock mining operations owing to my curiosity. I have also been learning the image processing and point cloud data analysis techniques to expand my research area and interests. All these efforts lead to an industry grant on LiDAR application in underground mines, worthy $140k.

### Being consistently proactive

Being proactive means taking initiative and responsibility for your life, actions, and circumstances. It's about anticipating and actively addressing challenges, rather than merely reacting to them. Being proactive fosters personal growth and development. By stepping outside your comfort zone, taking on new challenges, and seeking opportunities for learning and self-improvement, you expand your skills, knowledge, and capabilities. This is particularly more important to PhD students or junior academic who is new in the community and has no connections. Proactive communication would be essential for building strong relationships with seniors at work or social environments. Juniors are strongly encouraged to initiate conversations, express your needs and concerns and actively listen to others. By doing these, you can foster understanding, trust and collaborations. I have been proactive in seeking for research collaborations domestically and internationally. It has helped boost my research track record effectively with H-Index up to 20 now. I have also been proactively engaging with Australian mining industry by visiting various mine sites, talking with the engineers and managers, and doing consulting projects for them. The strong link as a result of the proactive communication and approaches with the industry brought me a few research grants so far. In addition, it is the communication skills gained along the proactive journey that is more important to me in connecting with industry as well as the researchers in the academic community.

## CONCLUSIONS

This paper provides five important tips for international students who want to pursue their careers in academic occupation. A few case studies of author's personal experiences were also shared to better explain and justify the advice. It is expected to assist the junior academic and PhD graduates in progressing their careers in tertial education sector.

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# Challenges and perspectives of attracting talents from developing countries – the case study of Horizon Education Agency in Azerbaijan

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## ABSTRACT

Azerbaijan has a mature petroleum industry, but the country's mineral resources sector is still developing. The lack of a robust domestic mining industry has resulted to a shortage of professionals in academia and industry able to mentor young talents, and to outdated and insufficient education which has led a few Azerbaijani geology and mining students to seek further training and job opportunities abroad. Recognising this gap, a group of postgraduate and undergraduate university students based primarily in Baku and other locations worldwide, using their experiences and knowledge from studying abroad, decided to put their skills to use in a new context.

Hence, these students established the Horizon Education Agency (HEA), the main goal of which has been to give their Azerbaijani peers relatively straightforward access opportunities to educational programs in foreign institutions, scholarships' awareness, and participation in regional and global initiatives. Since 2018, this small group of Azerbaijani students has organised several seminars, online workshops, and internship programs, in addition to launching a series of conferences called the 'Global Engineering Symposium' (GES).

HEA invited academics and industry experts from around the world to Baku, attracting the interest of hundreds of university students. Through participation at GES, students were able to increase their knowledge and skills, and be motivated to seek engineering careers' paths in Azerbaijan and abroad.

Many conference participants afterwards sought opportunities abroad for their postgraduate studies. In recent years, students have been studying at universities in China, Europe, and the United States. After finishing their studies abroad, some decided to return to Azerbaijan with the invaluable information and skills they gained from their international experiences. This inflow of highly educated individuals has the potential to substantially improve Azerbaijan's mining sector and academic scene, encouraging innovation and promoting advancement in many fields.

## INTRODUCTION

The demand for engineering experts is increasing worldwide due to rapid technological advancements and the specialised computer-based skills required in engineering disciplines (Gillett, 2001; Kossiakoff *et al*, 2020). Educational institutions are adapting curricula to meet industry demands and ensure that graduates possess the most up-to-date skills and knowledge. The engineering sector is significant in Azerbaijan, especially in the oil industry. The country's extensive infrastructure development projects rely on crucial engineering disciplines such as information technology, mechanical, electrical, and civil engineering. These projects demonstrate the nation's commitment to modernisation and economic progress, including initiatives to modernise transportation networks, improve energy efficiency, and expand telecommunications infrastructure.

However, even with these improvements, there are still significant gaps in the curriculum for different engineering disciplines. In contrast to petroleum engineering, which has prospered from an economic point of view because of the country's oil-centric focus, mining engineering has not received the attention it deserves. Research and exploration in mining have a long history in Azerbaijan, returning to the Soviet Union era. Numerous minerals and metals were discovered during the Soviet Occupation (1920–1991). However, since the country's independence in 1991, the government focused too much on petroleum, putting the minerals industry sector in low priority and hampering the advancement of mining engineering education. Azerbaijan has a significant deficiency in thoroughly incorporating literature reviews into mining engineering studies, which impedes the progress of scholars and professionals even further.

Recognising the gaps in the educational system, particularly in fields like mining engineering, has highlighted the need for broader educational reform and innovation. Addressing this need requires new platforms and initiatives to inspire and equip the next generation of Azerbaijani students and professionals. A group of students in Azerbaijan chose TED Talks as a potential catalyst for change, given its reputation for spreading ideas and fostering intellectual engagement globally. This marked the beginning of their journey to raise awareness of engineering fields.

Inspired by the thought-provoking and compelling content of TED Talks, this group of university students (including some of the authors in this paper) started looking at methods to introduce Azerbaijan State Oil and Industry University (ASOIU). By 2017, we (ten committed students) have effectively brought the TED platform to Baku. This considerable occasion expanded our perspectives and sparked several meetings and activities toward closing the gap in Azerbaijan's educational and professional systems. Inspired by our shared vision, we founded the Horizon Education Agency (HEA – http://www.hea-eu.com/) to advance our goal of developing the potential of young Azerbaijanis. In contrast to companies and organisations driven mainly by profit, the primary goal of HEA is to support young people in realising their full potential. After students benefited from HEA's programmes, this giving approach generated a unique atmosphere where these students were inspired to help and mentor other young talents, starting a domino effect of growth and development within the community.

HEA has been aiming to improve students' professional experiences by planning various conferences and activities. These programmes have been providing students with invaluable practical experience, turning novice event planners into competent pros even in trying times. These activities have had a significant influence. Engineering's importance in accomplishing strategic objectives, including waste management, renewable energy technologies, and net zero emissions, has gained much attention.

However, historically and until the recent decade, Azerbaijan's mining industry relied predominantly on geologists. Consequently, mining engineering was HEA's other vital goal; besides, the necessity for specialised mining engineers is becoming more widely acknowledged worldwide (Brady and Brown, 2005). To find solutions regarding engineering disciplines in Azerbaijan, HEA has organised several engineering-oriented events in Baku, engaging young engineers, talented students, academics domestically and internationally, and eventually governmental officers.

The Azerbaijani government has implemented significant reforms to modernise the mining industry and attract international investment. These reforms involve updating regulations to ensure environmental compliance and organising various events within the country. For example, in 2023, the first Geoscience and Mining Conference was held, and in November 2024, Baku will host COP 29. Additionally, extensive infrastructure development programs are underway, including constructing new roads and railroads to improve access to remote mining areas and enhance logistics operations.

In summary, Azerbaijan's journey has begun towards becoming an engineering and mining leader in the Caucasus region. It demonstrates the impact of vision, education, and collective effort in driving national progress. The experiences of these pioneering students serve as a testament to how determination and innovative thinking can bridge gaps, create opportunities, and pave the way for a prosperous and sustainable future.

## BACKGROUND

The development of industry and other growth sectors heavily depends on the country's education sector. Nowadays, many assessments use the Human Development Index (HDI) as a core parameter to analyse data accurately (Graedel and Reck, 2019). Azerbaijan is a post-Soviet country whose economy primarily depends on petroleum and offers petroleum-based job opportunities. In contrast, jobs in other sectors are difficult to find due to the underdevelopment of non-oil sectors and weak private businesses (Guliyev, 2016). As a non-oil sector, mining is one of the sectors that require much development; since the beginning, there have been many gaps in the academic part of mining in Azerbaijan. Nevertheless, the sector increased slightly in the recent years for various reasons, such as net zero emission initiatives, renewable energy, and the number of talented young people.

Mining stands out among non-oil industries that require substantial attention because of its great potential but undeveloped status. Historically, Azerbaijan's academic infrastructure for mining engineering has had significant inadequacies. Some progress has occurred recently, propelled by worldwide endeavours to achieve net zero emissions, the progression of renewable energy technology, and the rise of skilled young practitioners in the domain (Geo Mining Forum, 2023).

The 2010s were crucial for the mining industry in Azerbaijan, with significant investments made in exploratory projects throughout the nation. Despite these efforts, a discernible shortage of young, qualified mining engineers still existed. Businesses often hired geologists for mining engineering positions and primarily relied on foreign specialists, underscoring the critical necessity of developing local talent. Due to this severe scarcity, a deliberate effort was made to draw and develop new talent in mining engineering, highlighting the field's significance through special events and scientific conferences. These scientific conferences, events and symposiums have been held in Baku and especially by the effort of HEA mining, the attention of young talents and engineers has been gathered and centralised the development of the mining sector and highlighted the demand and job opportunities in the local market. Interestingly, not only was attention paid to the mining industry, but studying abroad was also one of the agency's essential projects, which, through this project, HEA aimed to broaden Azerbaijani student's horizons. Additionally, even though there are various agencies or international offices at the Universities, such as the DAAD office at ASOIU, most only promote foreign universities, especially highlighting studying in Germany in various programs. Some private agencies are also only interested in being paid by the students and finding reliable programs abroad.

HEA is unique among organisations because it promotes innovation and development. The TEDx ASOIU conference was a turning point for HEA; it broadened our perspectives and sparked new projects. HEA and the Global Engineering Symposium (GES) were introduced, building on this momentum. The main goal of HEA and the GES programme was to introduce fresh possibilities to Azerbaijan's engineering disciplines. These initiatives aimed to promote thorough growth in both the oil and gas and non-oil sectors.

It's important to note that Azerbaijan State Oil and Industry University, which houses many engineering faculties, did not provide funding for any of the activities hosted by HEA. However, the Azerbaijan Diaspora Support Foundation played a role in one of these conferences by providing students with funding for initiatives aimed at enhancing their skills and building connections during the event.

HEA was inspired by a dedication to developing young talent and promoting professional growth, unlike organisations whose primary motivation is profit. After gaining from HEA's programmes, students were motivated by altruism to mentor and assist other up-and-coming talents, which fostered a friendly community. This programme demonstrated how hard work can close gaps in knowledge and experience to create a domino effect of growth and development across the community. By implementing these initiatives, HEA has shown that it is dedicated to promoting engineering education and career advancement in Azerbaijan and creating a cooperative atmosphere that unites business and academics.

In conclusion, the founding and success of the Horizon Education Agency demonstrate the transformational potential of commitment, vision, and teamwork in advancing national development. HEA has made a substantial contribution to the growth of Azerbaijan's engineering industry by supporting young talent and creating a culture of mutual aid and ongoing education. This story is a motivational illustration of how focused efforts may result in significant progress, opening doors for the next generations and laying the groundwork for sustained growth.

## DESCRIPTION OF HEA

The distinctive goal and all-encompassing methodology of the Horizon Education Agency (HEA) set it apart from other professional development and education institutions. The goal of HEA was to solve the significant deficiencies in Azerbaijan's educational system and professional environment, especially in the engineering disciplines. The agency was founded in 2017 following an inspiring TEDx (ASOIU) event in Baku by students. In other words, this event stoked the founding team's enthusiasm for bringing about an educational revolution that would direct Azerbaijani students towards chances for further study abroad and promote a spirit of empowerment and mutual assistance.

HEA aims to raise awareness among driven Azerbaijani students and support them in accomplishing their international academic objectives. Being operated by a group of undergraduate and postgraduate university students, the agency's dedication to promoting a mentorship and community support culture sets it apart from the competition. In contrast to other organisations that prioritise profit, HEA is driven by empowering students and building a network of support that encourages lifelong learning and growth. Because of its giving nature, HEA has stood out and gained much respect and attention from the educational community. Because of the assistance of mentors who are academics and industry professionals from around the world or students studying abroad, this approach has enabled many students to come one step closer to fulfilling their dreams.

In addition to providing academic guidance, HEA hosts national and international conferences and activities to connect scholars, professionals, young grads, and students.

## METHODOLOGY

Horizon Education Agency takes a distinctive approach to attracting talent in developing countries, particularly considering approach challenges and perspectives encountered in Azerbaijan.

The study commences with an extensive research phase. During this stage, the underlying motivations behind such an undertaking are observed, followed by identifying young talents, project implementation, and collaboration to determine the most effective avenues for engagement and implementation of pedagogical initiatives.

The core team members first assembled to lead the TED Talks initiative in Baku, Azerbaijan, by leveraging digital platforms such as Google Forms and various social media channels to solicit interest and recruit members. Selected team members underwent interviews to evaluate their suitability and commitment to the project. At that time, social media channels such as Facebook were the primary method for promoting the projects. It is important to note that the selected team members were undergraduate students, ready to discover their potential in various aspects of event management. Each member was given specific responsibilities and tasks, including social media management, marketing, sales management, graphic design, web development, team coordinator, corporate partnership management and other jobs.

After a successful first conference, some team members decided to continue to organise various conferences in Azerbaijan. They adopted a methodology called 'Step by Step'. After a year, Horizon Education Agency (HEA) was founded as the umbrella organisation for various initiatives within the country and the agency's overseas initiatives. HEA focused on five key parameters to organise successful events: team members, speakers, tickets for funds, interested audience, and sponsors. The process for selecting potential team members for each consecutive project was like that of the TED Talks. Selected candidates were trained for a month, and their potential skills were evaluated for suitable positions.

The selection process for speakers took a different approach. For local and foreign academics, key scholars were identified and approached with a formal proposal outlining the benefits of participation in the project. Incentives such as three-day accommodation and expenses in Baku were offered to facilitate their involvement and enrich the project's academic content.

To secure funds for project execution, event tickets were sold to organisations and sponsors. Promotion efforts were also intensified to attract attendees while generating revenue to cover event costs. Regular team meetings were held to coordinate tasks, monitor progress, and address any challenges encountered during project execution. Project management tools such as Asana were utilised to track milestones, manage resources, and ensure the timely delivery of project objectives.

Post-event evaluations assessed the project's impact and effectiveness in achieving its objectives. Feedback from participants, speakers, and stakeholders was solicited to identify areas of improvement and inform future initiatives. Lessons learned, and best practices were documented and implemented to guide future projects and enhance organisational learning.

## ACTIVITIES AND OUTCOMES

The implemented methodology resulted in organising and delivering a series of successful events that are discussed below.

### Activities

#### *TEDxASOIU – 2017*

The first initiative was the TED Talks event, which took place in Baku in February 2017. A group of ten students from Azerbaijan State Oil and Industry University embarked on the inaugural project, driven solely by their passion and enthusiasm (Figure 1). Despite a lack of prior experience in event organisation, they successfully hosted the first TEDx event in the university's history.

**FIG 1** – The photo demonstrates TEDx ASOIU team members from the event in 2017.

The choice of the TEDx theme 'Zero Limits' stemmed from the recognition of the self-imposed barriers that often hinder human progress, stifling innovation, restricting forward momentum, and suppressing the free expression of thoughts and ideas. These students wish to push past these boundaries. Otherwise, they risk missing out on opportunities.

The event hosted over 100 guests. It was held in one of the central hotels in Baku, without any external funding. Event cost was covered entirely by student ticket sales in the spirit of 'Zero limits'.

The conference hosted about ten speakers from various fields, including engineers, psychologists, Moda designers, rappers, life coaches, human resources, among others, who spoke about how it's possible to push past fears and self-imposed limitations.

### *Zero To CEO – 2017*

In May 2017, the Horizon team decided to host an event designed to instil and strengthen an entrepreneurial spirit in young people while teaching them to overcome the obstacles they may encounter.

Following Azerbaijan's independence in the 1990s, a viable business ecosystem has flourished, underscoring the pivotal role of nurturing local expertise and talent to bolster the country's economic growth and global standing. Since then, this burgeoning business landscape has spurred the emergence of various enterprising individuals who, as CEOs, spearhead their innovative ventures and companies. The firsthand accounts of some of these captains of industry were coupled with their invaluable advice about the conference. The slogan for the event, 'Conference of CEOs of Today and Tomorrow,' embodies the ethos that every successful journey commences from nothing Ground Zero.

The chosen theme for the event was 'Take a Risk,' which highlighted the importance of taking chances reach goals. Attendees were able to glean insights from Azerbaijan's own CEOs, who have started from scratch in navigating significant challenges, embracing risk, and seizing opportunities (Figure 2). Notably, this conference departed from the traditional speaker-centric formats, instead fostering interactive dialogues on pertinent topics, offering a dynamic and enriching experience for all participants.

**FIG 2** – From Zero to CEO Forum, Baku 2017.

### *Lifelong Learning – 2018*

This event was held in 2018 in Baku. The name Lifelong Learning (LLL) is an acknowledgement that learning is a continuous process learning that one undergoes voluntarily on the personal and professional level while simultaneously promoting social integration and active citizenship.

The event was structured in two parts, addressing both continued personal and professional development. The speakers were leaders from Azerbaijan's academic and industrial spheres. Speakers from various fields, including the education, media, sport, and high-tech industries, were invited to share their experiences to a younger generation. The intended outcome was to continue to develop the necessary skills and tools for success, and how to implement them.

### *Global Engineering Symposium (GES) – 2019–2021*

The most successful initiative by Horizon Education Agency has been its Global Engineering Symposium series. Following all the previous successful events, the primary objective of the Symposium was to foster a platform for robust scientific and informational exchange between Azerbaijani students and foreign academics in the mining, IT, mechanical, chemistry, and petroleum engineering fields. This collaborative endeavour resulted in productive discussions among graduate students and representatives from various engineering fields. By bringing together a diverse body of stakeholders, the event facilitated dialogue and nurtured meaningful connections between students and professionals in the engineering sectors (Figure 3).

**FIG 3** – First Global Engineering Symposium.

Throughout the full-day program, attendees were treated to a rich array of presentations, including poster sessions and oral presentations by various postgrad and PhD students who spoke on current trends in various industries as well as alternative energy resources. Invitations were extended to professors and doctoral candidates from universities in Germany, Austria, Poland, Turkey, Malaysia, and Russia who shared their expertise across five distinct engineering disciplines and thematic panels encompassing oil and gas engineering, chemistry, mechanical engineering, IT, and mining engineering.

Each panel featured presentations and panel discussions, comprising both academics and industry professionals. Numerous news portals from Azerbaijan published compelling press reports highlighting the ground-breaking engineering initiatives within the country after the first Global Engineering Symposium. Such as Media coverage was not limited to Azerbaijan but included these initiatives regarding GES gathering GES gathering from universities in Germany, UAE, and Uzbekistan.

In addition to the contributions from international speakers, the Symposium showcased the specific accomplishments of young Azerbaijani specialists who had pursued studies abroad, capturing the audience's attention and inspiring future endeavours. The inaugural GES ignited a surge of ambition among Azerbaijani students, propelling them to pursue higher education opportunities at European universities; some students eventually managed to enrol in postgraduate mining engineering programs abroad.

One student enrolled at TU Bergakademie Freiberg in 2019, right after the first GES event, justifying the symposium's transformative influence. Simultaneously, many young scholars with petroleum engineering backgrounds afterwards clinched prestigious internships in the UAE, Qatar, and Kuwait. As a direct result of HEA's initiatives, Azerbaijani students started increasingly mixing their global experiences with local aspirations and, in so doing, reshaping the engineering landscape in Azerbaijan.

The second GES event was also held in Baku in 2020 and was the last event before the lockdown began in Azerbaijan. Despite the looming threat of a global pandemic, the show went on with the participation of over 15 speakers from various countries and approximately 200 Azerbaijani university students.

There was a significant increase in the number of panellists in the mining engineering session compared to the first GES. In 2019, only ten people participated in the mining panel; in the second conference this number had grown to almost five times that, with approximately 50 people. This outcome demonstrated the development and success of the GES initiative, especially its growing role in the evolving geopolitics of the mining industry in Azerbaijan. The Global Engineering Symposium (GES) brought together young professionals from diverse backgrounds, including students, young engineers, researchers, IT specialists, and managers. HEA received feedback from different groups, which had participating students expressing how attending the GES broadened their perspective on sustainable engineering practices.

'*Hearing from professors and professionals across different engineering disciplines enriched my understanding. It motivated me to seek internships and further academic journey abroad, which have been crucial for my professional growth*.' – Renad N, Mechanical Engineering Student at Azerbaijan Technical University.

Engineers and researchers found the symposium to be a unique networking platform, helping them connect with peers from different countries while gaining insights into cutting-edge research and industry trends (Figure 4). Overall, specialists agreed that the GES exceeded expectations, showcasing global engineering expertise while celebrating local talent. They believe the symposium's impact will ripple through their work, driving positive change.


**FIG 4** – Second GES team with speakers and participants.

The third GES Series was organised together with Nala Consultancy and Projects (another students' initiative in South Africa) and SAIMM–Young Professionals Council (YPC) in South Africa in September 2021. This time the GES boasted a highly engaged international audience of technical, operational, and policy-making engineers from both academia and industry who engaged in discussing current trends within these fields.

The rest of the developed world is slowly transitioning to the Fourth Industrial Revolution (4IR), and countries like Japan, South Korea, and Germany have already succeeded. In other words, the 4IR represents the current wave of technological advancements that blur the lines between the physical, digital, and biological realms. It is characterised by the fusion of technologies such as artificial intelligence (AI), robotics, the Internet of Things (IoT), 3D printing, genetic engineering, and quantum computing. It was determined that GES South Africa theme would be 'Bridging the Gap' as between research and industry transition to 4IR.

South Africa is on a trajectory towards achieving a sustainable transition into Industry 4.0. This made the topic a perfect foundation for the third GES, as such discussions are imperative in equipping current students with the skillsets, tools, and industry knowledge needed for a competitive advantage in their respective fields and ultimately help succeed in the goal.

The implementation of HEA's pedagogy model in South Africa by Nala Consultancy, based on HEA's methods, has led to many initiatives in African society. Nala started with various seminars, podcasts, and research-based works for African youth. Additionally, they supported finding suitable educational programs and scholarship opportunities in the EU for students.

In summary, the GES in both countries led to a knowledge exchange and networking opportunity that helped shape the future of engineering for all involved. NALA in South Africa has also implemented HEA's unique approach to studying abroad.

### *Caucasus Geopolitical Forum – 2020 (Webinar)*

Parallel to the organisation of GES, Horizon Education Agency also introduced the Caucasus Geopolitical Forum, representing a concerted effort to foster a comprehensive understanding of the evolving dynamics of the Caucasus' role in an increasingly interconnected geopolitical landscape and Global Village. HEA' sought to bring influential stakeholders from diverse backgrounds, including public officials, analysts, economists, researchers, and media personnel, together in a forum designed to examine geopolitical trends and their micro and macro implications. Unlike the other HEA's student-focused initiatives, this event targeted a different audience. It aimed to engage professionals and experts who could influence policy and decision-making on a broader scale. This influence is not limited to the Caucasus regions but also includes the impact on other regions such as Europe, Asia, and America. On the other hand, understanding complex geopolitical trends helps students gain a broader perspective on global issues, enriching their educational experience and fostering a more informed and globally aware student body. Additionally, the webinar provided

HEA's leadership team with diverse knowledge on global issues, aiding in developing more effective educational strategies to support a socially aware and well-informed student community.

At its core, the event served for open dialogue and the uninhibited exchange of ideas, aiming to cultivate a broader platform for discourse on the contemporary geopolitical milieu. Under the overarching theme of 'Think Big: The Future of Nagorno-Karabakh', the forum delved into the multifaceted dimensions of geopolitics, spanning political technology, political economy, and social paradigms across the Caucus region. The forum consisted of three panels with speakers from various countries, including the United States, the United Kingdom, Germany, Israel, and Azerbaijan to examine the political, social, and economic realities of these countries.

Driven by a spirit of ambition and collaboration, Horizon Education Agency spearheaded an ambitious initiative to establish the Caucasus Geopolitical Forum as a platform for global engagement. Through strategic partnerships spanning 20 countries and various industries, the project's goal was to foster innovation and creativity towards a more prosperous and sustainable future.

The forum's agenda focused on the political, social, and economic dynamics of the Caucasus region on various topics encompassing politics, history, law, psychology, sociology, and journalism. The intent was to bring about meaningful and productive dialogue, resulting in actionable insights for the benefit of participants. The event was held as a webinar, ensuring the engagement of a worldwide audience and fostering a more extensive interchange of thoughts and viewpoints.

### *Green Energy Revolution – 2022 (Webinar)*

In the spirit of the new online era, which was partially forced by the COVID pandemic, Horizon Education Agency introduced yet another event, the webinar 'Green Energy Revolution' to focus on the importance of natural resources and maintaining the balance between the economy and the environment by utilising green energy (Figure 5). The webinar was a one-day program whose primary objective was to bring together an international group of graduate students, researchers, environmental activists, and representatives from different engineering fields and industries. The goal was to give a comprehensive overview of what is happening in an increasingly linked global environment that is simultaneously undergoing climate change. There were diverse discussions on critical raw materials, alternative energy sources, and the world's reliance still on fuel minerals.

Despite their different focuses, all the speakers agreed on the importance of moving towards green energy. However, they collectively acknowledged that achieving this transition would not be feasible in the short-term, and that it could take several decades to reach desired goals. The forum, like prior HEA events, was designed to create an open platform for a wide range of discussion and the free exchange of ideas. The theme was 'Environmental Balance is the Only Way that We Have to Follow', combining an improved environmental comprehension with the use of technology, energy, economy, and social accomplishments.

The attendees gave overwhelmingly positive feedback. Many appreciated the in-depth analysis provided by the speakers. '*I found the Green Energy Revolution webinar to be an inspiring experience as a petroleum engineer. It challenged me to think beyond the traditional boundaries of my field and embrace the exciting possibilities that renewable energy sources offer for a sustainable future.'* – Dr Islamov S, Petroleum Engineer, BP, Russia.

The webinar succeeded in its goal of fostering a nuanced understanding of the complexities of the global shift towards green energy, resulting in the dissemination of actionable insights and collaborative initiatives for a more sustainable future for the incoming generation of young professionals who will have to implement it.


**FIG 5** – Speakers of Green Energy Revolution.

## Outcomes

The Horizon Education Agency (HEA)'s practical efforts have contributed to Azerbaijan's educational and professional environment in a tangible way. These events have developed an innovative, cooperative, and supportive atmosphere that offers students invaluable learning opportunities and exposure to outside influences they would not have otherwise had.

Attendees were urged to push their own boundaries and explore innovation at the TEDxASOIU event. Young entrepreneurs were equipped with helpful information and self-assurance to successfully traverse the business world through the 'Zero to CEO' conference. The 'Lifelong Learning' event highlighted the value of ongoing education for professional and personal development. Through the interchange of ideas and expertise between students and worldwide specialists, the GES series has significantly advanced engineering not just in Azerbaijan, but in the countries these students have subsequently worked or studied in, as well as evolving South Africa's engineering practices through the interchange of ideas.

The Green Energy Revolution webinar and the Caucasus Geopolitical Forum exemplified HEA's dedication to using innovative and forward-thinking ideals to address global issues. These programmes have naturally raised educational standards in Azerbaijan and helped to raise established the nation's international profile as a hub for intellectual and professional advancement.

HEA has also helped harvest and foster the talent of Azerbaijan's young people through study-abroad programs and establishing their own international networks. HEA's strategy, distinguished by its emphasis on dynamic and interactive learning experiences, has been quite successful. The innovative pedagogical model, which highlights the value of global connection and real-world applications, has subsequently been implemented in South Africa as a case study and secondary experiment locale, indicating that it has the potential to be replicated in other nations. Through identifying and developing student talent, HEA has established a framework that will continue to spur innovation and constructive change worldwide.

Overall, HEA's initiatives have motivated many students to pursue their goals, equipped them with the necessary information and skills, and fostering a culture of lifelong learning and global involvement. Since its inception, HEA has engaged about 150 students in various projects and supported their development. According to the company's statistics, over 5000 participants have attended HEA events, both in person and online. Notably, many young people launched their own start-up initiatives following the 'Zero to CEO' conference. Currently, three thriving high-tech, data, and media companies are in active operation in Azerbaijan, and the founders attribute their start-up decisions to the impact of the Zero to CEO event.

Additionally, after the successful GES series, many young engineering students had the opportunity to consider their future careers and decided to pursue further education and advanced degrees abroad. Former HEA students are now studying and working worldwide. In sum, HEA's initiatives have been successful in empowering a new generation of leaders and innovators, laying the foundation for a better future.

## CONCLUSION

The generally conservative policies of universities and companies in Azerbaijan do not allow for the necessary growth needed to build the infrastructure of the country and its standing on the world stage. However, by engaging a young generation and the leaders of industry and policy of the future with the pedagogical methods outlined in this paper, Horizons Education Agency has already begun to have a meaningful impact on some students with the potential to alter their professional course.

These students understand the value of a broad education and know that studying at the university and taking courses is not the end of personal and professional development. The interest in conferences such as the GES displays a hunger and market for further education. Some of these students have even elected to go further in their personal and professional development by studying abroad. Whether they remain abroad or return home to develop Azerbaijan, the interest, need, and market clearly exist.


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# Mining minds – cultivating emotional intelligence in technical titans

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## ABSTRACT

Within the dynamic field of mining engineering, the imperative to develop well-rounded professionals is increasingly evident. This paper presents insights from the Mine Management Principles and Entrepreneurship course at the School of Mining Engineering, University of the Witwatersrand. The curriculum, meticulously crafted to augment technical expertise with managerial acumen, extensively covers management theories, organisational concepts, and the principles of human resources. Inspired by Daniel Goleman's (1995) seminal work on emotional intelligence (EI), this paper delves into the strategic integration of EI within the curriculum, solidifying its commitment to nurturing future mining graduates into adept managers and leaders. Emotional intelligence, defined as the ability to manage oneself and foster effective relationships, occupies a pivotal role in the course. By introducing technical students to these soft skills early in their academic journey, the curriculum aims to equip them with the tools necessary to navigate high-stress environments, diverse personalities, and the intricate dynamics inherent in the mining industry. The discussion revolves around the pragmatic implications of incorporating emotional intelligence in a technical degree, referencing Goldman's foundational research on the subject. Students, armed with EI, are anticipated to enhance their adaptability, communication, and interpersonal skills, thereby contributing to a more resilient and collaborative mining workforce. This paper, grounded in both educational theory and real-world application, serves as a valuable contribution to the ongoing discussion within the Society of Mining Professors, offering innovative approaches to holistic education in mining engineering. It presents a holistic view of the curriculum's impact on students' development, emphasising the long-term benefits of instilling emotional intelligence in the next generation of mining professionals. The integration of EI into the curriculum reflects a forward-looking approach, recognising the evolving demands of the mining industry and the broader professional landscape.

## INTRODUCTION

In the rapidly evolving field of mining engineering, the need for graduates and professionals who are not only technically proficient but also possess a broad range of soft skill traits is becoming more increasingly important. Graduates are expected to have the ability of solving complex problems and managing multidisciplinary teams. Knowledge learned from technical courses only build the students ability to analyse and solve discipline specific problems. A critical view is that it is the integration of soft skills that assist students and graduates with the necessary tools to become effective professionals, and traditionally there is a lack of this training in mining engineering education. This paper provides an in-depth analysis at the innovative curriculum of the Mine Management Principles and Entrepreneurship course offered at the School of Mining Engineering, University of the Witwatersrand. The course is designed to equip the students with a blend of technical knowledge and managerial skills, preparing them to become the future proficient leaders of the mining industry in a global context. The curriculum, which covers a wide range of relevant topics from management theories to the principles of human resources includes the area of emotional intelligence (EI) that is inspired by Goleman's (1995) book which describes the theory effectively. Goleman (1995) research has shown that EI, the ability to manage oneself and foster effective relationships, is a critical skill in today's professional landscape. Recognising this, the authors have strategically integrated EI into the course curriculum with the aim to nurture students into adept managers and leaders.

This paper aims to delve into the practical implications of incorporating EI into a technical degree, with a particular focus on its application in the high stress, diverse and complicated mining industry environment. By introducing these soft skills early in their academic journey, the course's main focus is to equip students with the tools necessary to navigate these challenges effectively. The discussion will revolve around the long-term benefits of instilling EI in the next generation of mining professionals, with the anticipation that students armed with EI will enhance their ability, communication and interpersonal skills. The expectation is that in turn this should contribute to a more resilient and collaborative mining workforce. A key factor in the lesson plan is that it is rooted in educational theory and real-world application, this paper's intention is to offer an innovative approach to holistic education in mining engineering and to provide a comprehensive view of the curriculums transformative impact on final year student development. Specifically, the integration of emotional intelligence emphasises the University's forward-thinking approach, acknowledging the evolving demands of the mining industry and the broader landscape.

Through this analysis, the authors aspire to highlight the intrinsic values of fostering well rounded mining engineering equipped not only with the technical skills but also with the emotional intelligence necessary to thrive in an ever-evolving industry.

## ASSESSING EMOTIONAL INTELLIGENCE

Emotional Intelligence (EI) is the ability to manage oneself and relationships with others, which is crucial for workplace success. Goleman (1995) categorises EI into four quadrants: self-awareness, self-management, social awareness, and relationship management, as illustrated in Figure 1.

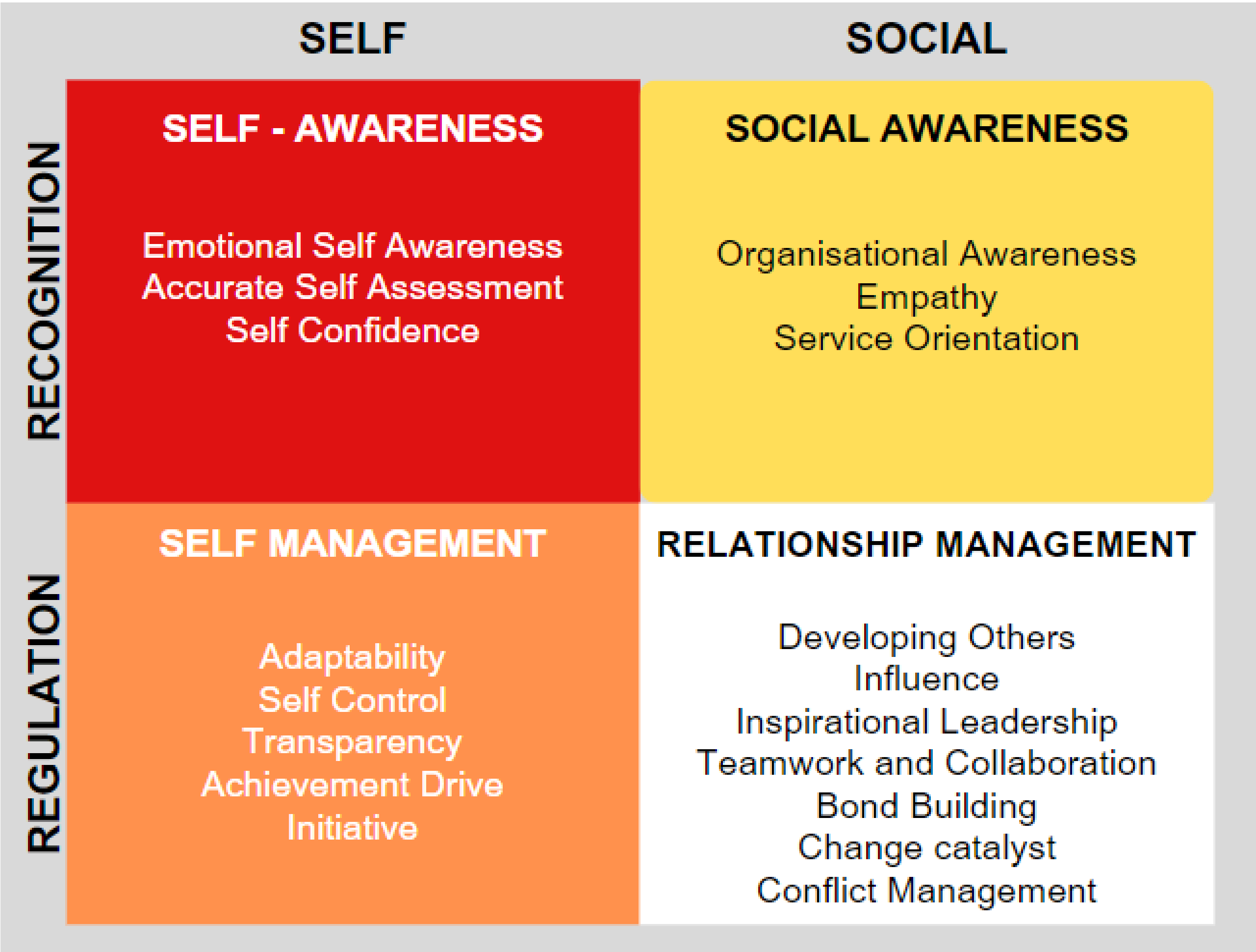


**FIG 1** – Goleman's intelligence model (after Goleman, Boyatzis and McKee, 2002).

These quadrants encompass five key areas: self-awareness/control, empathy, social expertness, personal influence, and mastery of purpose/vision.

1. **Self-Awareness and Self-Management** – These involve understanding one's impact on others and managing oneself productively. Key questions include describing instances where

one's actions had positive or negative impacts and recognising when to delay actions based on situational awareness (Lynn, 2023). Recognising and managing one's triggers is essential as this helps predict emotional reactions and avoid negative outcomes.

2. **Empathy** – Empathy is about understanding others' perspectives. Assessing empathy involves reflecting on times when one didn't understand something or someone's behaviour and how they responded. For leaders, it involves learning from peers and asking for information about problems.
3. **Social Expertness** – Social expertness focuses on building genuine relationships and managing conflicts healthily. Key questions involve identifying key relationships at work, leveraging positive relationships to achieve work goals, and handling resistance from others. Effective relationship-building includes friendly gestures, active listening, and inclusive actions (Lynn, 2023).
4. **Personal Influence and Self-Confidence** – Personal influence and self-confidence are about leading and inspiring oneself and others. Assessing one's influence involves describing times when one took on challenging tasks or confidently disagreed with others. Confidence is shown through commitment to one's ideas, non-verbal cues like standing straight, smiling, and making eye contact.
5. **Mastery of Purpose and Vision** – Mastery of purpose and vision entails bringing authenticity to life and aligning work with one's values. Questions to assess this include times when one was deeply absorbed in work, felt bored, or found certain types of work inspiring. Understanding these aspects helps align work with personal interests, enhancing engagement and productivity (Lynn, 2023).

Assessing EI effectively requires reflecting on these dimensions and understanding one's behaviours and their impacts. This introspection aids in personal growth and better management of professional relationships, contributing to overall workplace harmony and success. This concise assessment framework provides a comprehensive yet practical approach to evaluating and enhancing EI in professional settings. It underscores the pivotal role of EI in fostering a productive and empathetic workplace environment. The framework is applied throughout the mining management theories' subject for final-year mining engineering students.

## EMOTIONAL INTELLIGENCE AND MINE MANAGEMENT

When one thinks of management especially in a mining context, the question arises 'What is a manager?' 'What does a manager do?' The answer to these questions came through an in-class survey undertaken by the mine management principles students. The answers and ideas of what a manager is and what he/she does is shown in the word cloud in Figure 2. The ideas are far from complete but gives an idea of students' understanding of a manager's role.


**FIG 2** – Responses from mine management principles class.

In the context of a mining environment, management embodies the skilful arrangement of personnel, resources, and operational processes to achieve optimal outcomes while ensuring safety, sustainability, and productivity. It necessitates a structured approach to planning, organising, leading, and controlling activities within mining operations. Effective management in this setting extends beyond supervision, demanding a nuanced understanding of geological challenges, equipment maintenance and regulatory compliance. This is where EI can complement the mine manager, as it emerges as a crucial component of effective leadership within the mining sector, encompassing the ability to navigate high-pressure situations, foster team cohesion and resolve any conflicts sensitively. Research by Goleman (1995), and Salovey and Mayer (1990) underscores the importance of EI in enhancing a culture of safety, reducing accidents and promoting employee well-being within mining operations. Therefore, the authors recognise mine management as a dynamic discipline, informed by both technical expertise and emotional intelligence which has a learnable nature. Education, training, and practical experience together with the cultivation of EI are paramount in nurturing competent and adaptive managers capable of steering mining operations toward sustainable success. The knowledge on this broad subject can steer students into an understanding of the development of mine management and organisational behaviour. This will further encourage students to concentrate on the key aspects such as organisational structure, groups, motivation, leadership, organisational growth, and the role EI plays in these aspects.

## MOTIVATIONAL THEORIES AND EMOTIONAL INTELLIGENCE

EI is recognised as a critical factor in the success of individuals in technical careers. The relevance of fostering motivation and job satisfaction amongst technical professionals can find its background in traditional, classical and behavioural motivational theories. In the realm of technical careers, motivation and job satisfaction are pivotal to performance and innovation. Traditional, classical and behavioural motivational theories offer the framework for understanding these dynamics. Students are introduced to these concepts, and it is acknowledged that integrating the theories with EI provides a more comprehensive approach to enhancing the principles of workplace motivation and satisfaction.

### Traditional management theories

#### *Maslow's Hierarchy of Needs*

Maslow's (1943) Hierarchy of Needs is a foundational psychological theory that describes human motivation as a progression through five levels of needs: physiological, safety, social, esteem and self-actualisation as shown in Figure 3.


**FIG 3** – Hierarchy of Needs (after Maslow, 1943).

According to Maslow (1943), individuals are motivated to fulfill these needs sequentially starting from the most basic needs to the higher end need for self-actualisation. In technical fields, the application of Maslow's theory can be seen in several ways. For example, ensuring that employees' basic needs such as adequate salary and safe working conditions are met is fundamental. Moving up the hierarchy, fostering a supportive and collaborative work environment satisfies social needs, while recognising achievements and providing opportunities for professional development addresses esteem needs. Ultimately, enabling employees to engage in challenging projects and foster innovation. While Maslow's (1943) framework provides a rational approach to motivation, it is often criticised for its linearity and assumption that needs are fulfilled sequentially. A flaw unfortunately lies in what is commonly deemed as human nature, a human being always wants more than what he or she already has. The idea that humans always want more is a recurring theme in psychology, philosophy, and economics. This concept suggests that human desires are insatiable and that satisfaction of one need often leads to the emergence of new desires. Students are empowered and encouraged to apply themselves to the theory and understand that motivation moves upwards while at the same time are challenged to think about managerial solutions where employee demotivation occurs. The Herzberg (1959) model attempts to address the issue.

### *Herzberg Two Factor theory*

The Herzberg (1959) Two Factor theory distinguishes between hygiene/maintenance factors and motivators. The study was carried out by using an interview technique where people were asked about what pleased them and displeased them about their job. The findings established that hygiene factors (eg. salary, working conditions) prevent dissatisfaction but do not motivate. In contrast, motivators (eg. achievement, recognitions) foster job satisfaction and motivation. Students are taught that it is essential to manage hygiene factors to prevent job dissatisfaction. Which can be achieved through offering employees' competitive salaries and incentives, ensuring a safe and conducive working environments and to maintain good relationships with supervisors and peers. Motivators such as the recognition of technical achievements and by offering opportunities for career development and advancement and allowing employees to take on significant responsibilities are crucial for enhancing job satisfaction and feeling motivated.

The integration of EI with Herzberg (1959) theory can enhance its applicability, for instance, leaders with high EI are better equipped to communicate and understand the emotional needs of their team members resulting in better management, ensuring that both hygiene factors and motivators are effectively addressed. Leaders equipped with this knowledge and skill can create an environment where employees feel valued and motivated, leading to higher levels of job satisfaction and productivity. By addressing both the hierarchical needs and the factors influencing job satisfaction and motivation, and by leveraging EI, organisations can create a more motivated and satisfied workforce.

## Classical management theory

### *Fayol's theory (Fayolism)*

Fayol's (1949) foundational principles of management remain influential in contemporary management practices. Fayol (1949) identified five primary functions of management that is, planning, organising, commanding, coordinating, and controlling. These functions provide a structured framework essential for managing technical teams where precision and efficiency are critical, much like the mining environment. The integration of EI into these classical management functions can significantly enhance their effectiveness, particularly in technical careers. EI as defined by Goleman (1995) included self-awareness, self-regulation, motivation, empathy and social skills. These components are vital for understanding and responding to the emotional and psychological needs of team members, which is necessary in vocations that involve high stress situations and problem solving.

As a mining engineer, Fayol (1949) was well placed to understand the dynamics of management in mining environments. Fayol's (1949) principle of *'planning'* involves forecasting future conditions and preparing plans to address them. Integrating EI into planning allows managers to consider the emotional and motivational states of team members. For instance, involving employees in the planning process can increase their commitment and motivation, as they feel their inputs are valued. This participatory approach not only enhances the quality of plans but also boosts morale and fosters a sense of ownership among team members.

The *'organising'* function, which entails arranging resources and tasks to achieve objectives, can benefit from the empathetic aspects of EI. Understanding individual strengths, weaknesses, and emotional triggers enables managers to assign roles and responsibilities that align with each team member's capabilities and emotional well-being. This alignment can lead to increased productivity and job satisfaction, as employees are more likely to excel in roles that match their skills and emotional dispositions.

Fayol's (1949) *'commanding'* function, which focuses on leading teams to achieve organisational goals, is enhanced by the motivational and empathetic elements of EI. Leaders who demonstrate high emotional intelligence can inspire and motivate their teams through empathy and effective communication. This approach not only drives performance but also builds trust and loyalty within the team. Effective communication, a core component of EI, ensures that team members understand their roles and the importance of their contributions, leading to a more cohesive and motivated workforce.

The *'coordinating'* function involves harmonising activities and efforts to ensure that organisational goals are met efficiently. Integrating EI into coordination practices helps in managing interpersonal relationships and resolving conflicts amicably. By fostering a collaborative environment where team members feel valued and understood, managers can enhance cooperation and teamwork, which are crucial for the success of technical projects.

Finally, Fayol's (1949) *'controlling'* function, which includes monitoring and evaluating performance, benefits from the feedback and self-regulation aspects of EI. Managers who provide constructive feedback that is sensitive to the emotional states of their team members can significantly improve performance and job satisfaction. Such feedback helps employees feel supported and motivated to improve, leading to continuous personal and professional development.

## Behavioural management theories

### *McGregor's Theory X and Theory Y*

McGregor's (1960) Theory X and Theory Y provide two contrasting views of human motivation and management. Theory X speculates that individuals inherently dislike work and must be coerced and controlled to achieve organisational goals. This perspective suggests a management style that is authoritarian, relying on strict supervision and punishment to ensure compliance. In contrast, Theory Y presents a more optimistic view, where individuals are seen as naturally inclined to enjoy work, seek responsibility, and exercise self-direction and self-control. Managers who adopt Theory Y value teamwork, problem-solving, and on-the-job training, fostering an environment where employees' innate creativity and commitment can flourish.

### *Schein's Theories of Man at Work*

Schein's (1992) research further refines our understanding of workplace dynamics by categorising workers into four types: Rational Economic Man, Social Man, Self-Actualising Man, and Complex Man. Rational Economic Man views work purely as a means to maximise self-interest, necessitating a management style that neutralises emotions and relies heavily on systems and procedures. Social Man, on the other hand, is driven by social needs and peer influence, prompting managers to create a corporate family structure that emphasises group incentives. Self-Actualising Man is aligned with Maslow's Hierarchy of Needs, highlighting the importance of personal growth and intrinsic motivation. Lastly, Complex Man embodies the idea that human behaviour is multifaceted and variable, requiring a flexible and adaptive management approach.

By integrating these theories into the curriculum for final-year mining engineering students, we have cultivated a deeper understanding of emotional intelligence and its practical applications in the workplace. Teaching these future technical titans to recognise and adapt to different motivational drivers—whether they align more with Theory X or Theory Y or fit into one of Schein's categories—equips them with the diagnostic abilities and flexibility necessary for effective leadership. Emphasising the development of intrinsic motivation, personal growth, and a supportive organisational culture will not only enhance their technical capabilities but also their capacity to lead diverse teams with empathy and insight.

## INSIGHTS FROM THE MANAGERIAL GRID AND ROLE CONCEPT

The **Managerial Grid** shown in Figure 4, developed by Blake and Mouton (1964), offers a graphical representation of managerial attitudes and leadership styles, balancing concern for production with concern for people.

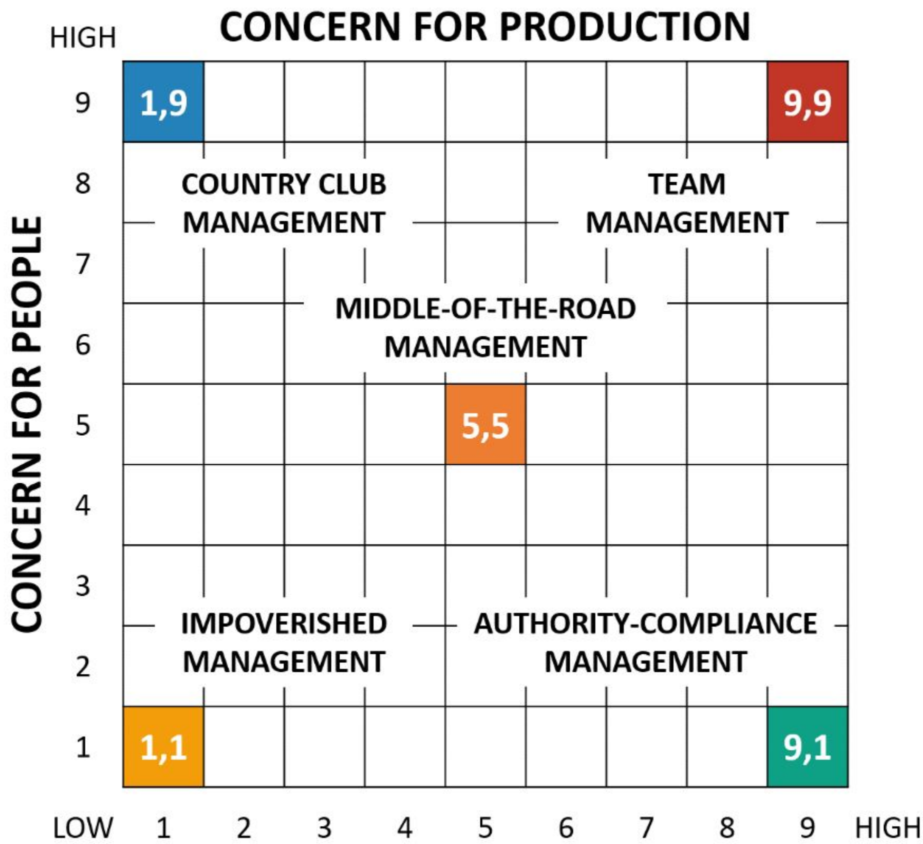


**FIG 4** – Managerial grid (after Blake and Mouton, 1964).

This model is particularly relevant for mining engineering students, who must often decide between task-oriented and people-oriented approaches. The grid's five managerial styles (9,1) 'Produce or Perish' (1,9) 'Country Club Management,' (5,5) 'Middle of the Road,' (1,1) 'Impoverished Management,' and (9,9) 'Team Management' provide a spectrum of leadership strategies. Each style presents distinct advantages and challenges; for instance, the (9,1) style, while potentially yielding short-term productivity, often leads to long-term dissatisfaction and union conflicts. Conversely, the (1,9) style prioritises employee happiness at the expense of productivity, jeopardising organisational survival.

For mining engineering students, understanding these styles is critical. Cultivating emotional intelligence involves recognising the impact of these managerial approaches on team dynamics and organisational outcomes. The (5,5) 'Middle of the Road' style, often perceived as a balanced approach, may lead to mediocrity and stress due to continuous compromise. In contrast, the (9,9) 'Team Management' style, which balances high concern for both production and people, is ideal for fostering a collaborative and productive work environment.

The **Role Concept** (McGregor, 1960) underscores the societal expectations placed upon individuals in various positions, necessitating distinctive behaviour patterns based on situational roles. In the context of mining engineering, this implies that students must learn to navigate multiple roles – manager, peer, subordinate, and external liaison – each with unique expectations and potential conflicts. Effective management in the mining sector requires an adeptness at balancing these roles, akin to managing a complex 'spider's web' of relationships. This complexity is further compounded by the corporate culture within mining organisations, which shapes managerial roles and expectations. Students must be equipped with the emotional intelligence to align their personal values with corporate philosophies, mitigating internal conflicts and fostering a harmonious work environment.

## LEADERSHIP IN MINING ENGINEERING

In the realm of mining engineering, where technical acumen is paramount, integrating EI into leadership education is pivotal for developing well-rounded professionals. The students are offered a comprehensive exploration of leadership traits and styles, emphasising that effective leadership is inherently linked to the motivation of people.

Effective leadership in mining engineering is characterised by a blend of assertiveness, confidence, intelligence, and motivational ability, among other traits. These qualities are indispensable in the high-stakes, structured environments typical of mining operations. The assertion that 'management and leadership are not synonymous' is particularly salient. While management focuses on structured roles and short-term problem solving, leadership extends beyond organisational boundaries, fostering long-term changes in followers' attitudes and behaviours. This distinction underscores the need for mining engineering students to develop both managerial and leadership skills, with an emphasis on the latter's inspirational and motivational aspects.

Lewin's (1939) three leadership styles—Authoritarian, Participative, and Delegative provide a foundational framework for understanding how different leadership approaches can be applied in various situations. Authoritarian leadership, with its command-and-control focus, can be effective in crisis situations requiring rapid decision-making but may stifle creativity and create a hostile work environment if misapplied. In contrast, Participative leadership, identified by Lewin (1939) as the most effective, fosters a collaborative environment where group members feel valued and motivated, leading to higher quality contributions and better workplace morale.

Integrating emotional intelligence into these leadership styles can significantly enhance their effectiveness. Emotional intelligence, defined by Goleman (1995) is crucial for mining engineers who must navigate complex interpersonal dynamics and high-pressure situations. For example, an emotionally intelligent participative leader can better manage group dynamics, address conflicts empathetically, and foster a more inclusive and supportive team environment (Goleman, 1995).

Moreover, the 7-S organisational framework—distinguishing managers who rely on strategy, structure, and systems from leaders who emphasise style, staff, skills, and shared goals – highlights the importance of soft skills in leadership (Peters and Waterman, 1982). Emotional intelligence enhances these soft skills, enabling leaders to communicate effectively, motivate their teams, and align their staff with the organisation's superordinate goals.

## CONCLUSIONS

Final-year mining engineering students are prepared for the multifaceted challenges they will face, integrating established management theories for fostering emotional intelligence and effective leadership. In technical careers, where stress and complex problem-solving are prevalent, the ability to manage one's own emotions and understand those of others is particularly beneficial. EI helps mitigate conflicts, improve teamwork, and maintain a positive work environment. Integrating EI with Fayol's (1949) management principles addresses both the technical and human aspects of management, leading to a more integrated approach that enhances efficiency and employee well-being. This synthesis of classical management theory and emotional intelligence creates a dynamic framework well-suited to the demands of contemporary technical workplaces fostering innovation, productivity, and a positive work culture in technical careers.

The integration of McGregor's (1960) and Schein's (1992) theories into our teaching strategies is essential. This is because the theories provide a comprehensive framework that underscores the importance of understanding human behaviour and motivation in the workplace. While the integration of the Role Concept and the Managerial Grid into the educational framework for final-year mining engineering students is essential for cultivating leaders who are not only technically proficient but also emotionally intelligent. This dual focus ensures that future leaders can manage both the operational demands of mining and the interpersonal dynamics of their teams, leading to sustainable success in the industry.

Incorporating these insights into the curriculum can prepare mining engineering students to become emotionally intelligent leaders who can navigate the complexities of managerial roles and styles effectively. By understanding the interplay between task orientation and people orientation, students can develop strategies that enhance both productivity and employee satisfaction. This holistic approach to leadership education not only equips students with technical expertise but also the emotional intelligence necessary to excel in the dynamic field of mining engineering.

For mining engineering students, developing emotional intelligence can be achieved through targeted educational programs that include training in self-awareness, self-regulation, social skills, empathy, and motivation. These programs can include simulations, role-playing exercises, and reflective practices that allow students to experience and navigate the emotional complexities of leadership scenarios. Cultivating emotional intelligence in future mining engineers is not merely an adjunct to their technical training but a fundamental component of their professional development. By integrating emotional intelligence with leadership principles, we can prepare students to become not only competent managers but also inspirational leaders who can navigate the technical and emotional challenges of the mining industry.

## ACKNOWLEDGEMENTS

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# Sourcing research candidates to address current mining challenges

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## INTRODUCTION

Mining industry is undergoing digital and societal transformation at an enormous pace than many other sectors. Being a consortium of fundamental science and engineering, Mining has always leveraged expertise from more traditional disciplines such as earth science, mechanical, electrical, civil, and chemical engineering. However, in the recent past, rapidly emerging areas of automation and data analytics along with increasing concerns and care for the socio environmental aspects of mining has diversified the required skillsets to advance the research. We now increasingly need to understand, embrace, and intelligently integrate interdisciplinarity to address contemporary mining challenges and bring innovations for the future. To this end, it has been necessitated to change our outlook while sourcing for a PhD candidate. However, the challenge remains to identify, assess, and recruit relevant high degree research (HDR) candidates in mining. This presentation outlines success story of the few HDR candidates, with diverse backgrounds, and narrates their recruitments, retentions, and results. As supervisors, we are also evolving to steer their research journey with an art and ability to critically question, filter required information and learn ourselves.

## CURRENT TRENDS IN MINING-RELATED RESEARCH

The current trends in mining-related research are multifaceted, reflecting advancements in various areas such as technology, sustainability, and regulatory frameworks. One of the significant trends is digitalisation, which includes automation, artificial intelligence, machine learning, and the Internet of Things (IoT). This trend is revolutionising mining operations by enhancing safety, productivity, and cost-efficiency. Moreover, there is a growing interest in low-carbon economies from investors and the public sector. This interest underscores the importance of compliance with Environmental, Social, and Governance (ESG) criteria.

Hence, achieving successful outcomes from academic investigations into complex areas of mining necessitates multidisciplinary collaboration. This is evident from recent publications and awarded grants that highlights the importance of collaborative research. For instance, when conducting a search for mining-related research within the years 2020 to 2024 in the Australian Research Council (ARC) grants database, multiple 'non-mining' primary Fields of Research (FoR) found dominant. Interestingly, the 'Discovery' program of ARC that mainly focuses on fundamental research had over 53 per cent (29/54) successful mining related grants with primary FoR belongs to non-traditional mining areas that excludes Resource Engineering and Extractive Metallurgy; Geology or Civil Engineering (Figure 1a). Similarly, over 58 per cent (32/55) successful grants under ARC's applied research 'Linkage' program had primary FoR from areas unrelated to traditional mining (Figure 1b).

These statistics collectively illustrate the importance of attracting and retaining HDR students from relevant non-tradition mining backgrounds and promoting collaborative research to enhance understanding and address contemporary issues efficiently.

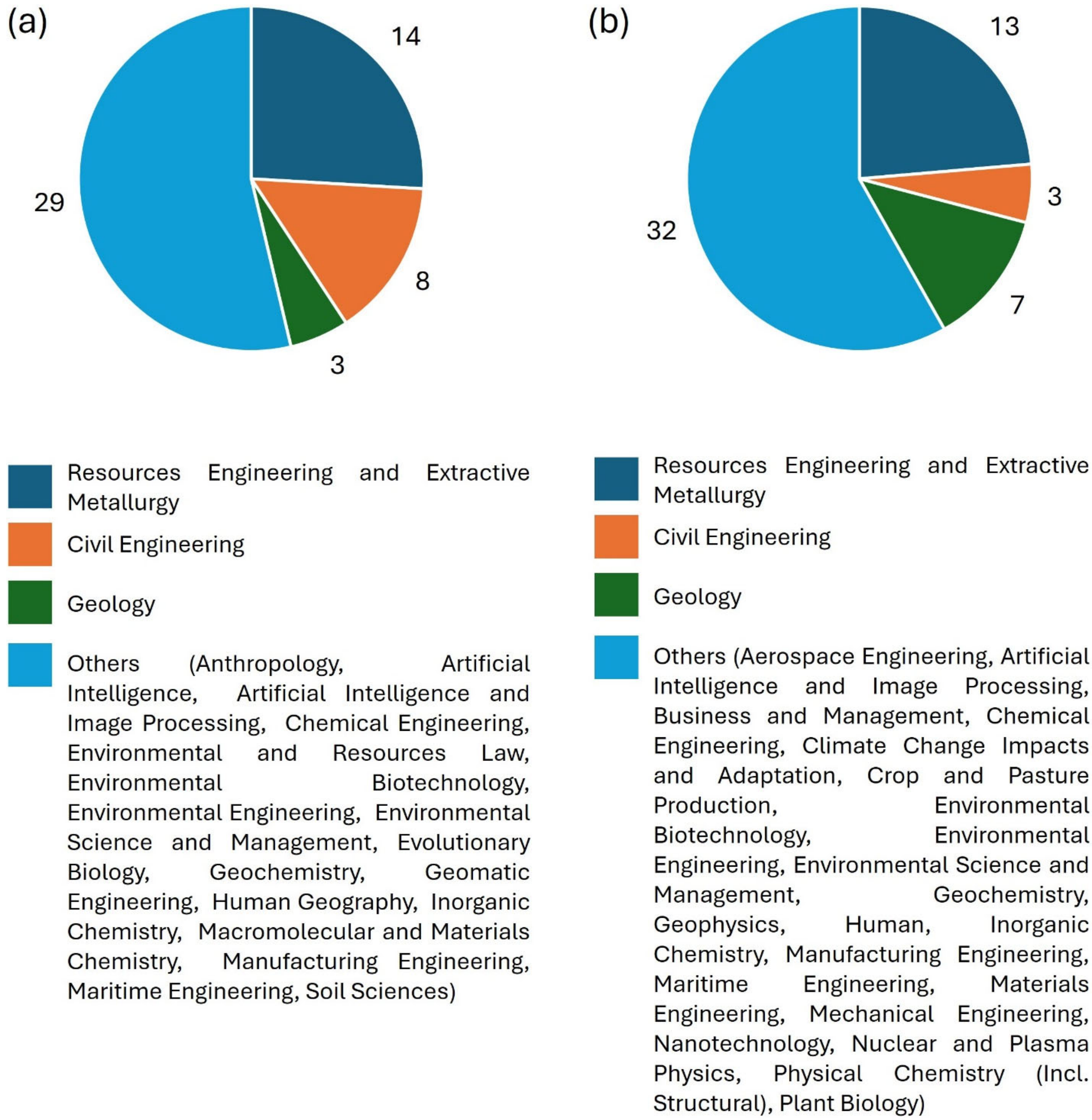


**FIG 1** – The proportion of Australian Research Council (ARC) grants allocated for mining-related research under: (a) the 'Discovery' program, and (b) the 'Linkage' program from 2020 to 2024, along with their primary Fields of Research (FoR).

## RECRUITMENT AND RETENTION STRATEGIES AT INSTITUTIONAL LEVEL

Recruitment and retention strategies of HDR students is a complex process, each with its own set of considerations. Recruitment can be effectively initiated by establishing an inclusive and supportive learning environment. This can be accomplished through sufficient career counselling attuned to diverse needs of students, exposure to role models, and personal motivation. Further, student satisfaction and word-of-mouth play crucial roles in recruitment and retention, emphasising the importance of positive student experiences and feedback. For instance, in the USA, the appeal of graduate programs significantly influences international student enrolment (Herrera, Specking and Ham, 2018).

Further, early intervention is crucial in recruitment and retention efforts. For instance, innovative programs like the Purdue Mission to Mars (PMTM) have successfully engaged high school students in hands-on engineering design experiences, fostering interest in STEM fields (Turner *et al*, 2016). Such strategies could be adapted to attract a diverse range of HDR students to higher studies in mining. The Vertically Integrated Projects (VIP), running at UNSW, is an innovative approach to enhancing higher education by engaging undergraduate and postgraduate students in ambitious, long-term, multidisciplinary project teams that are led by UNSW researchers. UNSW is part of the worldwide Vertically Integrated Projects Consortium (https://www.vip-consortium.org/) spanning 45 universities across 12 countries.

Furthermore, changes within the mining industry and academia, such as the enhancement of policies aimed at recruiting and retaining women and other underrepresented groups, could lead to significant shifts (Lord, Jefferson and Eastham, 2012). The creation of a collaborative mentoring culture, along with the promotion of the field's multidisciplinary potential, could inspire a more diverse group of students to pursue research in mining. This strategy, when combined with job assurance, could improve representation and inclusivity within both the industry and academia.

In conclusion, the process of attracting and retaining HDR students requires a well-rounded strategy that focuses on creating an appealing, supportive, and inclusive environment, offering innovative programs, and effectively mediating between various factors. By implementing such a strategy, institutions can successfully recruit and retain HDR students.

## RECRUITMENT AND RETENTION STRATEGIES AT THE SUPERVISOR LEVEL

To share my experiences, I obtained a consent to present stories of three of my HDR students. These individuals are from varied cultural and academic backgrounds, emphasising the need for a different approach in recruitment, retention and successful completion. The academic disciplines pursued by these students include electronics engineering, geology, and mining engineering. Despite their distinct backgrounds, they each successfully developed new competencies to address the research requirements prevalent within the mining sector, facilitated by a supportive yet challenging academic settings. Their success stories serve as a testament to the significance of the adaptive and supportive learning.

## CONCLUSIONS

The evolving needs of mining practices and societal demands underscore the importance of integrating multidisciplinary HDR students into mining-related research. The adaptive nature of the students presented in this talk, who came from various disciplines, resulted into their successful careers. Tailored supervisory approaches and inclusive institutional environment plays a big role in HDR success stories.

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# Bridging the gap – enhancing accessibility and inclusivity in scientific knowledge-sharing events and networking opportunities

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## INTRODUCTION

Enhancing accessibility and inclusivity in scientific knowledge-sharing events and networking opportunities requires a multifaceted approach that addresses physical, sensory, economic, and social barriers. It is crucial to acknowledge diversity in all its forms, including but not limited to race, colour, religion, gender identity, sexual orientation, national origin, marital status, disability, age, and parental status. While the scientific events often recognise visible aspects of diversity, it tends to overlook the invisible ones. In this context, we present a comprehensive set of accessibility and inclusivity considerations for both physical and online scientific events. We also include case studies that offer valuable insights into best practices.

## PHYSICAL EVENTS

Improving accessibility in in-person events involves addressing physical, social, and cultural barriers to ensure inclusivity for all participants. Understanding the complex needs of individuals with impairments is crucial, requiring collaboration with organisations like 'Attitude is Everything' to translate accessibility laws into practical guidance for event organisers (Chiarelli and Francesco, 2022). Additionally, offering assistance, clear information, and flexibility in event schedules can enhance accessibility, as highlighted in studies on academic conferences for visually impaired individuals (Van Havermaet *et al,* 2023). Implementing a tripartite approach that considers physical, financial, and cognitive accessibility can foster diversity and inclusivity in event organisation. Moreover, virtual conferences have shown to reduce barriers for underrepresented groups, emphasising the importance of diverse perspectives and increased participation in scientific events (Sarabipour, 2020).

## ONLINE EVENTS

Transitioning to virtual conferences has proven to be more inclusive, affordable, and less time-consuming, thereby increasing global accessibility, especially for early-career researchers (Sarabipour, 2020). However, it is crucial to address accessibility barriers on these platforms, particularly for participants with visual disabilities, by ensuring compliance with web content accessibility guidelines (WCAG) and improving features like screen reader navigation (Arias-Flores, Sanchez-Gordon and Calle-Jimenez, 2021). Utilising tools like SPARQL-AG can simplify data querying for non-technical users, making semantic data more accessible and user-friendly (Fathalla, Lange and Auer, 2019). Additionally, adopting a uniform conceptual modelling, such as the Scientific Events Ontology (OR-SEO), can facilitate the management and representation of event metadata, enhancing transparency and interoperability (Fathalla *et al,* 2019b). Promoting diverse and inclusive online spaces, as experienced during the COVID-19 pandemic, can encourage a collegial environment (Bottanelli *et al,* 2020). Furthermore, integrating innovative approaches like 'Guerilla Science' can engage non-traditional audiences by removing participation barriers and designing participant-centred activities (Rosin *et al,* 2023). The success of online scientific events post-pandemic underscores the potential for continued improvement and public engagement through enhanced digital platforms and tools. Finally, organising a variety of open science events, such as talks, podcasts, and summer schools, can cater to different audiences and promote open, transparent, and reproducible science (Fathalla *et al,* 2019a). By implementing these strategies, scientific events can become more accessible, inclusive, and effective in disseminating knowledge and fostering collaboration within the scientific community.

## CASE STUDIES

The Italian National Institute of Urban Planning's Accessible-to-all Cities project exemplifies how networking and sharing best practices can foster inclusive environments by overcoming various barriers, including physical and sensory ones (Chiarelli and Francesco, 2022). In the U.S., extension programs, which are organised educational activities designed to disseminate knowledge and skills to the public, have successfully integrated the principles of inclusion, diversity, equity, and accessibility. These principles have been applied to create accessible urban learning spaces, demonstrating their importance in enhancing the quality of life for participants (Jepsen *et al,* 2022). Geopolitical and economic disparities also impact conference participation, with researchers from low-income countries facing unaffordable costs, highlighting the need for measures to ensure equal access (Doğan *et al,* 2023). Initiatives like the Minority Carriers event at the Photovoltaics Specialists Conference support marginalised researchers and advocate for necessary changes to make research spaces inclusive (McMillon-Brown, 2021). A similar effort is observed in the Society of Mining Professors' 34th Annual General Meeting and Conference, where participants from developing nations, as defined by the OECD, are offered reduced registration fees. However, it is worth noting that the affordability for participants within the same country can also vary. This might require further consideration and increased representation from these nations. Efforts by networks like iEMBER to develop inclusive meetings in biology education research further illustrate the importance of intentional planning to address inclusion markers such as panel composition and affordability (Campbell-Montalvo *et al,* 2020). Understanding the interrelated nature of accessibility, diversity, and inclusion is crucial for designing events that welcome and enable full participation (Finkel and Dashper, 2020). The use of digital tools and open-source technologies in Scientific FabLabs can remove practical barriers and promote the inclusion of scholars with disabilities in scientific research (Canessa and Fonda, 2023). However, accessibility barriers in online platforms, such as those identified in teleconferencing tools, must be addressed to ensure visually impaired participants can fully engage in virtual scientific conferences (Arias-Flores, Sanchez-Gordon and Calle-Jimenez*,* 2021).

## CONCLUSION

In conclusion, implementing appropriate measures can ensure that scientific community events are accessible and inclusive, promoting knowledge sharing and networking opportunities for all participants, regardless of their background or abilities. This improves the overall experience of the participants and contributes to the advancement of science and technology. It is a step towards creating a scientific community that values and benefits from diversity and inclusion.

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# Research development and industry

# Experiences from developing a road map to attractive, inclusive and safe mining workplaces

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## ABSTRACT

The aim with this paper is to discuss experiences from the ongoing research project *Attract: A roadmap to attractive, inclusive, and safe mining workplaces*. This is a research project (2022–2025) at Human Work Science at Luleå University of Technology financed by the strategic innovation program Swedish Mining Innovation (a joint venture by the national research funds Vinnova, Formas and the Swedish Energy Agency). The project's aim is to analyse possibilities, effects, and consequences of the green and digital transformation in the Swedish mining industry from workplace, socio-technical and gender equality perspectives.

The project includes a multidisciplinary research group of five senior researchers and five PhD-students and a broad repertoire of methods, eg literature reviews, qualitative interviews with both managers and workers, workplace observations, workshops, surveys, and project seminars where the researchers and the company representatives together analyse the results. One important part of the project is the applied approach where the researchers work together with two mining companies and one subcontractor company. The project has two parallel main subprojects. The first one, *The digital and green miner*, is exploring how the implementation of autonomous technology will change the work for the miners and also what the mining work of the future will mean for workplace learning, competence development, and the possibilities to build attractive workplaces? The second one, *GenSafe*, is studying what prerequisites is needed in the workplace culture at multi-employer mine sites to develop a safe and inclusive mining culture.

The preliminary results show that new complex situations are emerging in the mining industry's work with electrification, circular material flows, digitalisation, and automation. Both the new technologies as well as the use of them affect and are affected by people and workplaces and the organisation of work, safety and learning. To support the functionality of the green and digital technology and at the same time develop inclusive, attractive, and safe workplaces there is a need of research that places people (all types of women and men) in the centre of technological development.

# Forecasting of methane gas concentrations in underground coalmines using univariate and multivariate modelling

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## ABSTRACT

Methane gas is emitted during underground coal mining operations. This is considered a significant threat to underground coalmine operations as, over the years, many miners have lost their lives due to explosions fuelled by hazardous concentrations of methane gas in underground coalmines worldwide. Nevertheless, as the world continues to depend on coal to meet critical energy needs, it is important to be able to forecast how methane emissions fluctuate in an underground production environment.

Previous work by the authors introduced a new forecasting approach for methane gas emissions in underground coalmines, utilising univariate and multivariate time series forecasting methods. The multivariate methods incorporate barometric pressure as a predictor of gas concentration. Data for this study were collected from the Atmospheric Monitoring Systems of three active underground coalmines in the eastern USA, and the performance of three time series methods (the univariate autoregressive integrated moving average (ARIMA), the multivariate vector autoregressive (VAR), and ARIMA with exogenous inputs (ARIMAX)) as applied to a number of daily average and 12 hr average data sets.

The work presented in this paper builds on previous work and presents an approach to deal with the non-stationarity and heteroskedasticity (temporal evolution of the variance) of the methane gas concentration time series. The ARIMA-GARCH model was implemented for forecasting. In this model, the GARCH (Generalized AutoRegressive Conditional Heteroskedasticity) equations account for the temporal evolution of the variance. In addition, it is shown that forecasts improve when model estimation is based on shorter segments of the data.

## INTRODUCTION

As coal is mined, trapped methane gas ($CH_4$) is released (Byrer, Havryluk and Uhrin*,* 2014; Flores, 1998). Methane is a potent greenhouse gas, making emissions from active, closed, and abandoned underground coalmines a significant environmental concern (US EPA, 2024). Moreover, developing accurate methods for measuring methane emissions has been recognised as a global challenge (IEF, 2024). Methane gas concentrations between 5 and 15 per cent can form explosive mixtures, leading to catastrophic accidents in underground coalmines (Kissell, 2006; NIOSH, 2020).

Hence, monitoring and managing $CH_4$ is crucial for personnel safety (Agioutantis *et al,* 2014; Diaz *et al,* 2021a, 2021b). The ability to model and forecast methane gas concentration is essential in this effort. Additionally, accurate measurements and models can be used to improve estimates of the environmental impacts of coalmine operations.

Different methane gas concentration forecast models exist in the literature, based on empirical, numerical, and statistical approaches (Diaz *et al,* 2023). Previous work by the authors introduced a new forecasting approach for methane gas emissions in underground coalmines, utilising univariate and multivariate time series forecasting methods (Diaz *et al*, 2022, 2023). The multivariate methods incorporate barometric pressure as a predictor of gas concentration. Data for this study were collected from the Atmospheric Monitoring Systems of three active underground coalmines in the eastern USA. Diaz *et al* (2023) compared and critically evaluated the performance of three time series methods (the univariate autoregressive integrated moving average (ARIMA), the multivariate vector autoregressive (VAR), and ARIMA with exogenous inputs (ARIMAX)) as applied to a number of daily average and 12 hr average data sets. The optimal model for each method was selected based on the Akaike Information Criterion and forecasting performance was assessed using cross-validation to determine the best overall model. It was concluded that all three methods can, in most cases, satisfactorily predict methane gas concentrations at exhaust shaft locations ventilating underground coalmines.

The work presented in this paper builds on previous work and presents an approach to deal with the non-stationarity and the heteroskedasticity (temporal evolution of the variance) of the methane gas concentration time series. In particular, it is shown that forecasts improve when model estimation is based on shorter segments of the data. In addition, the ARIMA-GARCH model was implemented for forecasting in which the GARCH (Generalized AutoRegressive Conditional Heteroskedasticity) equations account for the temporal evolution of the variance.

## MATERIALS AND METHODS

One of the key issues for a successful analysis of Time series data is to ensure that the time series are representative of the quantity monitored. In addition, time series data originating from different sources, eg custom monitoring systems, web-based interfaces, public domain, data sets etc, need to be filtered, homogenised, and reduced to data that correspond to the same date and time values.

As this was recognised early on in time series research, the authors built a custom database system which was initially presented by Agioutantis *et al* (2014) and which was subsequently enhanced with features necessary for this analysis.

The atmospheric management system (AMANDA) is capable of managing large quantities of raw data in a relational database environment managed by a Windows front end. Data are stored as received and then data sets with specific attributes can be generated. For example, barometric pressure data sets available in public weather stations may be collected at hourly intervals. However, these intervals are approximate and do not always correspond to a known time value, such as 1:00 pm, 2:00 pm etc. AMANDA can utilise the primary raw data and generate daily average data sets or data sets for 12 hr or 6 hr intervals for all variables in a project. These can include variables such as barometric pressure, temperature, methane concentration etc. This process has two advantages: a) it will create data sets with similar time stamps, eg daily average data sets that will have a time stamp of midnight every day or 12 hr data sets that will have timestamps of midnight and 12 noon every day; and b) it will facilitate the cross-correlation of the different time series data sets and the generation of statistics for each data set.

The AMANDA environment is instrumental in managing raw and filtered/processed data sets. Data sets are then exported as Excel or CSV files and subsequently processed in MATLAB that provides libraries (toolboxes) that can easily run the above mentioned forecast models.

The chart presented in Figure 1 compares the actual methane concentration measurements over a period of 30 days to the daily averages over the same period that were generated by AMANDA. Measurements were taken at one of the exhaust shafts of an operating longwall mine in the eastern USA. It is evident that the variability of daily average values is much less than the variability of the raw data. Figure 2 presents a comparison between a 12 hr methane concentration time series data set and a daily average methane concentration time series data set for a period of 180 days. As before, the daily average data set presents a lower volatility than the 12 hr average data set, while preserving the trend of the time series data; however, spikes within 12 hr intervals are sometimes eliminated. Previous work by the authors (Diaz *et al,* 2022*,* 2023) identified that the 12 hr average data sets provide better predictors than the daily average data sets. Figure 3 shows a comparison similar to that presented in Figure 1, and it pertains to 30 days of barometric pressure data. As before the daily average data sets curb the volatility of the approximately hourly barometric pressure measurements. The barometric pressure data presented in Figure 3 were downloaded from a nearby public weather station and are presented in inches of water gauge (inWG).

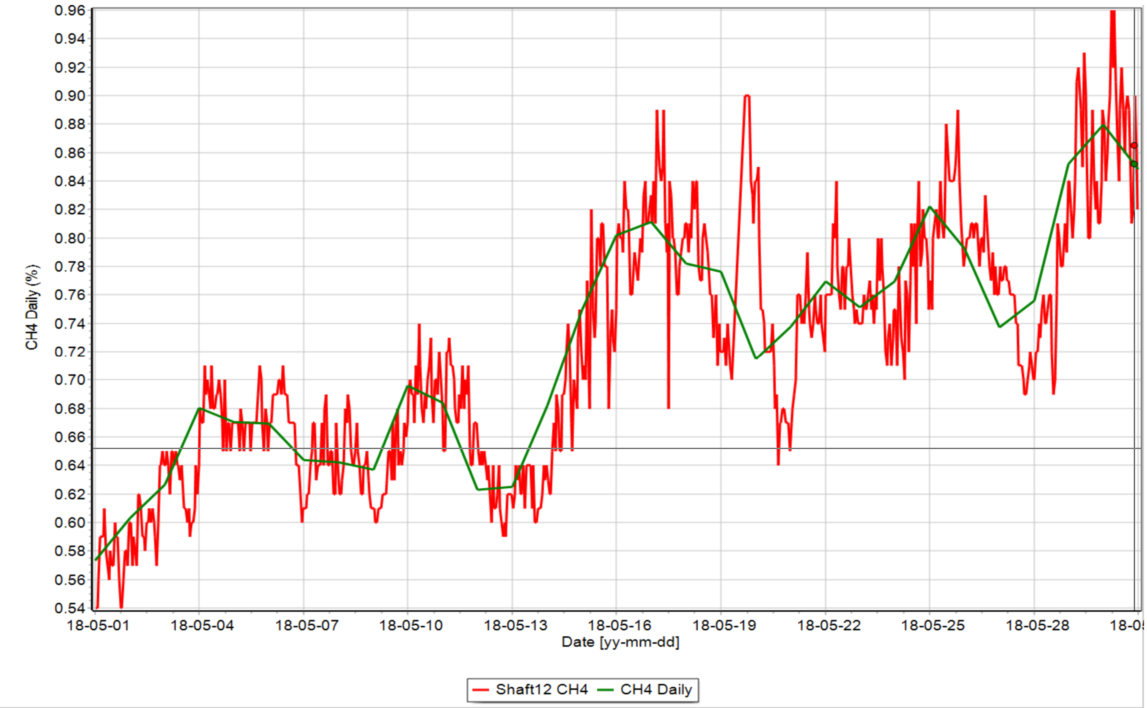


**FIG 1** – Comparison of raw methane measurements and daily averages for a 30 day time period.

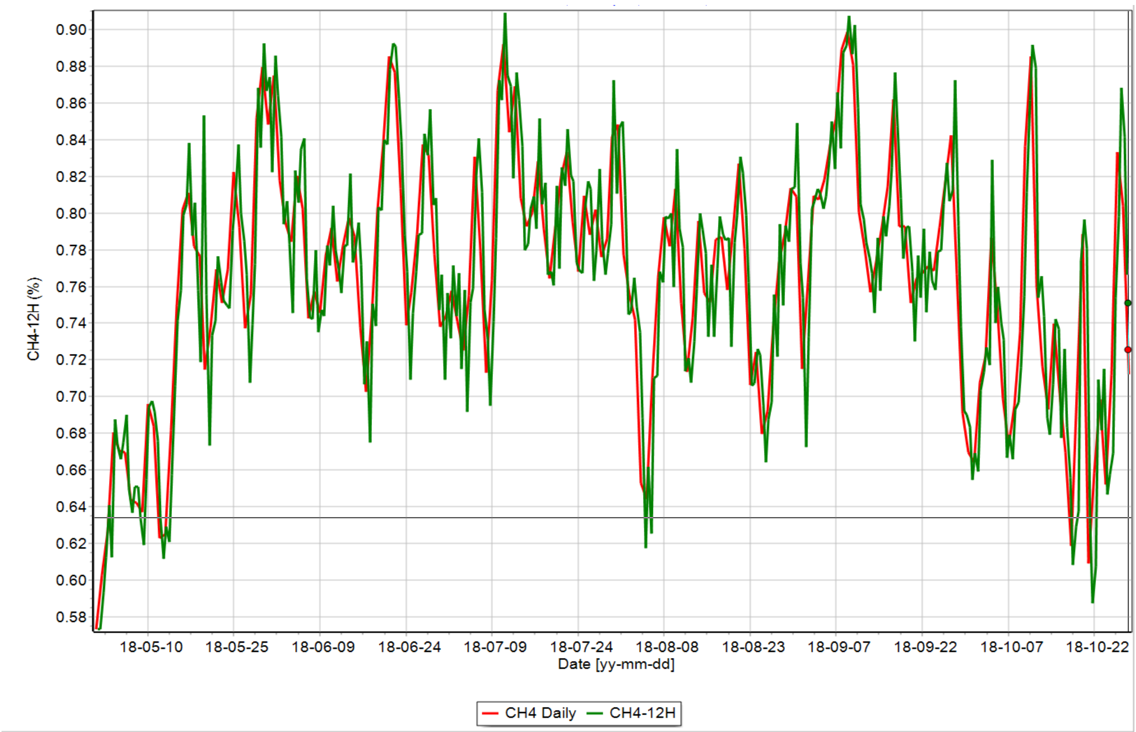


**FIG 2** – Comparison of 12 hr average and daily average time series data for methane concentration for a 180 day time period.

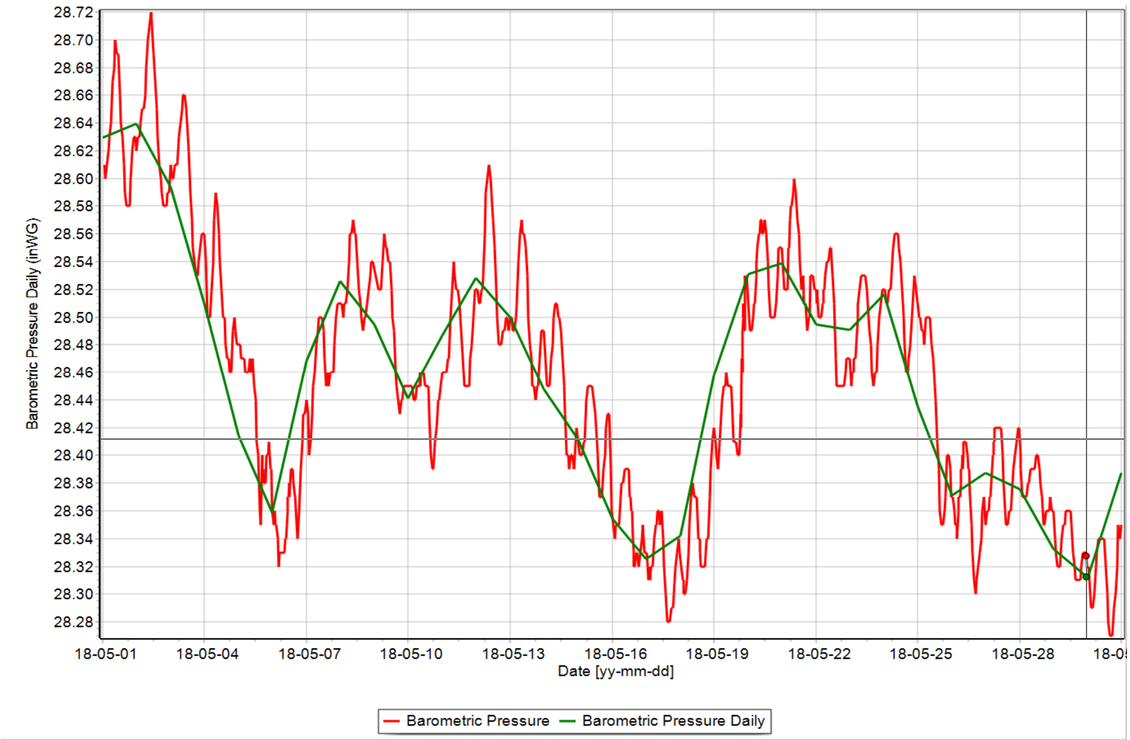


**FIG 3** – Comparison of barometric pressure measurements and a daily average time series for a 30 day time period.

It should be emphasised that the development of representative and complete data sets is pivotal to obtaining accurate forecasts of measured variables. Furthermore, it should be noted that the authors have utilised the same database environment (AMANDA) and its capabilities to successfully filter and process time series data for non-mining projects, such as the percent of pollutants in streams, the percent of gases or vapours in industrial environments etc.

Figure 4 shows a plot of a daily average barometric pressure time series and the corresponding daily average methane concentrations for a period of 30 days for the same underground coalmine in the eastern USA. The Pearson correlation coefficient calculated to examine the relationship between these two data sets is -0.7. The negative correlation coefficient indicates that a local peak in methane concentration will correspond to a local valley in barometric pressure and *vice versa*. This is depicted in multiple instances in Figure 4 where low barometric pressure corresponds to a peak in the measured methane concentration at the exhaust shaft. A correlation coefficient of -0.7 is pretty significant, and thus, barometric pressure was selected as the exogenous or auxiliary variable for the ARIMAX models, as presented by Diaz *et al* (2023).

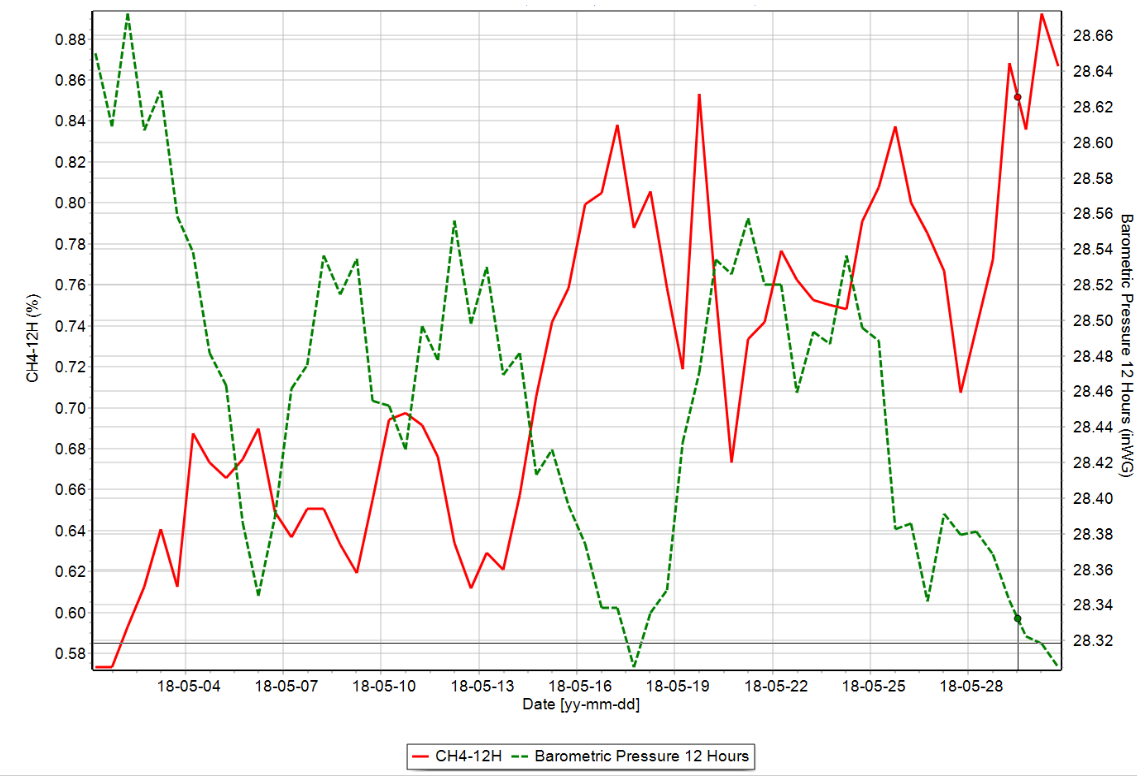


**FIG 4** – Correlation of a daily average methane concentration time series to a daily average barometric pressure time series for 30 days.

## TIME SERIES ANALYSIS METHODS

In previous studies (Diaz *et al,* 2023), the authors used the autoregressive integrated moving average (ARIMA) model to forecast the concentration of methane based on time series data. The ARIMA model allows for non-stationarities, such as stochastic trends or random-walk processes. Such non-stationarities can be handled by taking differences of the time series, as is done in the framework of ARIMA models. A different type of non-stationarity involves the temporal evolution of the variance, a phenomenon known as heteroskedasticity. This is clearly evidenced in Figure 5a, which displays fluctuations of significantly larger amplitude at the beginning than near the end of the time series. Such behaviour is better understood in terms of Figure 5b, which shows the evolution of the variance, calculated over a window of size L (where L=150, 300, 450). As expected, all three plots show an evolution of the variance over time thus motivating the need to model heteroskedasticity.

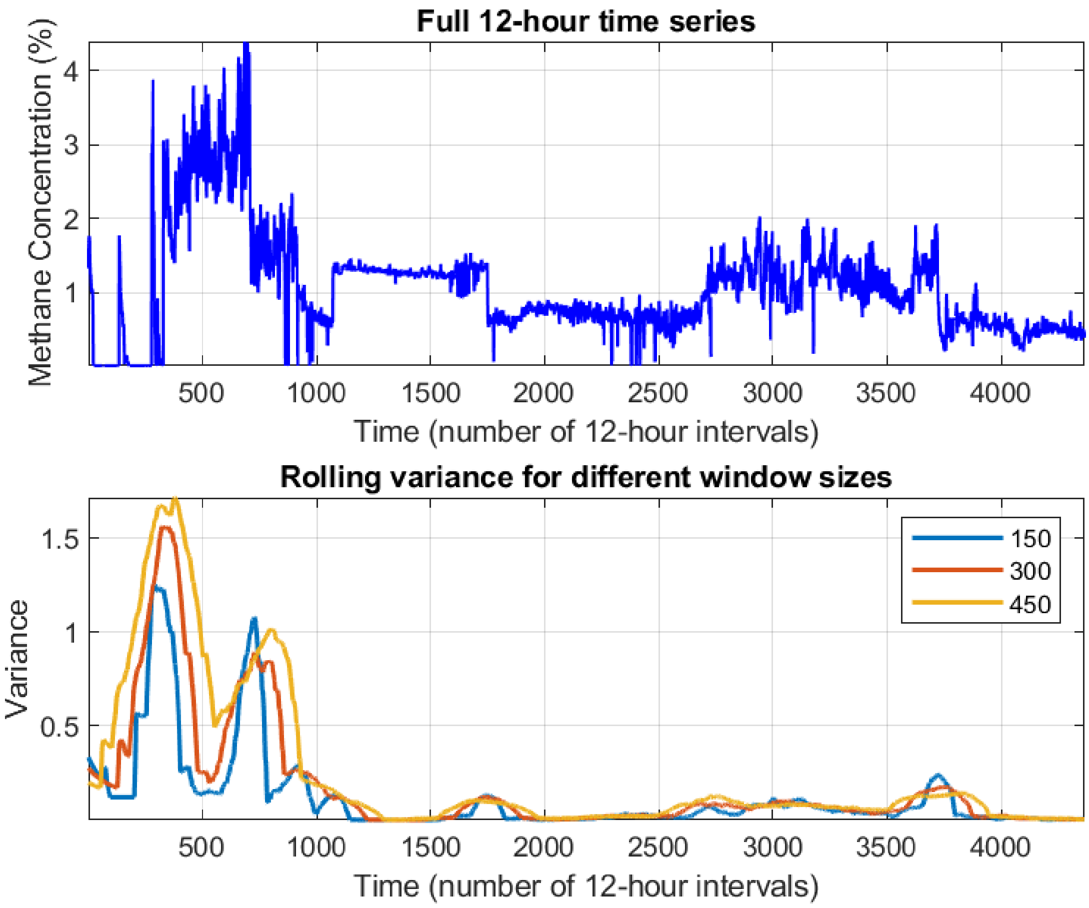


**FIG 5** – (a) Time series of methane concentrations for about 4380 12 hr intervals; (b) variance evolution for methane concentrations calculated for different time windows.

A static approach for handling heteroskedasticity involves the application of nonlinear transforms, such as the logarithm or, more generally, the power-law Box-Cox transform, which can reduce variations in the variance. A different approach is the so-called GARCH model. The latter involves autoregressive equations for the innovation variance, which relate the conditional variance at time *t,* to the variance at the previous time step, *t*-1, but also to the square of the process values at *t*-1. These equations can model dynamic variations of the variance.

The ARIMA(p,d,q) model is equivalent to an ARMA(p,q) model, applied to the difference of order d of the original time series. Taking differences does not introduce additional parameters in the model. For a specific set (p,d,q), constrained maximum likelihood is used to estimate the respective parameter values. The procedure is repeated for all (p,d,q) sets considered. The optimal model is determined using a model selection criterion (such as AIC or Bayesian information criterion). The ARMA model acting on the differences $x_t = y_t - y_{t-1}$ of the time series $y_t$ has the following form:

$$x_t = \varphi_0 + \varphi_1 x_{t-1} + \varphi_2 x_{t-2} + \cdots \varphi_p x_{t-p} + \varepsilon_t + \theta_1 \varepsilon_{t-1} + \theta_2 \varepsilon_{t-2} + \cdots \theta_q \varepsilon_{t-q},$$

where $\phi_i$, i=1, …, p are the autoregressive coefficients, and $\theta_j$, j=1, …, q are the moving average coefficients, while $\varepsilon_t$ is the so-called innovation process. The latter is a Gaussian white noise with zero mean and a time-dependent variance $\sigma_t^2$ that obeys the GARCH(1,1) equation, ie:

$$\sigma_t^2 = c_0 + \alpha_1 \sigma_{t-1}^2 + \beta_1 x_{t-1}^2$$

Hence, the parameters of the ARIMA(p,d,q)-GARCH(1,1) model include the set of the AR and MA coefficients for the ARIMA model and the three parameters $c_0, \alpha_1, \beta_1$, that determine the evolution of the variance.

Figures 6 to 8 represent forecasts of methane concentration based on 1000 points, of which 950 are used for training the model and 50 for model assessment via cross-validation measures. The shaded regions correspond to the 95 per cent prediction intervals. Three different models are used:

- The ARIMA-GARCH model treats heteroskedasticity by means of GARCH variance evolution. The forecasts are shown in Figure 6, and they are in good agreement with the true values.
- The ARIMA model addresses heteroskedasticity by means of the logarithmic transform of the concentration (hence, the ARIMA model is applied to the concentration logarithms). Figure 7 shows the concentration forecasts, which are obtained by inverting the forecasted logarithms. Again, the agreement is very good.
- Finally, the ARIMA-GARCH model is applied to the logarithms of the data. The forecasts are compared to the true values in Figure 8. The concentration forecasts are obtained by taking the exponential of the logarithmic forecasts.

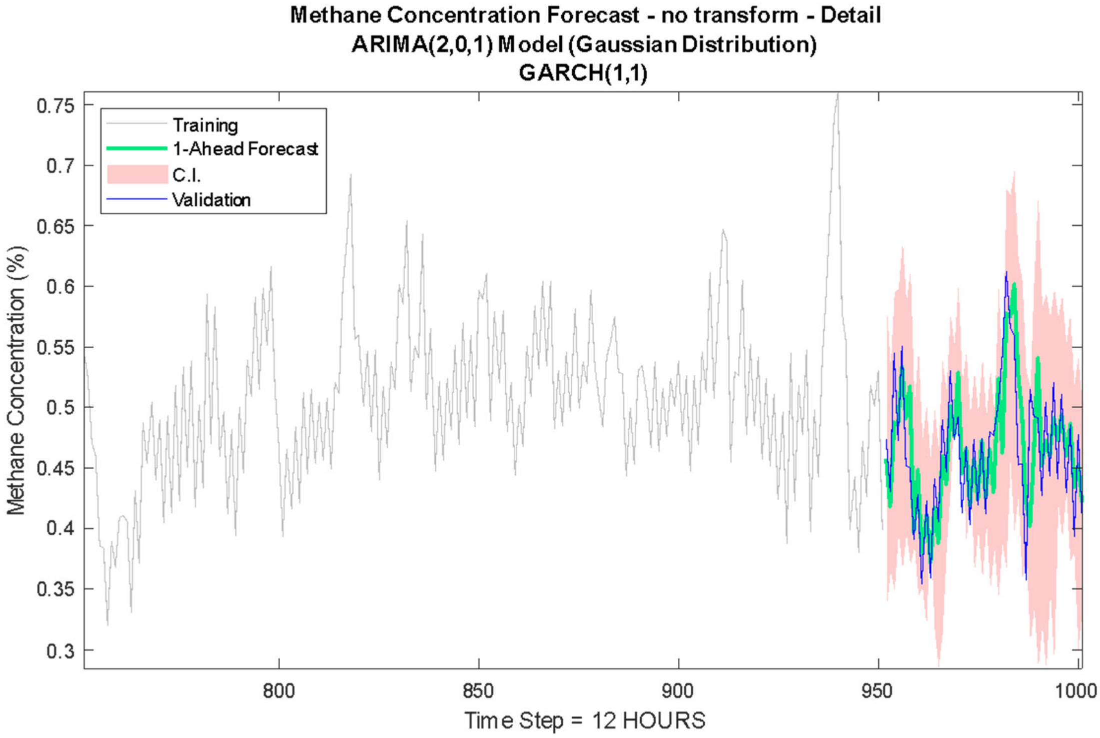


**FIG 6** – One-step-ahead methane concentration forecasts based on 12 hr averages for the last 1000 points of the time series using an ARIMA-GARCH model without transformation.

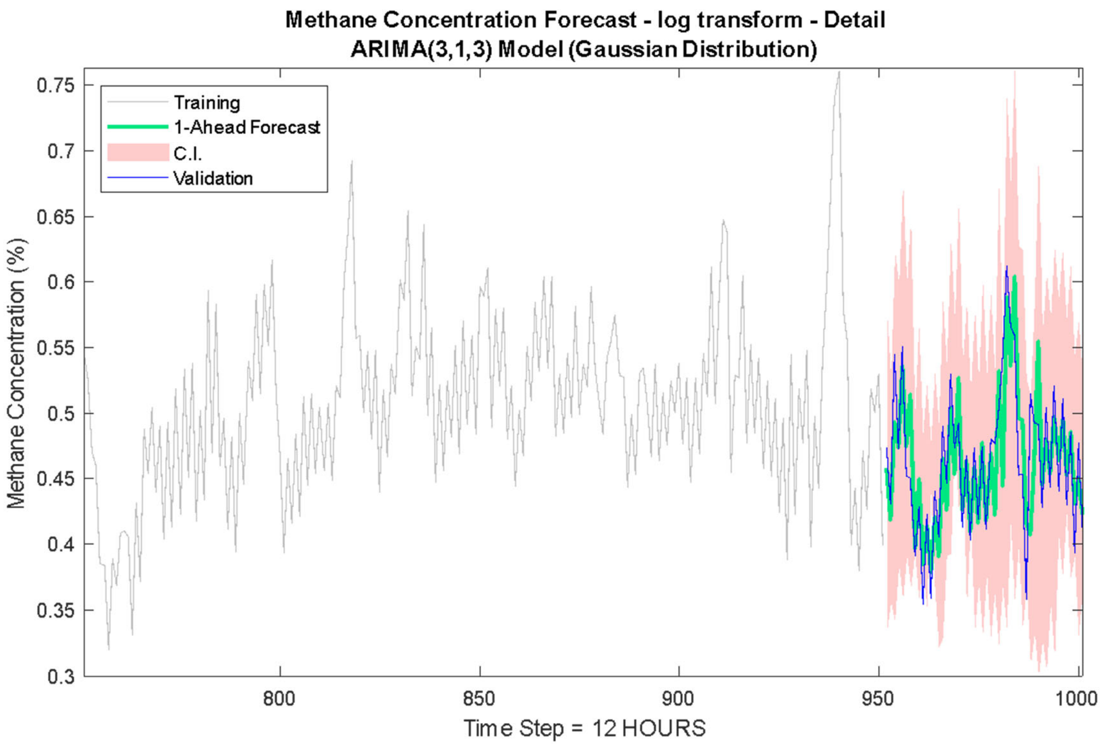


**FIG 7** – One-step-ahead methane concentration forecasts based on 12 hr averages for the last 1000 points of the time series using an ARIMA model with a logarithmic transformation.

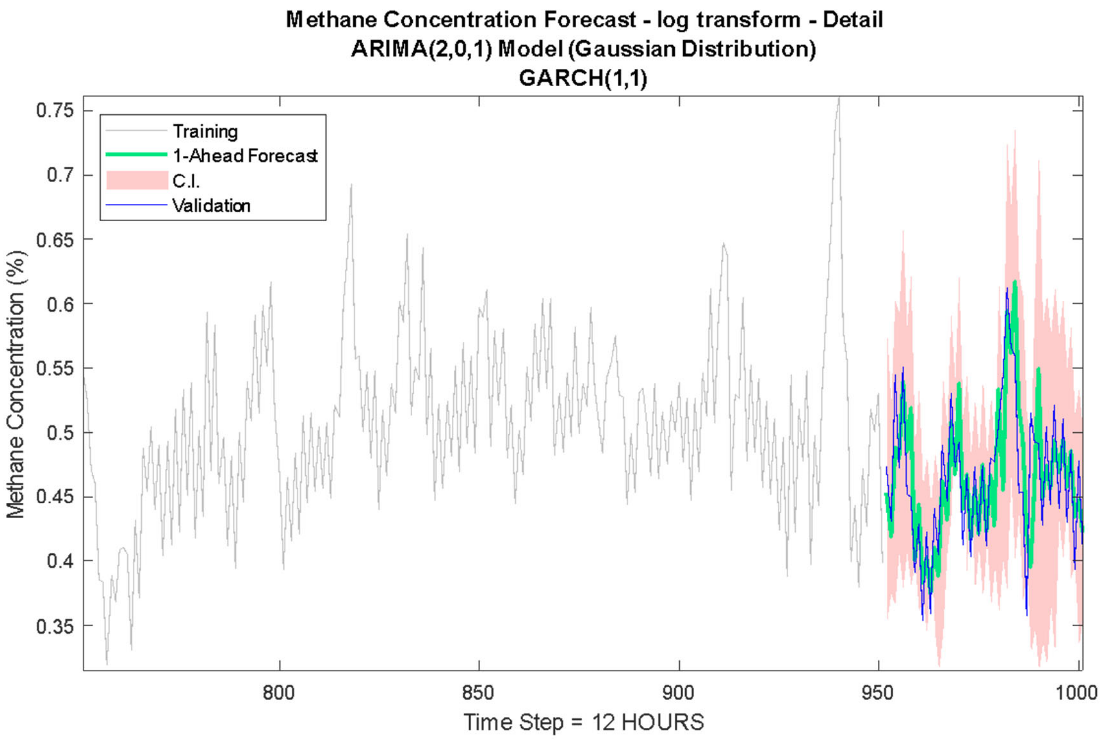


**FIG 8** – One-step-ahead methane concentration forecasts based on 12 hr averages for the last 1000 points of the time series using an ARIMA-GARCH model with a logarithmic transformation.

In order to have a basis for comparison, the cross-validation statistics obtained for the same time series studied by Diaz *et al* (2023) are presented in Table 1. The statistics include the mean error (ME), mean absolute error (MAE), root mean square error (RMSE), Pearson correlation coefficient, and the Nash-Sutcliffe efficiency (NS). The time series includes 4380 points that represent average concentrations for 12 hr intervals. The training set involves 95 per cent of the data points while the validation set involves 5 per cent of the data set, ie a total of 219 validation points. The models used, ARIMA, VAR(p), and ARIMAX, involve both univariate, ARIMA, and multivariate, VAR(p) and ARIMAX models. These time series models that were investigated by Diaz *et al* (2023) do not involve modelling of the heteroskedasticity.

**TABLE 1**

Cross-validation statistics for 1-step-ahead forecasts for univariate (ARIMA) and multivariate, VAR(p), ARIMAX, approaches utilising the entire data set of 4400 12 hr data points as given by Diaz *et al* (2023).

| Model | Model order (p,d,q) | RMSE | ME | MAE | R |
|---|---|---|---|---|---|
| Univariate (ARIMA) | (4, 1, 4) | 0.05 | 0.00 | 0.04 | 0.71 |
| Multivariate (VAR(p)) | (30, 0, 0) | 0.05 | –0.01 | 0.05 | 0.66 |
| Multivariate (ARIMAX) | (29, 0, 0) | 0.05 | –0.01 | 0.04 | 0.68 |

The performance of the three heteroskedastic models discussed above is assessed by means of the cross-validation statistics listed in Table 2. The same statistics as Table 1 are used (ie the mean error, the mean absolute error, the root mean square error, and the Pearson correlation coefficient) as well as the Nash-Sutcliffe efficiency (NS).

**TABLE 2**

Cross-validation statistics for 1 step ahead forecasts.

| Model | RMSE | ME | MAE | R | NS |
|---|---|---|---|---|---|
| ARIMA-GARCH without transformation | 0.04 | –0.001 | 0.03 | 0.77 | 0.58 |
| ARIMA using a log transformation | 0.036 | 0.001 | 0.03 | 0.79 | 0.61 |
| ARIMA-GARCH using a log transformation | 0.04 | –0.001 | 0.031 | 0.77 | 0.55 |

The statistics of the second and third models are based on the estimated concentrations obtained by inverting the logarithmic transform. Overall, the ARIMA model coupled with the logarithmic transform gives better cross-validation statistics with the exception of the ME, for which the lowest magnitude is obtained by means of the ARIMA-GARCH model applied to the logarithm of the data. Note that the statistics for all three models are quite close. In addition, the cross-validation statistics of all three models are superior to the respective ones in Table 1. This is due in part to the modelling of the heteroskedasticity and partly due to the fact that a shorter time series is used for training; hence, the models are trained over a segment of the data, which contains values more similar to those in the validation period. Another difference between the two sets of models is that the heteroskedastic models use a shorter validation set, which contains 50 points, in contrast with the models from Diaz *et al* (2023), which are validated using 219 points (in both cases, the validation period includes 5 per cent of the time series used for training and validation).

## CONCLUSIONS

Forecasting methane concentrations at underground coal operations can provide valuable insights into managing safe operations and preventing the buildup of methane gas underground.

This research expands on the results presented by Diaz *et al* (2023) and discusses the performance of three heteroskedastic models, ie an ARIMA-GARCH model without transformation, an ARIMA model using a logarithmic transformation and an ARIMA-GARCH model with a logarithmic transformation. The models are assessed by means of cross-validation statistics that include the mean error, the mean absolute error, the root mean square error, the Pearson correlation coefficient, and the Nash-Sutcliffe efficiency. The heteroskedastic models were applied on shorted data sets (ie the last 1000 12 hr averages or data for 500 days instead of modelling the entire data set of about

2200 days). In addition, the ARIMA-GARCH model was applied using Gaussian innovations. This restriction can be relaxed in future studies.

Although the statistics for all three models are quite close, the ARIMA model using the logarithmic transform gives better overall cross-validation performance with the exception of the ME, for which the lowest magnitude is obtained by means of the ARIMA-GARCH model applied to the logarithm of the data. In addition, the cross-validation statistics of all three heteroskedastic models are superior to the univariate and multivariate models (without heteroskedasticity modelling) that were presented by Diaz *et al* (2023).

This is partly due to the modelling of the heteroskedasticity and partly due to the fact that a shorter time series is used for training as the models are based on training data over a period, which contains values more similar to those in the validation period.

Th inclusion of heteroscedasticity modelling as well as the use of a rolling window of reduced length (instead of the entire time series) for training the model look promising and will be further explored in future work.

## ACKNOWLEDGEMENTS

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# Reviewing technological developments impact in implementation of synergistic energy solutions around the world

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## ABSTRACT

After the Industrial Revolution, the adverse effects of industrialisation on climate and the environment have garnered global attention and raised concerns among researchers, governments, and various stakeholders. The transition to renewable energies (REs) has been identified as the primary strategy to address this global issue. However, policymakers do not have frameworks that can assist them in deciding what synergies, between different energy generation sources, exist and whether they are viable and sustainable over the longer term. This lack of credible decision-making frameworks may be hindering progress in this area. This study aims to develop a PESTLE based framework, encompassing political, economic, social, technical, legal, and environmental aspects, for understanding the driving forces behind the transition to REs. PESTLE aspects are further divided into 39 sub-factors.

In this study, the most pertinent peer-reviewed journal articles in English were systematically selected using PRISMA method. Additionally, selected energy transition policies published by the International Energy Agency (IEA) were also analysed to understand the enabling mechanisms of energy transition around the world.

Overall, the technological aspect has been consistently found to be effective in energy transition in both literature and policies. The 'Technological Development' sub-factor is particularly prominent in both sources. Additionally, the most effective sub-factors for the Political, Legal, and Environmental aspects are similar between the literature review and the selected IEA policies. However, there are differences in the most effective sub-factors for the Economic and Social aspects, with IEA policies focusing more on improving policies and legislations. It is important to acknowledge that the purpose of the study can influence the emphasis on different aspects and sub-factors in energy transition research and policy development.

## INTRODUCTION

Energy is a fundamental requirement for fulfilling the daily needs of humans. With the continuous growth of the global population and improved living standards, there is an upward pressure on the demand for energy (Owusu and Asumadu-Sarkodie, 2016). According to the United Nations' 2019 projections, the world's population is expected to reach 10.3 billion by 2100, up from eight billion in 2022 (United Nations, 2022). This exponential population growth will inevitably lead to an increased energy demand.

Currently, the primary source of meeting this energy demand is derived from fossil fuels. In Australia, 79 per cent of the electricity generation was provided from hydrocarbons in 2019 (Department of Industry, Science, Energy and Resources, 2020). However, the combustion of fossil fuels contributes significantly to greenhouse gas (GHG) emissions, resulting in the accumulation of heat around the Earth's surface and subsequent temperature rise (USGS, 2021). To provide a comparison, the carbon intensity of coal is approximately 820 g $CO_2$/kWh, oil is around 800 g $CO_2$/kWh, and natural gas emits about 490 g $CO_2$/kWh. In contrast, nuclear power, hydroelectric power, wind energy, and solar systems all produce less than 50 g $CO_2$/kWh (IPCC, 2022). These higher temperatures have far-reaching impacts, including the melting of glaciers, submergence of low-lying areas, disruptions to ecosystems, droughts, challenges in water and food supply, economic complexities, forced migrations, severe storms, and alterations to the habitats of plants and animals (USGS, 2021). It is evident that such consequences pose significant challenges to the planet and its inhabitants.

Renewable energies (REs) are widely recognised as the most recommended approach for reducing emissions, despite their unique advantages and challenges (de Best-Waldhober, Brunsting and Paukovic, 2012; Howard, Stephen and Paul, 2009). To provide a comparison, the carbon intensity of coal is approximately 820 g $CO_2$/kWh, oil is around 800 g $CO_2$/kWh, and natural gas emits about 490 g $CO_2$/kWh. In contrast, nuclear power, hydroelectric power, wind energy, and solar systems all produce less than 50 g $CO_2$/kWh (IPCC, 2022).

When comparing renewable energies, solar energy has several advantages. It is not only a cost-effective and abundant renewable energy source in Australia, but it is also relatively easy to install and requires minimal maintenance (C2ES, 2020). Solar energy systems can be deployed in remote locations, making it accessible to areas that may not have access to traditional energy infrastructure. Additionally, solar energy can be utilised for various purposes, further enhancing its versatility and applicability (Blakers, Lu and Stocks, 2017).

Despite the numerous benefits of REs, it is important to acknowledge that they also have certain drawbacks, including concerns about reliability, cost, and government support (Owusu and Asumadu-Sarkodie, 2016; Johnston, 2019). These drawbacks need to be considered for feasibility study and implementation of REs.

On the other hand, natural gas has gained significant attention as part of the transition to a cleaner future due to its relatively lower $CO_2$ emissions compared to other fossil fuels. Natural gas offers several advantages, such as high energy content, reliability, adherence to high safety standards, and comparatively lower operational costs (US Energy Information Administration, 2019; Ainouche, 2006). Moreover, the infrastructure and technologies required for storing, transporting, and utilising natural gas already exist (Ainouche, 2006). Its versatile nature allows for its use in various sectors including cooking, heating, electricity generation, manufacturing, and transportation (Lee, Zinaman and Logan, 2012).

Integration of natural gas and solar energy can enhance the benefits of both technologies and potentially mitigate their limitations (Lee, Zinaman and Logan, 2012). This integration allows for a complementary relationship where natural gas can serve as a backup for intermittent renewable energy sources until more advanced storage systems become widely available (Lee, Zinaman and Logan, 2012).

In this research, a comprehensive study utilising the PESTLE (Political, Environment, Social, Technical, Legal, and Economic) framework is developed to identify and analyse the various factors that will impact the transition towards emissions reduction in the energy supply system. The framework allows for a holistic assessment of the political, environmental, social, technical, legal, and economic aspects that influence the integration of natural gas and solar PV technologies.

The findings derived from the PESTLE analysis will provide valuable insights and information to policymakers for decision-making process. It will inform the development of policies and plans aimed at attracting investments in these technologies. Additionally, the study will provide evidence that can be used to address scepticism and concerns from the public and other stakeholders regarding the potential benefits and feasibility of this integration.

This research also seeks to contribute to the advancement of knowledge in the field and support the development of sustainable energy strategies that prioritise emissions reduction while ensuring a constant and efficient energy supply system, and to figure out the PESTLE factors that are driving actions to reduce the $CO_2$ emissions in electricity sectors globally.

## METHODOLOGY

### Sample description for systematic review

The objective of the literature review is to systematically identify the most pertinent peer-reviewed journal articles, exclusively focusing on papers published in English. Additionally, energy transition policies published by the International Energy Agency (IEA) are also considered. To achieve this goal, the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) framework is employed to categorise the selected papers and documents (refer to Figure 1). PRISMA is a set of evidence-based reporting guidelines designed for systematic reviews, enabling the evaluation and comprehensive reporting of research findings (Page *et al*, 2020).

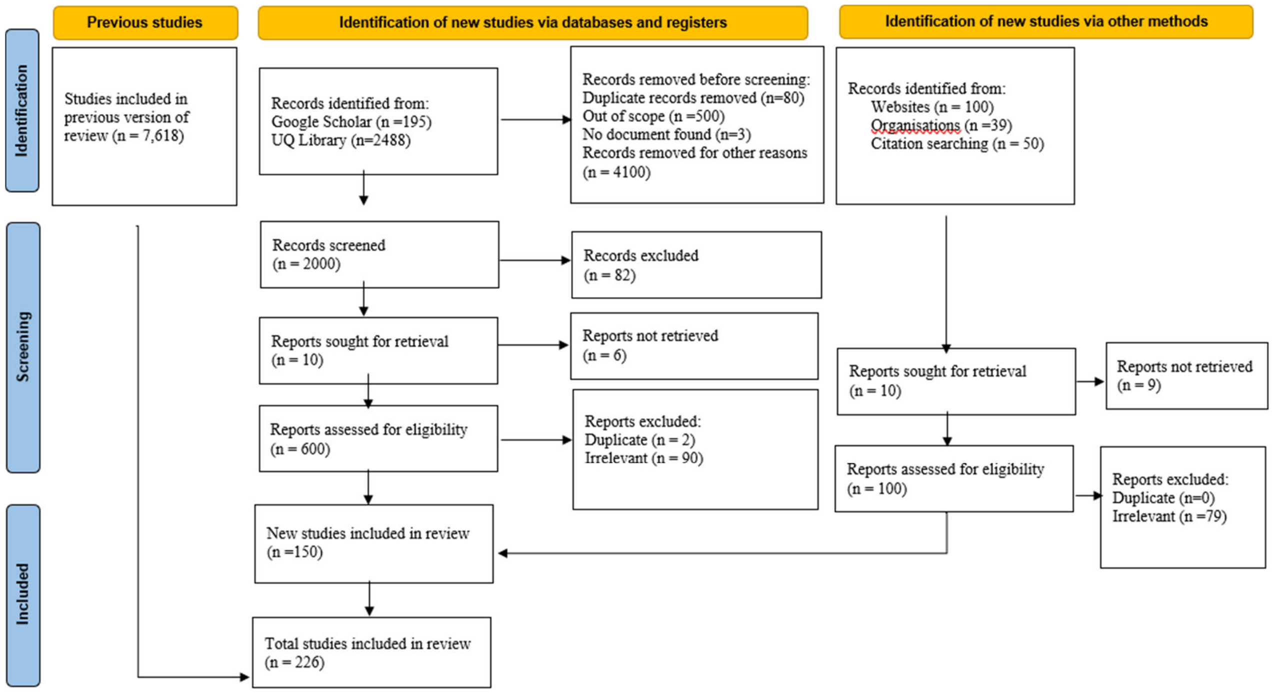



**FIG 1** – PRISMA 2020 flow diagram for new systematic reviews which included searches of databases, registers and other sources (Page *et al*, 2020).

The initial search commenced in 2019, using Google Scholar and The University of Queensland library, which grant access to reputable databases such as Scopus, Web of Science, and Science Direct. These databases offer comprehensive coverage of a wide range of articles. The search focused on published articles from January 2010 up to the present, as REs' policies and technologies undergo frequent updates. Generally, publications prior to 2010 were excluded. However, 13 studies published before 2010 were included due to their ongoing relevance and utility. The literature search extended until 2022.

The initial search query aimed to explore potential synergies between renewable energies and fossil fuels, with a specific focus on 'solar PV and natural gas synergy.' In this context, synergy refers to the interaction or cooperation of two or more energy sources, resulting in a combined effect that surpasses the sum of individual effects. The primary objective is to reduce net greenhouse gas emissions while ensuring meeting base-load demand (IISD, 2020). The initial search yielded 6540 articles from Google Scholar and 1078 articles from the UQ library.

The secondary search string aimed to identify studies focusing on the PESTLE considerations that drive the energy transition. The search criteria were set as follows:

('political aspect' OR 'economic aspect' OR 'social aspect' OR 'technological aspect' OR 'legal aspect' OR 'environmental aspect') AND ('energy transition')

The secondary search string yielded a total of 195 articles from Google Scholar and 2488 articles from the UQ library. All citations were imported and organised using the EndNote™ referencing software. In instances where automatic exporting of references to EndNote™ was not feasible, the references were manually added to the software.

Figure 1 shows PRISMA flow diagram for the systematic review of databases, registers and other sources.

The PRISMA flow diagram depicted in Figure 1 provides an overview of the literature selection process, including the removal of duplicates and irrelevant publications. Initially, a diverse range of articles were screened based on their titles and abstracts. Following the initial screening, the articles underwent a more detailed assessment to determine their eligibility, utilising the inclusion criteria specified in Table 1. Articles that did not meet the established criteria were subsequently excluded from the review.

**TABLE 1**

Inclusion criteria for the retrieved peer-reviewed research articles.

| Inclusion factor | Criteria |
|---|---|
| Period | 2010–2022 |
| Article type | Peer reviewed |
| Geographical area | Around the world |
| Scale | National/International |
| Keywords | 'solar PV and natural gas synergy', ('political aspect' OR 'economic aspect' OR 'social aspect' OR 'technological aspect' OR 'legal aspect' OR 'environmental aspect') AND ('energy transition'), solar PV and natural gas synergy |
| Access | Open and paid |
| Language | English |
| Technology | Solar PV, Natural Gas |
| Energy source | RE, fossil fuel |

A total of over 7000 journals and academic papers addressing REs and their synergies with fossil fuels, as well as the strategies for accelerating the energy transition, were subjected to screening. The review process consisted of 16 distinct steps, which were categorised into five phases as illustrated in Figure 2:

a. Identify the research topic and questions
b. Find the relevant studies
c. Choose studies
d. Data mapping
e. Summarisation, conclusion, and reporting

Phases a, b, and c have been covered under PRISMA (steps 1 to 10)

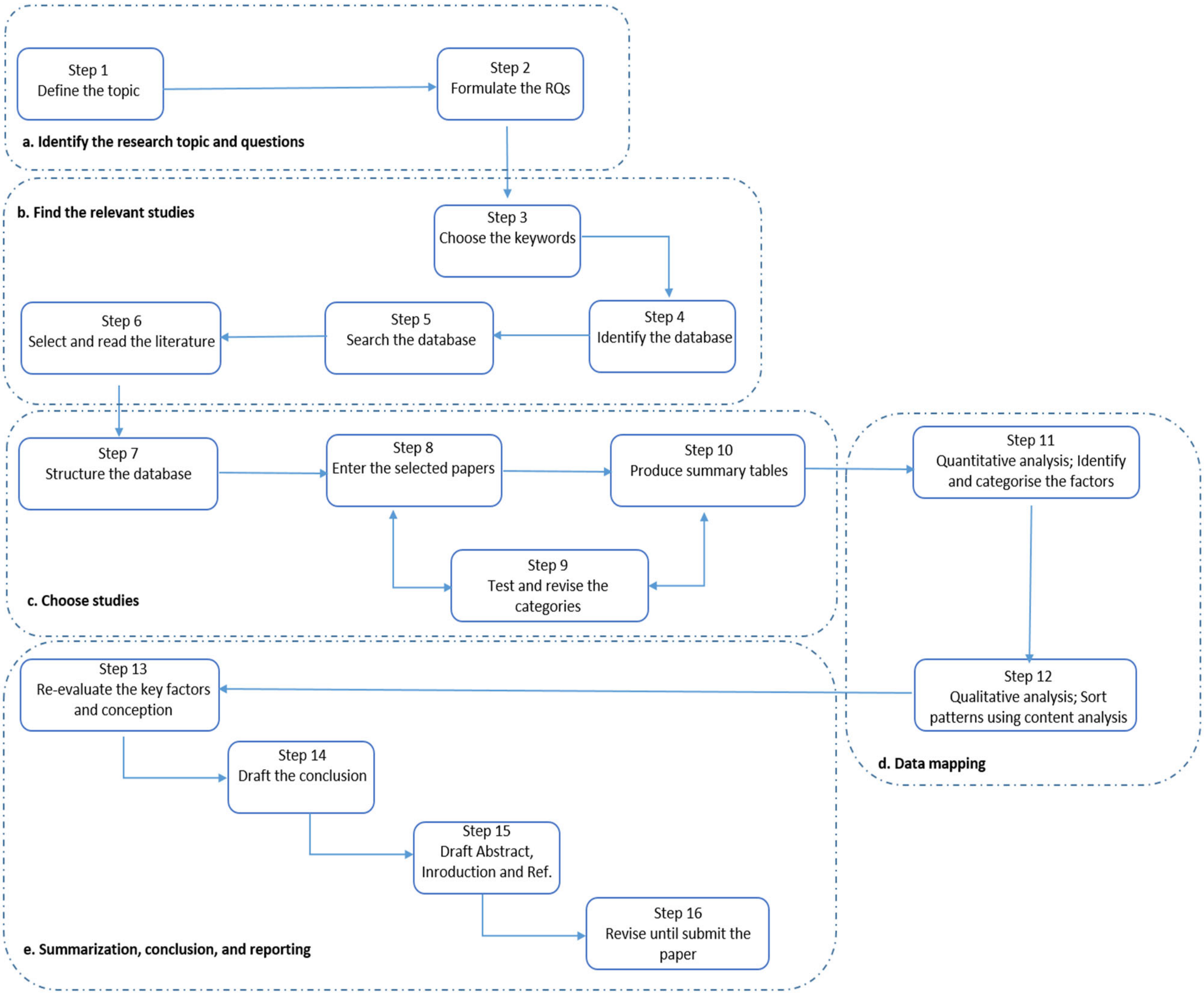



**FIG 2** – The systematic review process applied in this study; A modified version from (Pickering and Byrne, 2014).

Following the study selection process using PRISMA, a total of 226 articles were deemed suitable for the final review and data mapping. Figure 3 illustrates the distribution of the included publications per annum, providing an overview of the number of articles selected for analysis in each year.

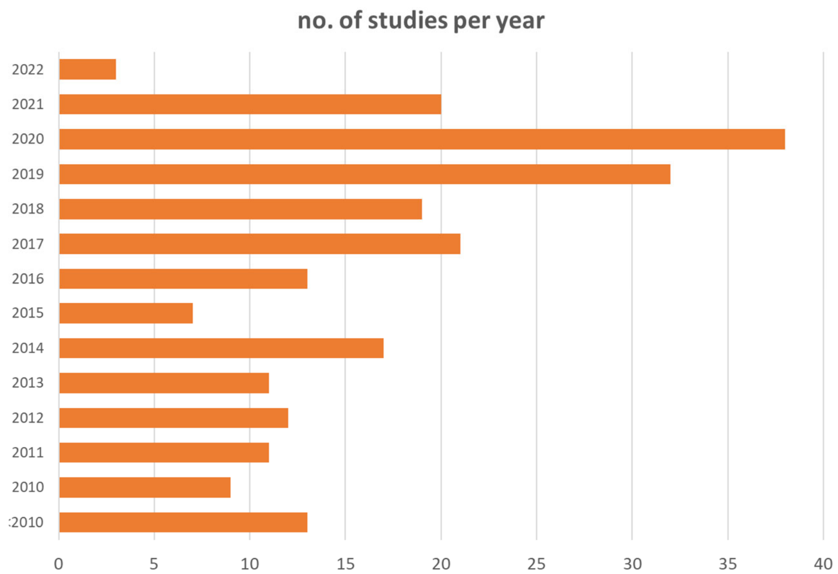



**FIG 3** – Number of the included publications per annum.

## PESTLE framework

A comprehensive plan was developed before starting the project. This includes choosing a proper analysis tool. There are various analysis tools such as SWOT analysis, PEST analysis, Porter's Five Forces, 5C analysis, VRIO analysis, and PESTLE analysis which can be used to conduct this research. Table 2 provides a comparison of these different methods, highlighting their respective features and benefits for this purpose.

**TABLE 2**

Comparing various analysis method comparison.

| Analysis method | Description | Advantages | Disadvantages |
|---|---|---|---|
| SWOT (PESTLEanalysis Team, 2020) | SWOT talks of the basics of a business, evaluates a project/business venture's strengths, weaknesses, opportunities, and threats (SWOT). | To be edited in real time as brainstorming with team. Can be used for products, places, and people. | Less detailed compared to PEST method. It is best done as a team. If there is not a strong collaboration and communication, different perspectives, cannot be captures. |
| PEST (PESTLEanalysis Team, 2020) | Studies Political, Economic, Social, and Technological aspects and their impacts. | Studies the opportunities and threats section of SWOT, but in more details. | Studies only four dimensions, compared to PESTLE. |
| Porter's Five Forces (Yapabandara, 2021) | First introduced by Harvard University in 1970s. Studies: threat of substitute, threat of new competitors, threat of established competitors, bargaining power of suppliers, bargaining power of customers. | Helps to analyse a competition and identify/eliminate threats, identifies power/opportunities, helps to understand corporate risks and to make strategy and vision. | Composition limitation, no quantitative dimensions, not usable on large companies or all industries universally, a starting point for analysis, doesn't consider business risk factors. |
| 5C (SMStudy, 2016) | Five factors impacting a business are considered: company, competitors, customers, collaborators, and political/legal/economic climate. | Provides insight into key drivers of success, as well as the risk exposure to various environmental factors. | Studies only five aspects of a business. |
| VIRO (Lucidity, 2023) | VRIO analysis is a method for evaluating resources and competitive advantages/disadvantages. | Identifies competitive advantages from four perspectives: Being valuable, rare, imitable, and organised. | It is time consuming, relies on subjective judgement. Focuses only on internal analysis. |
| PESTLE (Oxford, 2020) | PESTLE is an acronym for an analysis tool which Studies political, economic, social, technological, legal, and environmental aspects. | It's simple, analyses wider business environment, develops external and strategic thinking, anticipates business threats/opportunities. | Too much or not enough data could be captured. To be effective, should be repeated on a regular basis. |

Managers can choose any analysis method, based on the nature of the subject and the specific factors they intend to study. In this paper, the PESTLE method has been chosen due to its comprehensive nature and ability to encompass a wide range of factors (Oxford, 2020). PESTLE analysis aids in the identification of key factors that should be acknowledged, understood, and potentially leveraged to one's advantage.

Although several studies worldwide have explored the synergies between fossil fuels and renewable energies (REs), there remains a notable absence of cohesion in categorising the PESTLE aspects of energy transition within a practical framework. Currently, no comprehensive analysis has been undertaken to systematically organise and evaluate these aspects. It is envisioned that conducting such an analysis would greatly assist in the planning and decision-making processes of policymakers, facilitate the achievement of energy transition goals, and provide valuable insights for drawing conclusions (Makos, 2019).

To accomplish the above objectives, the energy transition factors identified in existing literature were mapped utilising the PESTLE framework. Each PESTLE aspect was further divided into specific sub-factors (Washington State University, 2023), as summarised here:

Political (P): tariffs, taxation, fiscal policies, and conflicts.

Economic (Ec): inflation rate, disposable income, Unemployment rate, interest rates, foreign exchange rates, and economic growth patterns.

Social (S): religion and ethics, consumer buying patterns, demographics, health, opinions and attitudes, media, brand preference, and education.

Technological (T): automation, technological development, patents, licensing, communication, information technology, research and development, and technological awareness.

Legal (L): employment laws, consumer protection, Industry specific regulations, regulatory bodies, and environmental regulations.

Environmental (En): geographical location, stakeholder and consumer values, environmental offsets, weather, and global climate change.

## Energy policies around the world

In this section, the energy policies of different countries around the world were reviewed, as established by the International Energy Agency (IEA). Three countries from each continent were selected and thoroughly examined and compared for their energy transition policies. This analysis focused on various aspects, including the target year, policy type, energy sector, related technology, policy status, and whether the policy jurisdiction was at the national or international level. The energy policies of each country were then mapped into the PESTLE framework. The summarised results of this analysis can be found in the Analysis section.

# ANALYSIS AND DISCUSSION

The findings from the 41 studies on the synergies between fossil fuels and REs from around the world, which were selected using the previously mentioned two search strings, reveals the level of attention given to different aspects of the energy transition within the PESTLE framework. The economic aspect has received the most discussion and coverage in the reviewed literature. This indicates that researchers and scholars have extensively examined the economic implications and considerations associated with the transition to REs.

Next comes the technological aspect, followed by the political and social aspects. The legal aspect has received the least attention among the PESTLE dimensions in the reviewed literature. However, it is important to note that this does not necessarily imply that the legal aspect is less significant or influential in the energy transition process. It could be attributed to the limited attention or fewer studies addressing the legal dimension in the selected research.

These findings highlight the need for further exploration and research on the legal aspect of the PESTLE framework in relation to energy transition. Understanding the legal considerations and implications can contribute to a more comprehensive and holistic approach in designing effective policies and strategies for the transition to renewable energies.

In addition to the literature review, an analysis of energy policies from the International Energy Agency (IEA) for selected countries in different regions was conducted. These policies were compared based on various factors, including their target year, policy type, energy sector, associated technology, policy status, and jurisdiction. The results show that technological aspects received the highest focus, followed by legal and political aspects. On the other hand, the economic, social, and environmental aspects were not discussed as extensively in the energy policies.

This emphasis on technological aspects aligns with the findings from the literature review, suggesting the importance of technology in facilitating the energy transition. While the political and legal aspects receive notable attention in the energy policies, the limited discussion of economic, social, and environmental aspects may be attributed to the specific focus of energy policies on the political and legal dimensions of the energy transition. These policies often prioritise the development of regulatory frameworks, incentives, and legal mechanisms to facilitate the adoption of REs.

## Gap analysis in literature and energy policies

The order of emphasis on the PESTLE aspects in the reviewed literature is: Economic, Technological, Political/Social, Environmental and Legal. The order of emphasis on the PESTLE aspects in the selected IEA policies is: Technological, Political, Legal, Social, Environmental and Economic. These findings are summarised in Table 3.

**TABLE 3**

Comparing emphasis on PESTLE aspects in literature review versus the selected IEA energy policies.

| Order of emphasis | Literature review (41 literature) | | IEA policies (21 countries) | |
|---|---|---|---|---|
| | PESTLE aspects | Frequencies | PESTLE aspects | Frequencies |
| 1 | Economic | 30 | Technological | 15 |
| 2 | Technological | 26 | Political | 13 |
| 3 | Political/Social | 23 | Legal | 11 |
| 4 | Environmental | 17 | Social | 4 |
| 5 | Legal | 6 | Environmental | 3 |
| 6 | | | Economic | 2 |

These findings highlight the different priorities and perspectives in the literature and the policies. While the literature places a strong emphasis on the economic dimension and recognises the significance of technological advancements, the IEA policies prioritise the technological dimension as the key driver for energy transition. The political and legal aspects are also important considerations in both the literature and the policies.

The social and environmental aspects received relatively less attention in both the literature and the policies, indicating a potential gap in addressing these dimensions in the energy transition discourse.

Figure 4 compares the frequency of each PESTLE aspect in the reviewed literature and in the selected IEA policies. Indeed, the difference in emphasis on the economic aspect between the literature and the IEA policies indicates that the purpose and focus of the analysis can influence the aspects that are considered in the energy transition. The literature, which may encompass a broader range of studies and perspectives, tends to place a higher emphasis on the economic dimension, possibly due to the recognition of the economic implications in energy transition.

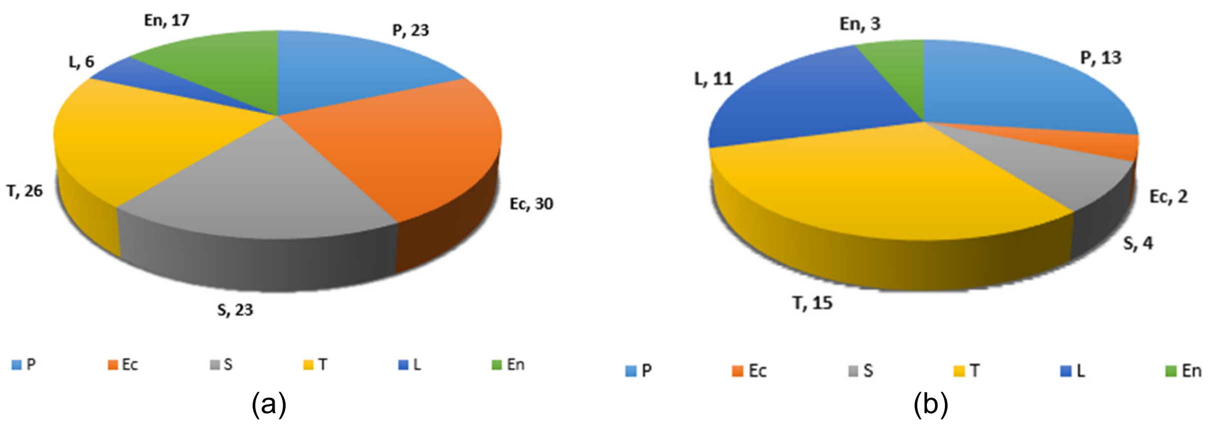
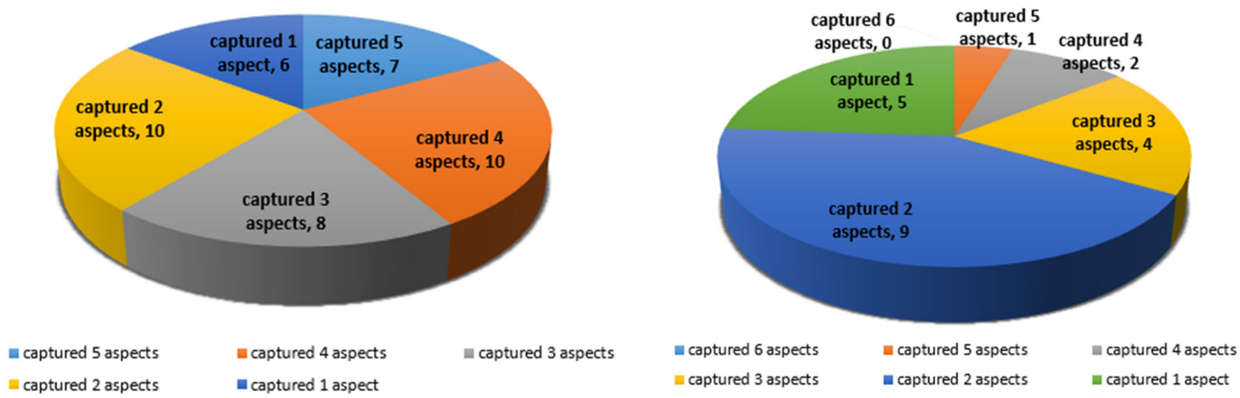



**FIG 4** – Comparing the frequency of PESTLE aspects in the selected literature and the IEA policies: (a) PESTLE in the literature; (b) PESTLE in the policies.

On the other hand, the IEA policies, which are specifically designed to guide and facilitate the transition process, may prioritise other aspects such as technological advancements, political considerations, and legal frameworks. This could be attributed to the practical and policy-oriented nature of the IEA policies, where the focus is on implementing effective measures to drive the transition rather than solely considering the economic aspect.

The total number of PESTLE aspects being captured in the reviewed literature and in the selected IEA policies are summarised in Figure 5. Most of the reviewed literature considered only two or four aspects of the PESTLE framework, while IEA policies mostly just captured two aspects of the PESTLE framework. None of the reviewed literature or the selected IEA policies reviewed all the aspects of the PESTLE framework. Hence, this shows the importance of creating a detailed PESTLE framework to analyse how the energy transition can be accelerated considering all the aspects of the PESTLE model.




(a) (b)

**FIG 5** – Comparing the number of PESTLE aspects captured in the selected literature and the IEA policies: (a) PESTLE in the literature; (b) PESTLE in the policies.

Overall, these findings emphasise the multidimensional nature of the energy transition and the importance of considering various PESTLE aspects in developing comprehensive strategies and policies. They also indicate the need for further research and policy development to ensure a balanced approach that addresses all PESTLE aspects in achieving a sustainable energy transition.

## Analysis of the PESTLE aspects affecting the energy transition

Although, the economic aspect of PESTLE model has been presented the most in the energy transition studies which have been reviewed around the world; however, the literature review indicates that the emphasis on different PESTLE aspects in energy transition varies across different countries or regions. In this section, the PESTLE aspects, from literature review, were colour-coded and plotted on the world's map based on their country/region (Figure 6). The colour coding has been explained in the map's legend.

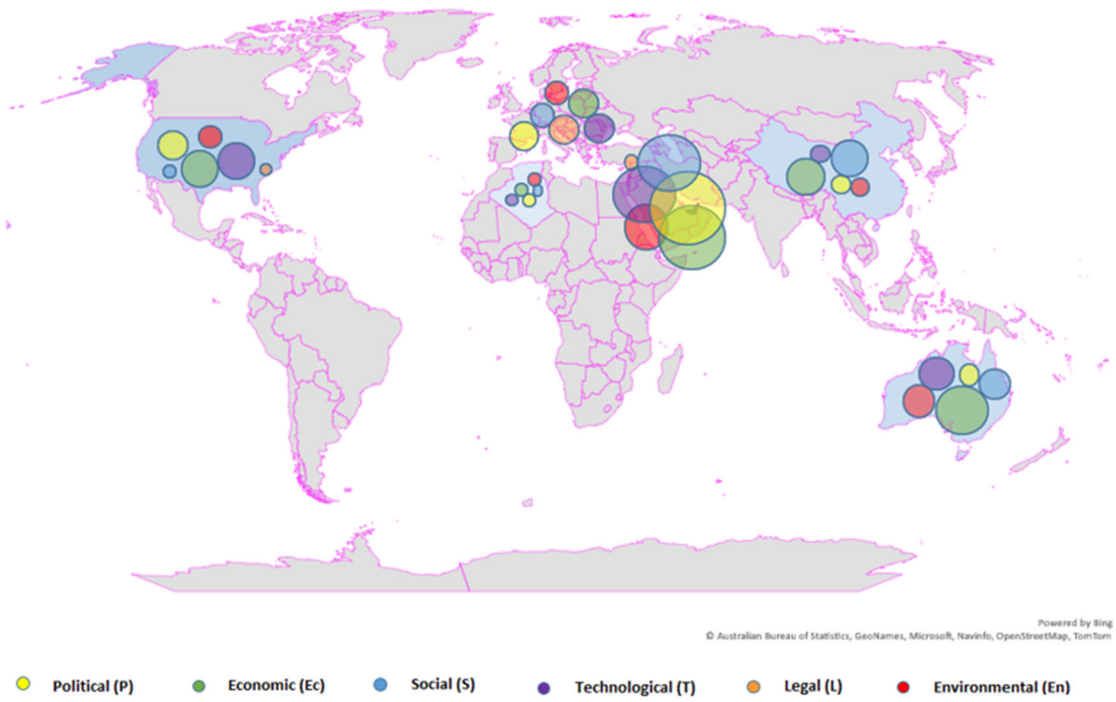



**FIG 6** – Analysis of the PESTLE aspects affecting the energy transition by country/region (from Lit rev).

The literature review shows that the economic aspect seems to be the most prevailing aspect in the energy transition in Australia. In China; the economic and social aspects, in the USA; technological and economic aspects, and in the Middle East; the political aspects, were considered as the most effective aspects of PESTLE model in energy transition. In Europe, all aspects of the PESTLE model are viewed as equally effective, suggesting a balanced approach that considers various dimensions in the energy transition (Table 4). The findings provide a comprehensive overview of the emphasis on PESTLE aspects in different countries or regions based on their frequencies in the studies for each region, offering valuable insights for policymakers and researchers in understanding the diverse factors influencing energy transition across the globe.

**TABLE 4**

Analysis of the PESTLE aspects affecting the energy transition by country/region (from Lit Rev).

| | P | Ec | S | T | L | En |
|---|---|---|---|---|---|---|
| Middle East | 10 | 9 | 8 | 8 | 2 | 5 |
| Australia | 2 | 7 | 3 | 4 | 0 | 3 |
| USA | 3 | 4 | 1 | 4 | 1 | 2 |
| Around the World | 3 | 3 | 5 | 4 | 0 | 3 |
| China | 2 | 4 | 4 | 3 | 0 | 2 |
| Europe | 3 | 3 | 2 | 3 | 3 | 2 |
| Total | 23 | 30 | 23 | 26 | 6 | 17 |

Moreover, the PESTLE aspects, from IEA policies, were colour-coded and plotted on the world's map based on their country/region (Figure 7). It appears that there are regional similarities in the emphasis placed on PESTLE aspects in energy transition policies. For example, as shown in Figure 7, in both Australia and South-east Asia, the political and technical aspects are the dominant aspects of the PESTLE model in energy transition policies which also drive the energy transition in North and South America and the Middle East. However, in Europe and Africa, more attention has been given to the technological and legal aspects. The legal aspect seems to be also an influencing aspect in the North and South America. In summary, the nearby areas are prioritising similar aspects in energy transition.

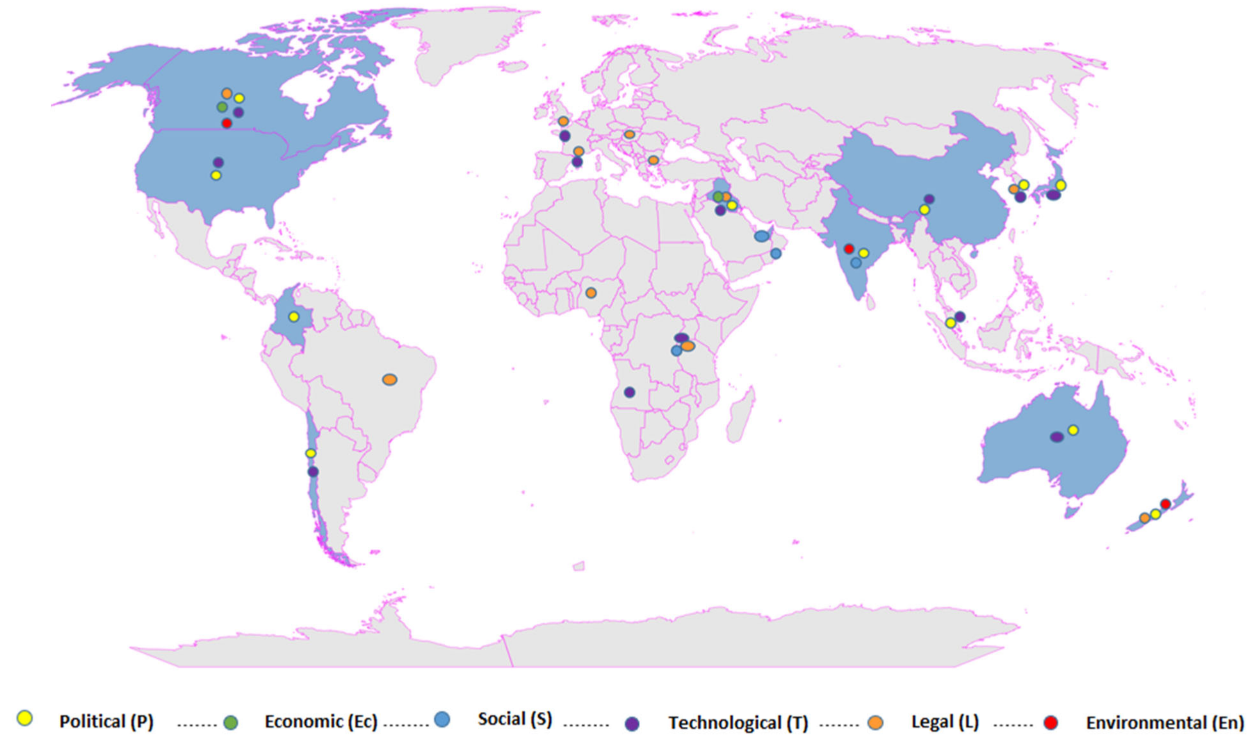



**FIG 7** – Analysis of the PESTLE Aspects affecting the energy transition by country/area (from IEA policies).

These findings highlight the contextual nature of energy transition and the importance of considering country-specific or regional factors when developing energy policies and strategies. Each country or region may have unique challenges, priorities, and opportunities, which influence the emphasis placed on different aspects of the PESTLE model. By understanding these variations, policymakers can tailor their approaches to address specific needs and leverage the strengths of each country or region in driving the energy transition.

## Analysis of the PESTLE sub-factors affecting the energy transition

As mentioned before, each PESTLE aspect is divided into sub-factors. The sub-factors are summarised in the *PESTLE framework* section. As shown in the following 'Word Clouds', the yellow colour represents the political sub-factors. Economic, Social, Technical, Legal and Environmental sub-factors are shown in green, blue, purple, orange, and red colours, respectively.

All the reviewed literature, after mapping into the PESTLE model, were further analysed and categorised into the PESTLE sub-factors. 'Technological Development' which is a sub-factor of the Technological aspect, was the sub-factor which received the most attention in the studies around the world. In the following 'Word Cloud' that is based on the results of the literature review, the bigger the font size, the relevant sub-factor has been reported more often as the potential to drive the energy transition around the world (Figure 8). Then Productivity and Economic Growth Patterns (from Economic aspect), Fiscal Policies (from Political aspect), Consumer Buying Patterns and Opinions and Attitudes (from Social aspect), Environmental Offsets (from Environmental aspect) and Environmental Regulations (from Legal aspect) are the next on the list.

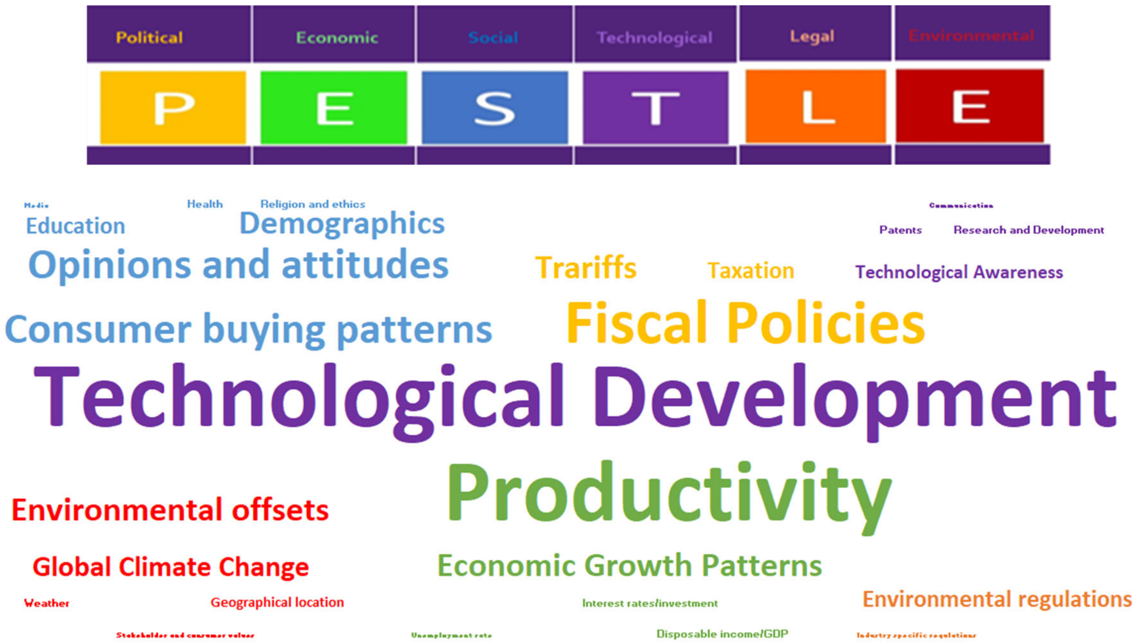



**FIG 8** – PESTLE sub-factors frequency analysis based on the literature review.

The IEA energy transition policies which were included in this study, after mapping into the PESTLE model, were further analysed and categorised into the PESTLE sub-factors. Again, 'Technological Development' which is a sub-factor of the Technological aspect, was the sub-factor which received the most attention in the selected energy policies around the world. In the following 'Word Cloud' which is based on the results of the IEA energy policies, the bigger the font size, shows that the relevant sub-factor has been reported more often as the potential to drive the energy transition around the world (Figure 9). As found in the literature review, Fiscal Policies (from Political aspect) are the next on the list in the IEA policies, as well. Industry Specific Regulations and Environmental Regulations (from Legal Aspect) are the next significant energy transition sub-factor, based on the energy policies. The rest of the sub-factors effect is not significant in the selected energy transition policies.

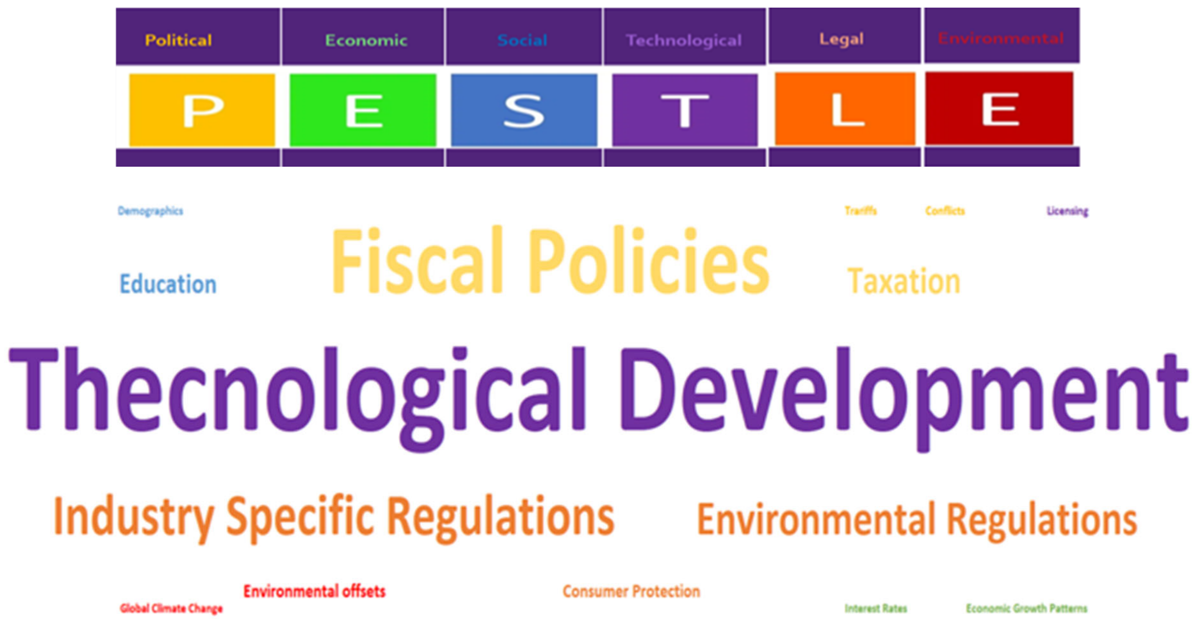



**FIG 9** – PESTLE sub-factors frequency analysis based on the selected IEA energy policies.

Overall, combining all the results from the literature review as well as the selected energy policies by IEA, shows that Technological Development (from Technological aspect), was the sub-factor that was reviewed the most around the world. The presented 'Word Cloud' visually represents the frequency of reported sub-factors based on the results from both the literature review and the selected energy policies. The larger font size indicates that the corresponding sub-factor has been mentioned more frequently as having the potential to drive the energy transition globally (Figure 10). Fiscal Policies (from Political aspect), Productivity (from Economic aspect) Environmental Regulation (from Legal aspect), Consumer Buying Patterns (from Social aspect) and Environmental offsets (from Environmental aspect) are the next influencing sub-factors. The top three sub-factors of each PESTLE aspect, from literature review and IEA policies and combined studies (Literature + IEA policies) is summarised in Table 5, which demonstrates and compares the most effective sub-factors in energy transition for each of the study sources.

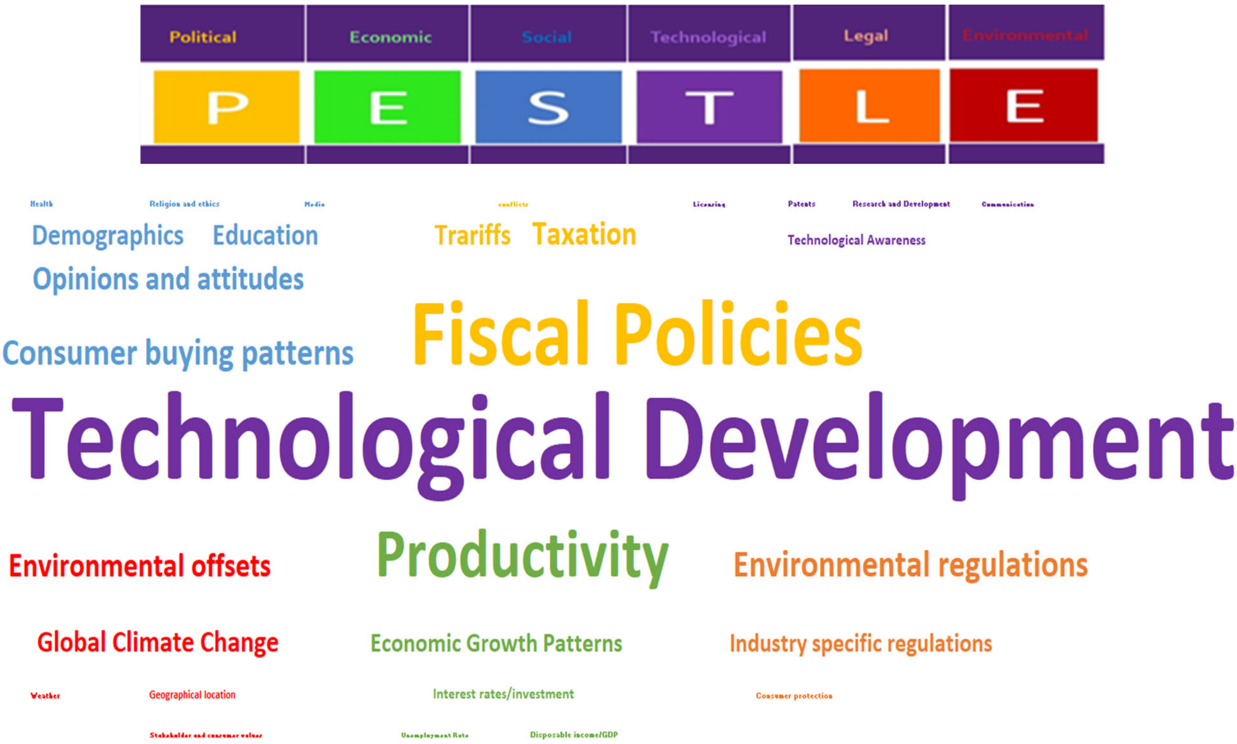



**FIG 10** – Combined PESTLE sub-factors frequency analysis based on both literature review and the selected IEA energy policies.

From the results summarised in Table 5, it can be concluded that there is a similarity in the most effective sub-factors for the Political, Technological, Legal, and Environmental aspects of the PESTLE framework, in both the literature and the selected IEA policies. However, there are differences in the most effective sub-factors for the Economic and Social aspects. The focus of IEA policies is primarily on improving the social and economic sub-factors of the energy transition through policies and legislations. On the other hand, the literature provides a more comprehensive and wholistic review of the social and economic aspects.

**TABLE 5**

Comparing top three sub-factors of each PESTLE aspect in literature review, the selected IEA energy policies, and combined studies (literature review + energy policies).

| PESTLE aspects | Literature review | IEA policies | Literature review + IEA policies |
|---|---|---|---|
| Political | **Fiscal policies**<br>Tariffs<br>Taxation | **Fiscal policies**<br>Taxation<br>Tariffs/Conflicts | **Fiscal policies**<br>Taxation<br>Tariffs |
| Economic | **Productivity/cost**<br>Economic growth patterns<br>Interest rates/investment | Economic growth patterns<br>Interest rates | **Productivity/cost**<br>Economic growth patterns<br>Interest rates/investment |
| Social | **Consumer buying patterns/**Opinions and attitudes<br>Demographics<br>Education | **Education**<br>Demographics | **Consumer buying patterns**<br>Opinions and attitudes<br>Demographics/Education |
| Technological | **Technological development**<br>Technological awareness<br>Research and development | **Technological development**<br>Licensing | **Technological development**<br>Technological awareness<br>Research and development |
| Legal | **Environmental regulations**<br>Industry specific regulations | **Environmental regulations**<br>Industry specific regulations<br>Consumer protection | **Environmental regulations**<br>Industry specific regulations<br>Consumer protection |
| Environmental | **Environmental offsets**<br>Global climate change<br>Geographical location | **Environmental offsets**<br>Global climate change | **Environmental offsets**<br>Global climate change<br>Geographical location |

## CONCLUSION

Based on the literature review, it is evident that the legal aspect of the PESTLE framework has received less attention compared to other aspects in the context of energy transition. However, this does not necessarily mean that the legal aspect is not a driving factor in energy transition. It may simply indicate a lack of reporting or research on this specific aspect. Further exploration is needed to investigate the role of the legal aspect and its impact on energy transition.

On the other hand, the economic aspect has been extensively studied and emphasised in the literature, potentially leading to a risk of neglecting other important aspects. It is crucial to recognise that there may be additional factors beyond the PESTLE framework that can influence energy transition, and these factors should not be overlooked in the development of synergistic systems.

In terms of IEA energy transition policies, there is a notable emphasis on the technical aspects followed by the political and legal aspects. This indicates that other PESTLE aspects have not been given equal consideration and discussion. Therefore, further studies that involve collecting the perspectives and ideas of decision-makers and experts through questionnaires and interviews are necessary to gain insights into the motivation factors driving energy transition, which go beyond the scope of the current article.

Overall, the technological aspect has been consistently found to be effective in energy transition in both the literature and policies. The 'Technological Development' sub-factor is particularly prominent in both sources. Additionally, the most effective sub-factors for the Political, Legal, and Environmental aspects are similar between the literature review and the selected IEA policies. However, there are differences in the most effective sub-factors for the Economic and Social aspects, with IEA policies focusing more on improving these aspects through policies and legislations, while the literature takes a more comprehensive approach to reviewing the social and economic aspects. It is important to recognise that the purpose and scope of a study can significantly impact its findings.

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# Ventilation challenges for more sustainable underground mines in Brazil

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## ABSTRACT

Sustainable mining can be considered related to the decrease of negative environmental, social, and governance (ESG) impacts of mining operations by means of responsible stewardship of the natural environment, meeting current society's needs for resources while ensuring the requirements of upcoming generations. Apart from ore comminution, mine ventilation is deemed the greatest consumer of electrical power. Therefore, in underground mining sustainable practices include measures for controlling and reducing energy consumption besides workers' safety. In Brazil, although mining is mainly open pit, underground mining remains quite significant, and with a great expansion trend, demonstrated by the expressive number of underground mines and relevant new projects with underground mining. This work aims to present a current panorama of ventilation systems in Brazilian mines, highlighting the adoption or challenges for the implementation of more sustainable practices, such as the adoption of ventilation control (popular 'ventilation on demand', VOD) technology. Based on extensive bibliographic, the analysis of the results revealed a marked heterogeneity between the Brazilian underground mines, depending on their sizes and types of ore exploited, allowing the identification of distinct patterns in terms of sustainability.

## INTRODUCTION

Sustainable mining can be considered related to the decrease of negative environmental, social, and governance (ESG) impacts of mining operations through responsible stewardship of the natural environment, meeting current society's needs for resources while ensuring the requirements of future generations.

Columbia Center on Sustainable Investment *et al* (2016) relate mining to the United Nations Sustainable Development Goals (SDGs) established in 2015 as part of the 2030 Agenda to overcome global challenges such as poverty, inequality, climate change, environmental degradation, peace, and justice (United Nations, 2015). In particular, they present ESG actions that can be adopted by the mining sector towards sustainable mining as shown in Figure 1.


**FIG 1** – Mining and the 17 SDGs (Columbia Center on Sustainable Investment *et al* (2016)).

Among these practices, the improvement of energy efficiency (SDG 7) stands out by reducing operational energy demand among other measures. It is known that ventilation systems, apart from ore comminution, have long been identified worldwide as major energy consumers (Udd, Clarke and Hardcastle, 1996; Dicks and Clausen, 2017; Ayres da Silva *et al,* 2024). Therefore, the implementation of technologies and practices focused on optimising energy use in mine ventilation is increasingly important today.

In Brazil, although mining is predominantly open pit, underground mining is quite significant and with a great expansion trend demonstrated by the high number of new projects with underground mining or expansion of underground mines driven by the growing need for critical and strategic minerals (MCE) (Table 1) for domestic and foreign supply.

**TABLE 1**

MCE for Brazil.

| | | | |
|---|---|---|---|
| **Mineral goods that the country depends on for supply to vital economic sectors** | | | |
| Sulfur | Phosphate | Potassium | Molybdenum |
| **Mineral goods important for their application in high-tech products and processes** | | | |
| Cobalt | Copper | Tin | Graphite |
| Platinum Group Metals | Lithium | Niobium | Nickel |
| Silicon | Thallium | Tantalum | Rare Earths |
| Titanium | Tungsten | Uranium | Vanadium |
| **Mineral goods that the country holds competitive advantages and are essential for the economy** | | | |
| Aluminium | Copper | Iron | Graphite |
| Gold | Manganese | Niobium | Uranium |

Source: de Castro, Peiter and Góes (2022).

The country has more than 70 active underground mines of various sizes, mainly in the central-west, south-east, south, and north-east regions (Heider, 2017).

Among the new projects, the extraction of lithium essential for lithium-ion batteries used in electric vehicles and other energy storage technologies stands out, such as the Bandeira project by Lithium Ionic and the expansion of the Cachoeira da CBL (Companhia Brasileira de Lítio) underground lithium mine, both in the Jequitinhonha Valley (Minas Gerais), currently known as ‘Lithium Valley’ (Bruscky, 2023; IBRAM, Humana Serviços em Sustentabilidade Ltda. and CETEM, 2024).

The underground potash mine in Autazes, Amazonas, for the production of potassium chloride for fertilisers is also under discussion, which should use the Room and Pillar mining method and include refrigeration systems (Potássio Brasil, 2016; Kiefer, Uhlein and Fanton, 2019; Goto, 2022), in addition to projects for the expansion of underground gold, copper, and rare earth mines (Ero Copper, 2024).

## OBJECTIVES

This work aims to present an up-to-date overview of Brazilian underground mines regarding their ventilation systems, highlighting the adoption, opportunities, and challenges faced for the implementation of more sustainable practices such as the adoption of ventilation control technology (popularly known as ‘ventilation on demand’ VOD), among others.

## METHODOLOGY

The methodology employed can be divided into two phases.

The first phase, based on extensive bibliographic research, consisted of surveying practices directly related to mine ventilation that seek to make underground mining more sustainable within the framework of the 17 SDGs.

Although many actions are related to various SDGs, two key SDGs for each specific practice were also highlighted.

In the second phase, it was investigated whether such practices are currently adopted in the country. For each practice, the main difficulties and challenges to be overcome for the implementation of these actions were also verified. Data was obtained through comprehensive bibliographic research and contacts with Brazilian underground mining companies.

## RESULTS AND DISCUSSION

The results of each research phase with their respective analyses are presented in the following sections.

### Sustainable practices related to mine ventilation

Table 2 presents actions focused on ventilation, and aligned with the UN SDGs (2015) that could make Brazilian underground mines more sustainable.

**TABLE 2**

Sustainable practices related to mine ventilation.

| Practice | Simplified description | Main related SDG |
|---|---|---|
| Software for optimising ventilation systems | Use of software for modelling, simulation, and optimisation of mine ventilation networks for optimising airflow and increasing ventilation system efficiency | **ODS 7 – Affordable and Clean Energy:** reduction of energy consumption<br>**ODS 12 – Responsible Consumption and Production:** optimising the use of resources |
| Monitor and continuously control air quality | Implementation of advanced monitoring systems for real-time detection and reduction of air contaminants | **ODS 3 – Good Health and Well-Being:** protection of underground workforce health<br>**ODS 9 – Infrastructure, Innovation and Industrialisation:** use of advanced technologies to improve environmental conditions |
| Ventilation control systems (VCS) at different automation levels (known as VOD) | Optimisation of energy use through adjusting airflow according to real mine needs | **ODS 7 – Affordable and Clean Energy:** improvement of energy efficiency<br>**ODS 13 – Climate Action:** reduction of greenhouse gas emissions |
| High-efficiency fans | Use of fans with additional mechanisms for high efficiency, such as auxiliary fans with engineering modifications (altered rotor blades) and high-efficiency fans with blades optimised by CFD (computational fluid dynamics) modelling, among others | **ODS 7 – Affordable and Clean Energy:** improvement of energy efficiency<br>**ODS 12 – Responsible Consumption and Production:** promotion of efficiency in the use of resources |
| Controlled recirculation and reuse of primary | Controlled recirculation of primary airflow with reconditioning to reduce the | **ODS 7 – Affordable and Clean Energy:** reduction of additional energy needs |

| | | |
|---|---|---|
| airflow with reconditioning | need for additional ventilation infrastructure | **ODS 12 – Responsible Consumption and Production:** promotion of efficiency in the use of resources |
| Electrification of equipment or use of alternative fuels to diesel | Replacement of fossil fuel-powered machines and vehicles with electric alternatives or less polluting fuels alternative to diesel | **ODS 3 – Good Health and Well-Being**: improvement of air quality and health of workers and nearby communities<br>**ODS 7 – Affordable and Clean Energy:** reducing dependence on fossil fuels and promoting the use of cleaner and more sustainable energy sources |

Sources: Suvar *et al,* 2012; Hu *et al,* 2013; Chatterjee, Zhang and Xia, 2015; de Souza, 2015; Wallace, Prosser and Stinnette, 2015; Acuña, Alvarez and Hurtado, 2016; Demirel, 2018; van den Berg, Manns and Bluhm, 2019; Fúnez Guerra *et al,* 2020; Shriwas and Pritchard, 2020; Gonen, 2021; Nikolakis *et al,* 2021; Demirkan *et al,* 2022; Kohmann and da Silva, 2022; Laamanen *et al,* 2022; Szlązak and Korzec, 2022; Saeidi and Allen, 2023.

## Overview of Brazilian underground mines concerning their ventilation systems

According to Heider (2017), Brazil officially has 76 underground mines in operation along with several significant projects that include underground mining. It is noteworthy that in this count the author considers some conglomerates of mines as a single mine since many of them are interconnected underground or located very close to each other. Considering that in the last seven years, two mines ceased activities (temporarily) and two new mines came into operation (one of copper and one of nickel), the number used in the research remained at 76.

Table 3 summarises the results of the second research phase, quantifying the number of mines that currently adopt the practices presented in the first phase, the types of ore extracted in each of them, and their respective mining methods.

**TABLE 3**

Sustainable practices related to mine ventilation.

| Practice | Type of ore extracted (number of mines) | Mining method | Number of mines where practice is adopted |
|---|---|---|---|
| Software for optimising ventilation systems | Gold ore (7); Chromium ore (1); Zinc ore (2); Manganese ore (1); Coal ore (2); Limestone ore (1). | Sublevel stoping (7); Sublevel stoping/Sublevel caving (1); VRM Vertical Retreat Mining (2); Room and Pillar (4). | 14 |
| Monitoring and continuous air quality control | Gold ore (3); Chromium ore (1); Copper ore (1). | Sublevel stoping (4); Sublevel stoping/Sublevel caving (1). | 5 |
| Ventilation control systems (VCS) at different automation levels (known as VOD) | Gold ore (7); Chromium ore (1); Zinc ore (2); Manganese ore (1); Coal ore (1). | Sublevel stoping (6); Sublevel stoping/Sublevel caving (1); VRM Vertical Retreat Mining (2); Room and Pillar (3). | 12 |
| High-efficiency fans | Copper ore (1); Zinc ore (1). | Sublevel stoping (1); VRM Vertical Retreat Mining (1). | 2 |
| Controlled recirculation and reuse of primary air flow with reconditioning | - | - | - |
| Electrification of equipment or use of alternative fuels to diesel | Gold ore (1); Salt ore (1); Chromium ore (1). | Sublevel stoping (1); Room and Pillar (1); Sublevel stoping/Sublevel caving (1). | 3 |
| Total | | **76** | |

Sources: Ayres da Silva *et al,* 2024; Brasil Ministério do Trabalho e Emprego, 2024 and personal communications.

It is observed that some of these practices can be presented in combination, such as ventilation control systems (VCS), which, depending on the level of automation, can include continuous air contaminant monitoring sensors.

Controlled recirculation and reuse of primary air flow is often considered an effective technique to reduce the need for constant fresh air and, consequently, energy consumption and additional ventilation infrastructure (van den Berg, Manns and Bluhm, 2019).

However, in Brazil, it is prohibited by Brazilian regulation NR-22 – OCCUPATIONAL SAFETY AND HEALTH IN MINING in the item that addresses mine ventilation (item 22.22.3) (Brasil Ministério do Trabalho e Emprego, 2024).

The analysis of the results shows that only 18.2 per cent of Brazilian mines use some software as a tool for simulating and optimising their ventilation networks. Continuous monitoring and control of air quality occur in 6.5 per cent of the mines, and the use of ventilation control systems (VOD) at different levels of automation is employed in 15.6 per cent of them.

About 2.6 per cent of the mines have high-efficiency fans, and 3.9 per cent use electric equipment or alternative fuels to diesel. Brazil's energy matrix is predominantly renewable, with a strong dependence on hydroelectric power and significant growth in wind and solar sources. Approximately 61.4 per cent of Brazil's total installed capacity comes from hydropower (de Oliveira *et al,* 2018).

However, many challenges still hinder the adoption of more sustainable practices underground.

Besides the high costs, which often make acquiring more energy-efficient equipment and technologies unfeasible, the lack of adequate infrastructure for such improvements can represent a significant problem.

The majority of the country's underground mines (approximately 84.4 per cent) do not have any automation of their ventilation systems (use of VOD systems). It is observed that an initial obstacle to the adoption of the automation process of ventilation systems in many of them is the lack of robust communication networks that allow for automatic operation or remote control of ventilation assets (Ayres da Silva *et al,* 2024).

## CONCLUSIONS

Based on the results presented, it can be concluded that currently, less than 20 per cent of Brazilian underground mines adopt any ventilation practices considered 'sustainable,' that is, aligned with the SDGs, such as actions aimed at reducing the energy consumption of ventilation operations (SDG 7 – Clean and Affordable Energy).

It is essential to mention that this percentage does not include illegal mines, which are not registered with the Brazilian Ministry of Mines and Energy and are excluded from official statistics. In these subsistence-focused mines, rudimentary and artisanal mining techniques are generally used without an adequate ventilation system (de Vieira, Silva and Ayres da Silva, 2021).

Such values can be explained by the need for greater investments in equipment, infrastructure, maintenance (including component calibration), and well-trained and skilled teams, which sometimes can become unfeasible for the reality of the mine and the region. On the other hand, some Brazilian mines also do not present very favourable characteristics for the use of certain technologies, such as VOD, because they require a continuous supply of airflow (Hardcastle and Kocsis, 2004), such as mines with radioactivity problems and hot mines.

There are also cultural issues that sometimes interfere with the workforce's adaptation to new technologies. In these cases, it is essential, before the implementation phase, to have proper management aimed at preparing everyone for such changes, including, for example, an efficient and transparent process of dissemination, information, and communication to explain how the new system will work, the expected benefits for the mine and its employees/operators regarding occupational health and safety, and what to do if the system does not work as expected (Acuña and Feliú, 2014).

The outlook, however, is that the adoption of technology will see significant growth in the country over the coming years, particularly in mines and projects involving medium and large-scale underground metal mining. These operations typically utilise high-productivity mining methods such as Sublevel Stoping and its variants.

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# Simulating mineral resource block listings for narrow, tabular gold deposits

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## ABSTRACT

Academics often struggle to access suitable data for testing optimisation models. In a PhD study focusing on mineral resource royalty costs and cut-off grade determination for narrow, tabular gold deposits, the optimisation model's initial development used proprietary block listings from mining companies. Because companies do not release raw block listings into the public domain, an alternative source for block listings was required to publish the final thesis. Grade-tonnage curves are published in the various mining companies' annual Mineral Resource and Reserve reports and are considered to be in the public domain. A method has been devised where these grade-tonnage curves are used to develop simulated block lists. The distribution of the grades (in g/t or cmg/t) is determined using the Distribution Fitting application in the Real Options Valuation, Inc Risk Simulator 2023 software and a probability function is derived. This function is then used to populate the grade column in a blank block list. The total number of blocks in the list is selected so the total Measured and Indicated tonnage matches the published figures (using standard block sizes and the published channel and stoping widths). The resultant simulated block lists were compared to the published curves and are considered adequate for cut-off grade optimisation, acknowledging potential variations in mine block sizes and grade distributions. These simulated block lists have been used for further research work including a study in managing cut-off grades considering grade estimation variations. The use of public domain information to create simulated block lists allows researchers the freedom to publish the study results without requiring company permission to use propriety information.

## INTRODUCTION

The geological model and mining block models are two critical elements of the mine planning process (SRK Consulting, 2018). The author, however, found that these block models are not available in the public domain. Researchers who wish to study the effects of optimisation models on mine outputs which may require the block models as an input are thus hampered by the availability of these block models. These block models form the basis of the grade-tonnage curve which is often published as part of mines' annual mineral resource and reserve statements (Ronald, 2018). For this paper, two deep-level Witwatersrand gold mines located in the West Wits will be used as examples. These are Mponeng and Kusasalethu (Figure 1). Gold grade distributions are generally considered to be lognormal, although studies show this to be more likely to be of the two, or even three parameter lognormal type in the Witwatersrand reefs (Janisch, 1986; Krige, 2004). These types of lognormal distributions have different kurtosis and are skewed compared to the lognormal distribution (Sichel, 1987). The two mines selected for this paper have unique challenges which had to be considered when developing their respective simulated block lists.

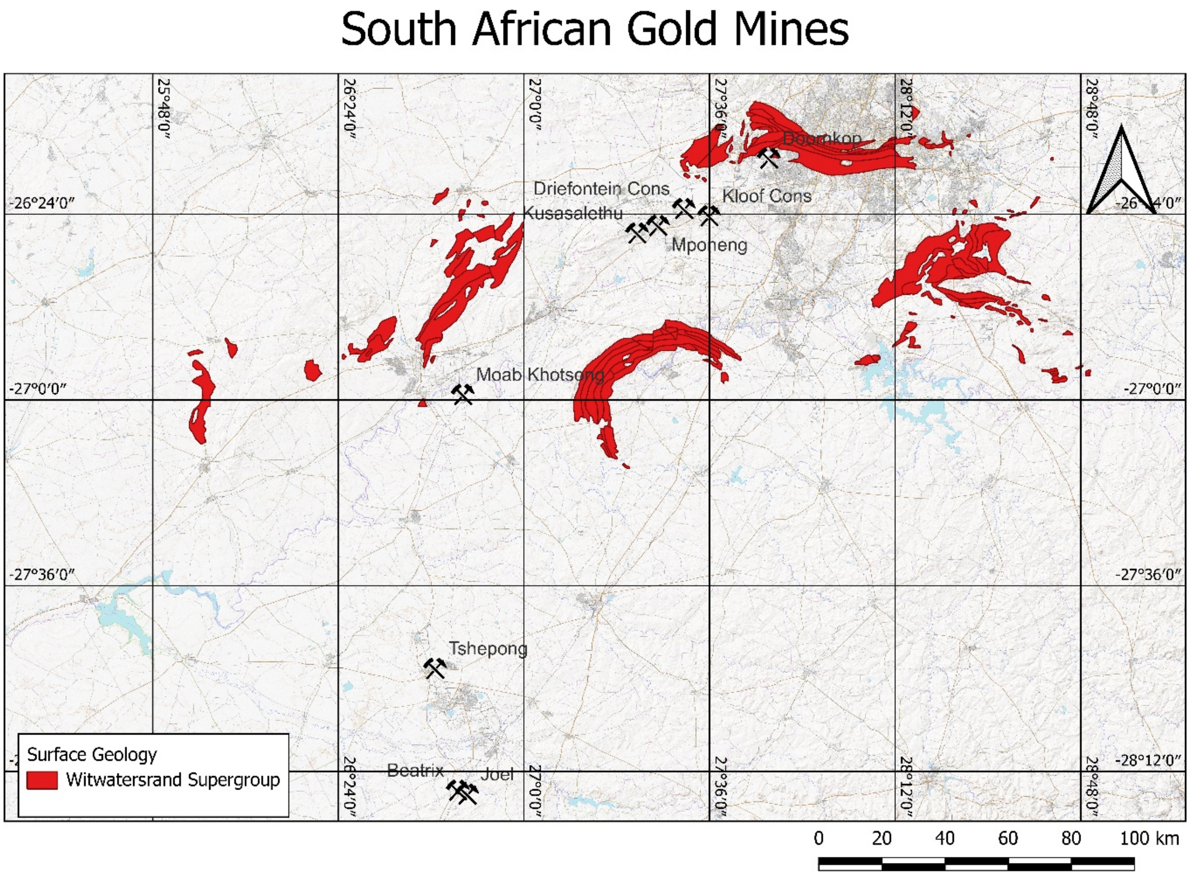


**FIG 1** – South African deep-level gold mines. The positions of Mponeng and Kusasalethu gold mines can be clearly seen in the West Wits portion of the Witwatersrand (Council for Geosciences, 2021).

The grade-tonnage curve for Mponeng Mine is shown in Figure 2. This is for the combined Ventersdorp Contact Reef (VCR) and the Carbon Leader Reef (CLR).

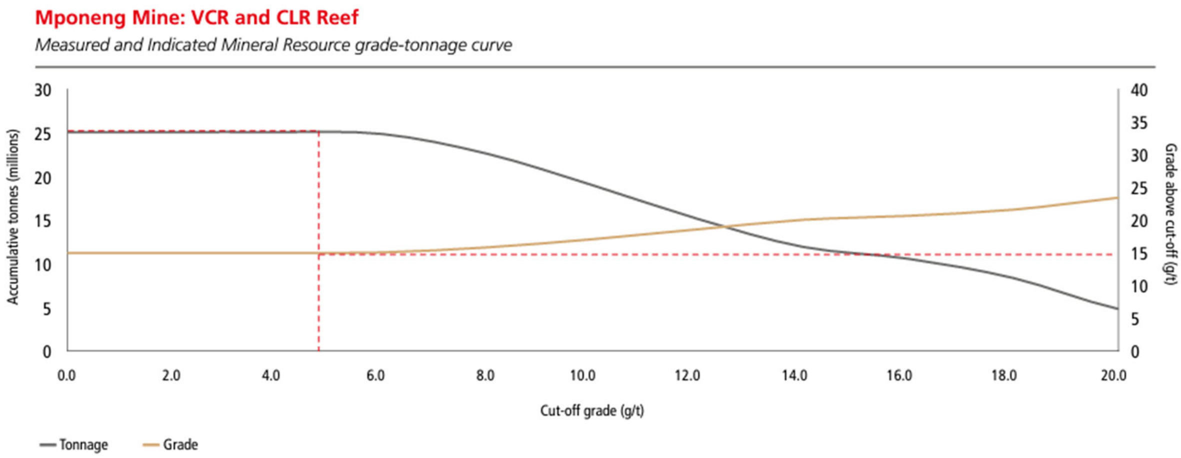


**FIG 2** – The grade-tonnage curve for Mponeng Mine. The grey line represents the tonnage, whilst the brown line represents the grade. The red dashed vertical line at approximately 5 g/t represents the resource cut-off grade, which corresponds to 25.4 million tonnes above the cut-off grade and an average grade of 14.9 g/t for those tonnes which is shown by the two horizontal red dashed lines (Harmony Gold Mining Company Limited, 2023).

The grade-tonnage curve for Kusasalethu Mine is shown in Figure 3. This is for the VCR only.

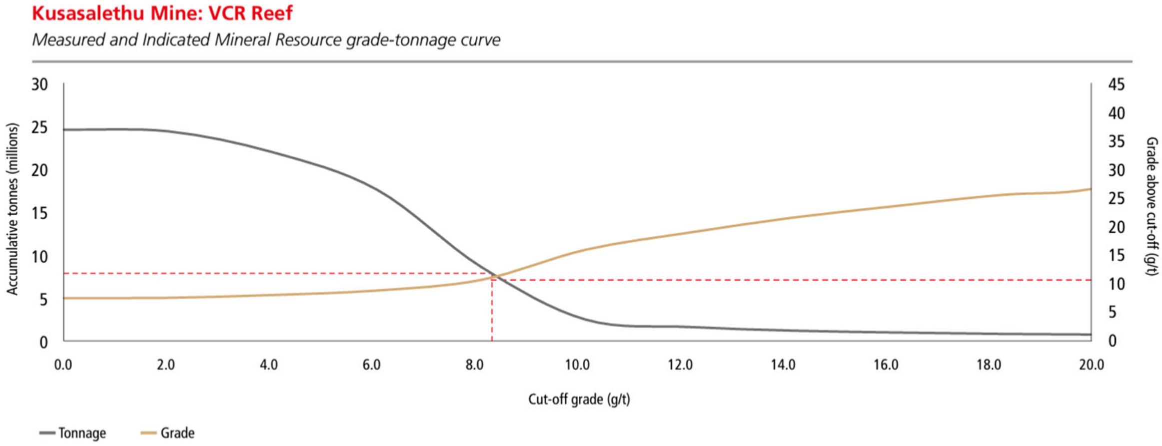


**FIG 3** – The grade-tonnage curve for Kusasalethu Mine. The resource cut-off grade of approximately 8.3 g/t results in 8.1 million tonnes above this grade, at an average Measured and Indicated Resource grade of 10.9 g/t (Harmony Gold Mining Company Limited, 2023).

The application of the cut-off grades in the two examples can be noted. For Mponeng Mine, the cut-off grade presented correlates with a resource cut-off grade of approximately 5 g/t, whilst in the Kusasalethu Mine example it correlates to a resource cut-off grade of approximately 8.2 g/t. It should be noted that the published grade-tonnage curve for Mponeng Mine reflects the mineral resource cut-off grade and no tonnes are reported for blocks with grades below this. For Kusasalethu Mine, this is not the same. The grade-tonnage curve includes all the blocks down to about 2 g/t. The resultant total tonnage reflected in the published grade-tonnage curve (25 Mt) is thus significantly higher than the Measured and Indicated Mineral Resource tonnes (8.1 Mt) (Harmony Gold Mining Company Limited, 2023).

Whilst the geological model resolution is guided by the sampling data spacing, the sizes of the blocks in the mining block model are driven by the mining method and how selectively the ore can be mined to minimise dilution (Hartman *et al,* 1992). The blocks should represent the smallest mining unit.

Mining companies classify their Mineral Resources into three categories, Measured, Indicated and Inferred. This classification is based on geoscientific knowledge but some companies use different size blocks for the three categories for their geological block modelling. These geological block model sizes are then taken as the same as their Mineral Resource mining block sizes. The grade-tonnage curves depicted in Figures 2 and 3 only represent the Measured and Indicated Resources for the two examples. Figure 4 displays the relationship between the various Mineral Resource categories and the modifying factors.

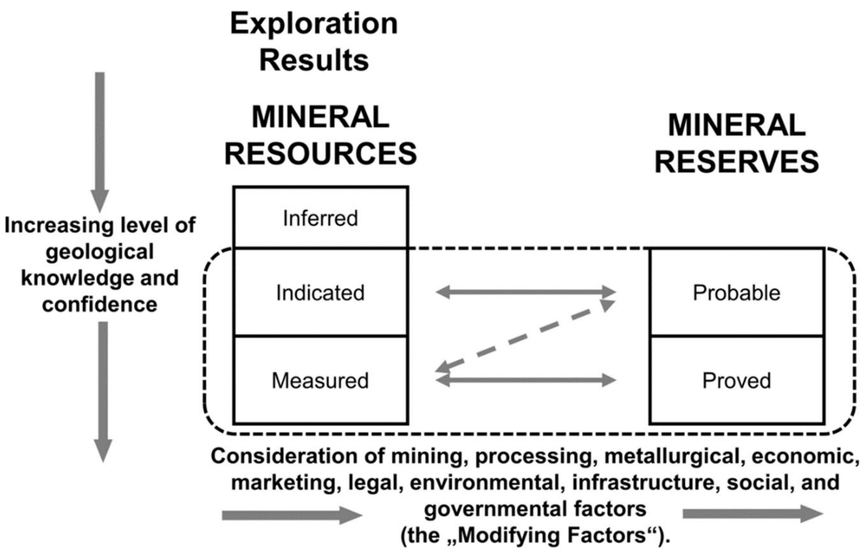


**FIG 4** – The relationship between Exploration Results, Mineral Resources and Mineral Reserves (Stiftner, Weber and Rechberger, 2023).

It can be observed that only the Measured and Indicated Resources can be included in the Proved and Probable Mineral Reserves after the application of the various modifying factors (Lomberg and Rupprecht, 2017). Figure 5 shows the Mineral Resource estimates for the Mponeng Mine, whilst Figure 6 shows the Mineral Reserve estimates for the Kusasalethu Mine.

**Mponeng**

**Gold – Mineral Resource estimates at 30 June 2023 (inclusive)**

| | Measured | | | | Indicated | | | | Inferred | | | | Total | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Tonnes | | Gold | | Tonnes | | Gold | | Tonnes | | Gold | | Tonnes | | Gold | |
| | (Mt) | (g/t) | (000kg) | (000oz) | (Mt) | (g/t) | (000kg) | (000oz) | (Mt) | (g/t) | (000kg) | (000oz) | (Mt) | (g/t) | (000kg) | (000oz) |
| Mponeng | 4.6 | 18.07 | 83 | 2 675 | 20.8 | 14.20 | 296 | 9 510 | 31.5 | 11.70 | 369 | 11 855 | 57.0 | 13.13 | 748 | 24 039 |

**FIG 5** – The Mineral Resources of Mponeng Mine for 2023 (Harmony Gold Mining Company Limited, 2023).

**Kusasalethu**

**Gold – Mineral Resource estimates at 30 June 2023 (inclusive)**

| | Measured | | | | Indicated | | | | Inferred | | | | Total | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Tonnes | | Gold | | Tonnes | | Gold | | Tonnes | | Gold | | Tonnes | | Gold | |
| | (Mt) | (g/t) | (000kg) | (000oz) | (Mt) | (g/t) | (000kg) | (000oz) | (Mt) | (g/t) | (000kg) | (000oz) | (Mt) | (g/t) | (000kg) | (000oz) |
| Ventersdorp Contact Reef | 1.6 | 13.50 | 22 | 698 | 6.5 | 10.08 | 66 | 2 110 | 2.5 | 8.85 | 22 | 698 | 10.6 | 10.32 | 109 | 3 506 |

**FIG 6** – The Mineral Resources of Kusasalethu Mine for 2023 (Harmony Gold Mining Company Limited, 2023).

It can be observed from Figure 5 that the total Measured and Indicated Mineral Resources (4.6 and 20.8 Mt) align with the 25.4 Mt displayed in Figure 2 for Mponeng Mine. The cut-off grade (shown as 5 g/t in Figure 2) is the Resource cut-off grade and not the Reserve cut-off grade. The same relationship can be observed for Kusasalethu Mine where the Resource cut-off grade of 8.2 g/t results in 8.1 Mt (and an average grade for the Measured and Indicated Resource of 10.9 g/t).

The Reserve cut-off grade can be estimated using the following equation (Break-even grade):

$$g/t = \frac{(\frac{AISC}{p})}{(r \times SM)} \quad (1)$$

where:

$g/t$ is the break-even grade in grams per tonne

$AISC$ is the all-in sustaining costs in US$/tonne

$r$ is the mine recovery factor in %

$p$ is the metal price in US$ per gram and SM is the ratio of stope to milled tonnes (in %) (Birch, 2022)

At the break-even grade, total revenue equals total costs. Before 2013, gold mining companies used various methods to report their mining costs. Some companies only reported mining and processing expenses, neglecting crucial factors like sustaining capital (Yapo and Camm, 2017). This type of cost reporting is not suitable for this study because the cut-off grade must account for the costs of replacing mined ground. To address this, the World Gold Council established a more consistent reporting method, including all-in-sustaining costs (AISC) and all-in costs (AIC) (Gianfrate, 2017). All companies included in this study report their AIC and AISC in their annual Mineral Resource and Reserve reports. The AISC figure is considered appropriate for determining the cut-off grade and has been used in this study because it includes the costs of replacing mined ground (Meredith, 2021). Using the figures published in Harmony Gold Mining Company's Annual Resource and Reserve Statement, the break-even cut-off grades for Mponeng and Kusasalethu Mines can be estimated as shown in Table 1.

**TABLE 1**

The break-even cut-off grade for Mponeng Mine.

| Mine | Average gold price (US$/oz) | Stope to milled tonnes | MRF | AISC (US$/t) | Break-even cut-off grade |
|---|---|---|---|---|---|
| Mponeng | US$1836 | 68.7% | 79.4% | US$372 | 11.6 g/t |
| Kusasalethu | US$1821 | 84.6% | 82.6% | US$367 | 8.9 g/t |

If this break-even cut-off grade is applied to the grade-tonnage graph in Figure 2 for Mponeng Mine it would indicate approximately 16 Mt at an average grade of approximately 18 g/t. For Kusasalethu mine, the cut-off grade of 8.9 g/t would correspond to approximately 6 Mt at an average grade of approximately 12 g/t. The tonnages and grades published for the Mineral Reserves for both mines are significantly lower as shown in Figures 7 and 8.

**Gold – Mineral Reserve estimates at 30 June 2023**

| | Proved | | | | Probable | | | | Total | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Tonnes | Gold | | | Tonnes | Gold | | | Tonnes | Gold | | |
| | (Mt) | (g/t) | (000kg) | (000oz) | (Mt) | (g/t) | (000kg) | (000oz) | (Mt) | (g/t) | (000kg) | (000oz) |
| Mponeng | 2.7 | 9.68 | 26 | 834 | 3.3 | 8.87 | 29 | 946 | 6.0 | 9.23 | 55 | 1 779 |

**FIG 7** – The Mineral Reserves of Mponeng Mine for 2023 (Harmony Gold Mining Company Limited, 2023).

**Gold – Mineral Reserve estimates at 30 June 2023**

| | Proved | | | | Probable | | | | Total | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Tonnes | Gold | | | Tonnes | Gold | | | Tonnes | Gold | | |
| | (Mt) | (g/t) | (000kg) | (000oz) | (Mt) | (g/t) | (000kg) | (000oz) | (Mt) | (g/t) | (000kg) | (000oz) |
| Ventersdorp Contact Reef | 1.7 | 7.44 | 12 | 402 | 0.1 | 5.04 | 0.3 | 10 | 1.7 | 7.36 | 13 | 412 |

**FIG 8** – The Mineral Reserves of Kusasalethu Mine for 2023 (Harmony Gold Mining Company Limited, 2023).

The Mineral Reserve statements show that there is a significant drop in both tonnage and grades for both mines when compared to what is expected and this shows the impact of the modifying factors. However, there could be confusion amongst investors when considering the significant deviation from what would be expected by applying a cut-off grade calculated using the published figures. It is understanding these types of inconsistencies in public reporting that Mining Engineering academics could be interested in.

## PROBLEM STATEMENT

Faced with the type of research questions raised above, the author developed an optimisation model which has the mine's block models as its starting data set. For initial studies, block models were obtained directly from various South African gold mines. However, these mines could not be named in the various research publications and only a limited number of block models could be obtained. Mines do not make their block models available in the public domain. The author required a broader spread of South African mines for his PhD research into the effect of the mineral resources royalty that was introduced in 2010. A method was thus developed to simulate the block models from the published information in the various companies' Mineral Resource and Reserve statements (Birch, 2022).

## BLOCK MODEL SIMULATION METHOD

The first step in the block simulation process is to establish the grade-tonnage profile. Measurements are taken at regular grade intervals. For Mponeng Mine and the example from Kusasalethu Mine shown in Figure 9, 1.0 g/t intervals were selected.

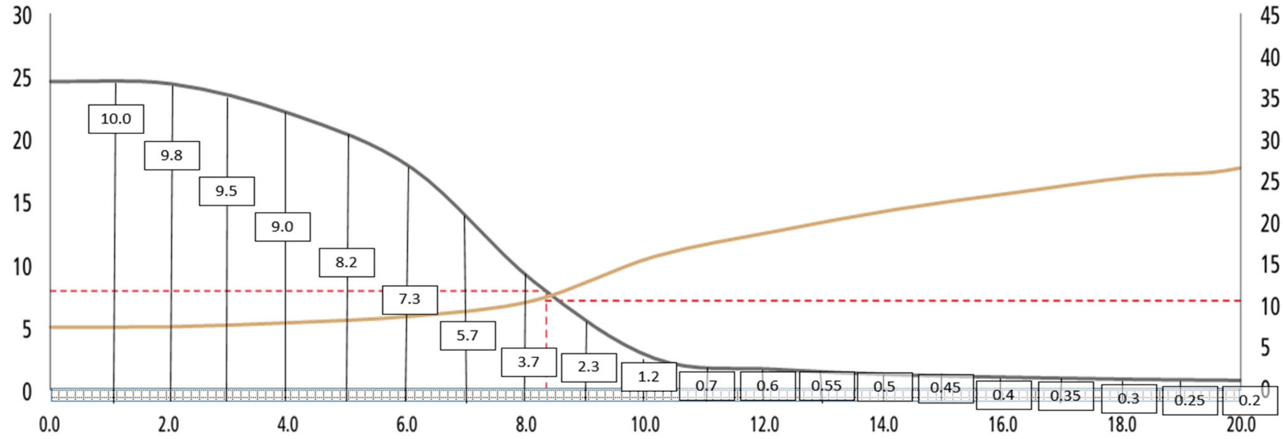


**FIG 9** – Establishing the grade-tonnage profile for Kusasalethu Mine in 1 g/t intervals.

Figure 9 displays the grade profiling for Kusasalethu Mine. For Mponeng Mine, there are no tonnes included below 5 g/t due to the application of a Mineral Resource cut-off in the published grade-tonnage curve. The assumption for this is that all the blocks with grades lower than the resource cut-off grade have been excluded from the block list used to create the published grade-tonnage curve. This was not found to be the case with Kusasalethu where all the blocks above 1 g/t appeared to be included in the block listing used to create the published grade-tonnage curve (Harmony Gold Mining Company Limited, 2023).

The lengths of the lines can be proportioned and tonnages can be allocated to each grade category. These are listed in Appendix A for Mponeng Mine and Appendix B for Kusasalethu Mine.

For Mponeng Mine, the 25.4 Mt is allocated to the grade categories. There are 5 Mt in the blocks with grades above 20 g/t and these are split into the next seven grade categories due to the truncation of the published grade tonnage curve. The balance is split into grade categories and allocated to the mid-point grades. The grade categories with the tonnage percentage allocated to each category are displayed in Figure 10 for Mponeng Mine.

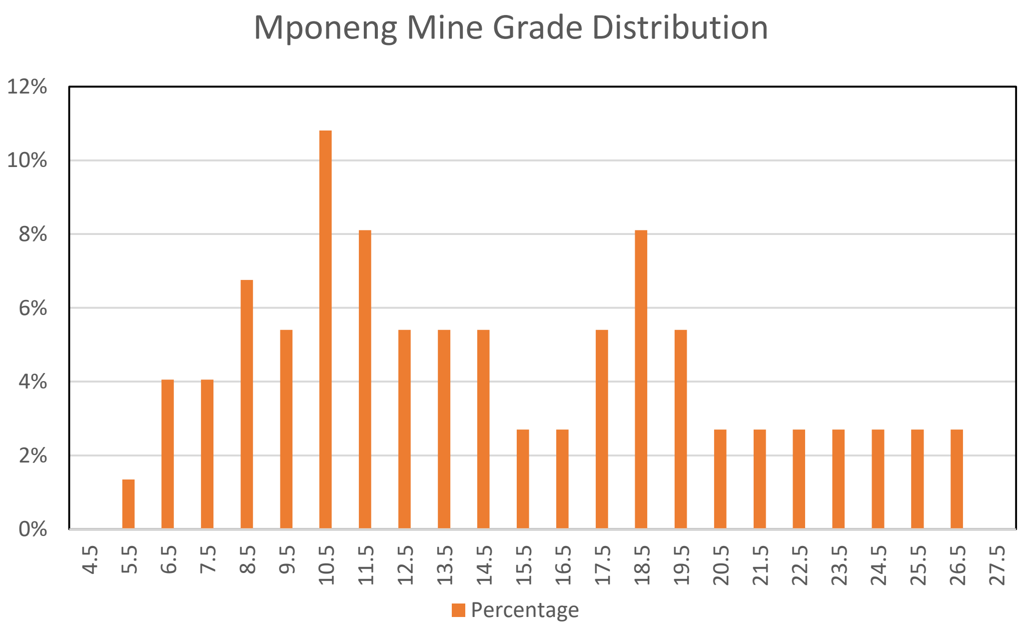


**FIG 10** – Grade-tonnage percentage distribution for Mponeng Mine.

The bimodal nature of the grades noted at Mponeng Mine (Figure 10) are considered to represent the profiles of the two different orebodies being mined there (VCR and CLR). At Kusasalethu (Figure 11), only VCR is being mined. However, the profile includes blocks in grade categories which are below the resource cut-off grade used to declare the Mineral Resource (8.2 g/t).

The bimodal distribution at Mponeng would ideally require the VCR and CLR to be modelled separately. However, the available single combined grade-tonnage curve on which this study relies on does not allow this and so only single lognormal distributions were applied to create the Measured and Indicated block lists respectively.

This process was repeated for Kusasalethu Mine. The grade categories with the tonnage percentage allocated to each category are displayed in Figure 11 for Kusasalethu Mine.

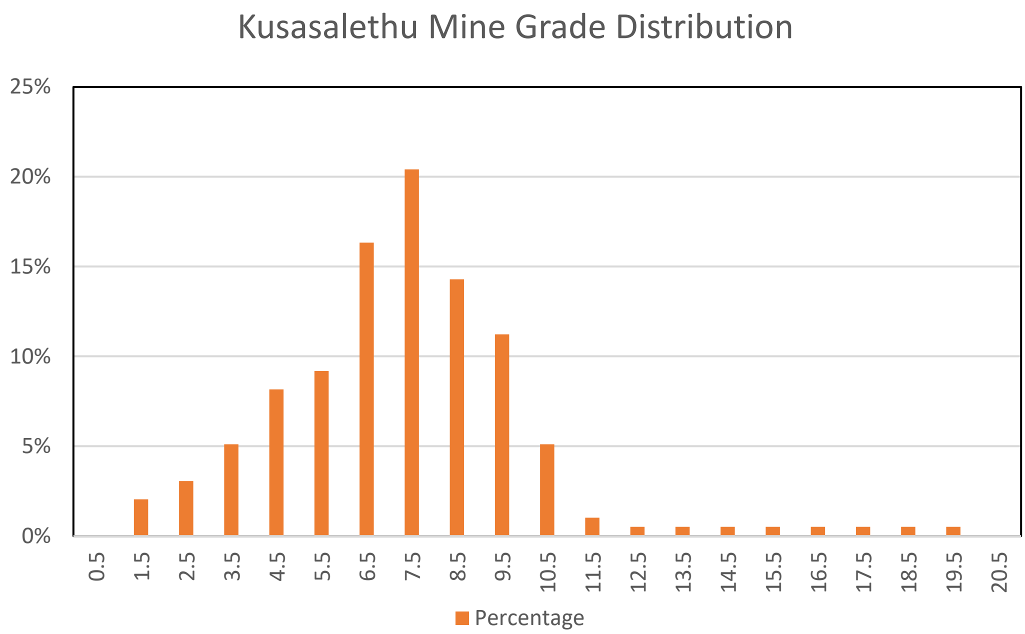


**FIG 11** – Grade-tonnage percentage distribution for Kusasalethu Mine.

If only the blocks are included above the resource cut-off grade to ensure the resultant simulated block model fits the published figures, the shape would not then be considered lognormal because the peak is found to be 7.5 g/t. In this case, an exponential profile provides a better fit. This is shown in Figure 12.

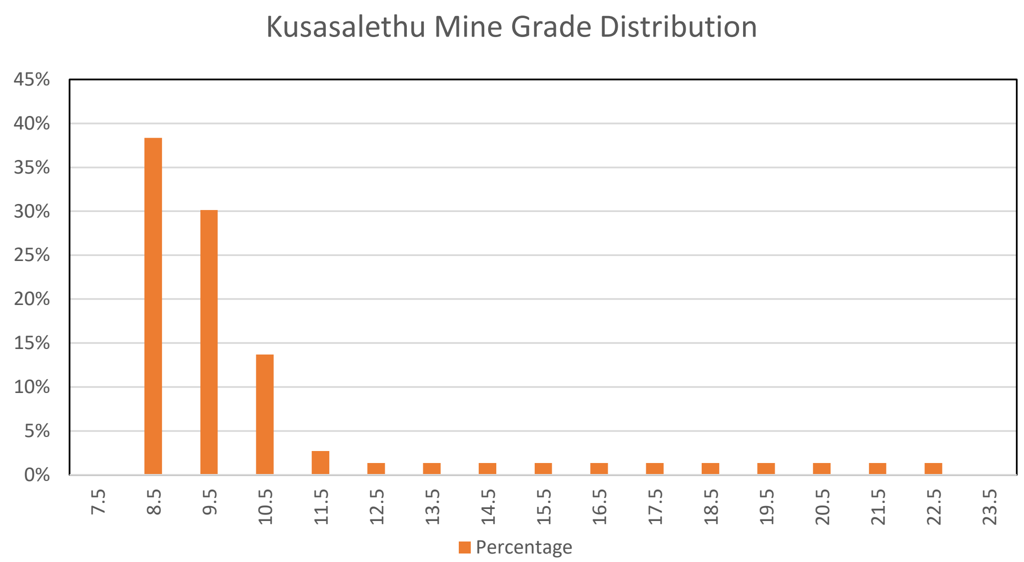


**FIG 12** – Grade-tonnage percentage distribution for Kusasalethu Mine applying the Mineral Resource cut-off grade of 8.2 g/t.

The next step in simulating the block list requires the use of distribution fitting software (Risk Simulator 2023). A lognormal distribution was identified by the distribution fitting exercise as being appropriate for Mponeng Mine. Although a two- or even three-parameter lognormal type would probably better model the gold grade distribution, the additional parameters could not be reliably determined from the information available in the published grade-tonnage curves. Ideally, Mponeng Mine would be split into the two different orebodies (VCR and CLR) and not modelled as a single unit. However, the published grade-tonnage curves have combined the two into a single graphic and therefore cannot be split.

For Kusasalethu Mine, two methods were tested. Initially, the lognormal distribution was tried. The minimum value was set to the Mineral Resource cut-off grade (8.2 g/t) and the mean values for the Measured and Indicated blocks were used (13.5 and 10.1 g/t, respectively). Secondly, an exponential distribution was selected. The minimum value was set to the Mineral Resource cut-off grade (8.2 g/t) and a maximum of 22 g/t was specified. The lambda value was adjusted to alter the shape of the distribution curve until the desired total gold kilograms for the two resource categories were obtained. Lambda represents the rate parameter, which determines the shape and scale of the distribution.

The parameters used to populate the grades of the blocks for the Measured and Indicated Reserves, respectively, are shown in Table 2.

**TABLE 2**

Input parameters for simulating block grades.

| Mine | Classification | Mean | Standard deviation |
|---|---|---|---|
| Mponeng Mine | Measured Resource | 18.1 | 9.1 |
| | Indicated Resource | 14.2 | 7.2 |
| Kusasalethu Mine | Measured Resource | 13.5 | 3.5 |
| | Indicated Resource | 10.1 | 1.2 |
| **Mine** | **Classification** | **Mean** | **Lambda** |
| Kusasalethu Mine | Measured Resource | 13.5 | 0.1 |
| | Indicated Resource | 10.1 | 0.5 |

The tonnage for the blocks to be populated (split into Measured and Inferred) is determined by the block sizes indicated in the annual Mineral Resource and Reserve reports, stoping width, and the density. For both Mponeng and Kusasalethu mines, the Measured Resource blocks are stated to be 30 m × 30 m, whilst the Indicated Resource blocks are stated to be 60 m × 60 m. The resultant areas are thus 900 $m^2$ and 3600 $m^2$ respectively.

For Mponeng Mine, company states that the Mineral Resource is stated with an average width of 136 cm (153 cm for the VCR and 125 cm for the CLR). The average width (channel width) is different from the average stoping width which is published to be 147 cm (Harmony Gold Mining Company Limited, 2023).

On Kusasalethu Mine, the average channel width is not stated, but the stoping width is 132 cm.

The channel widths are used for this exercise for Mponeng Mine because the purpose is to demonstrate the process to simulate the grade-tonnage curve. The stoping width is used for Kusasalethu Mine because the channel width is not stated and thus it is assumed that the Mineral Resource is estimated using the stoping width. For mining optimisation studies, the stoping width would be used as the input into the financial model. The density assumed for the exercise is 2.72.

The mine estimated the grades for the Measured Mineral Resource using ordinary kriging, whilst simple macro-kriging is used for the Indicated Mineral Resource (Harmony Gold Mining Company Limited, 2023). The mean grades for the Measured and Indicated blocks were selected to match the average grades for the two resource categories indicated in the published resource estimates shown in Figure 4. The standard deviations or lambda values were adjusted so that the total gold kilograms matched the published grams as shown in Figures 5 and 6. Table 3 shows how the number of blocks was required to populate the simulated block model.

**TABLE 3**
Number of blocks in the simulated block model.

| Mine | Classification | Published tonnage | Tonnage per block | Number of blocks |
|---|---|---|---|---|
| Mponeng Mine | Measured Resource | 4 600 000 | 3329 | 1382 |
| | Indicated Resource | 20 800 000 | 13 317 | 1562 |
| Kusasalethu Mine | Measured Resource | 1 600 000 | 3231 | 496 |
| | Indicated Resource | 6 500 000 | 12 925 | 503 |

## OBSERVATIONS AND FINDINGS

Figure 13 shows the simulated grade-tonnage curves for Mponeng. The break-even cut-off grades determined in Table 1 are indicated, along with the corresponding tonnes and average grades above the cut-off grade.

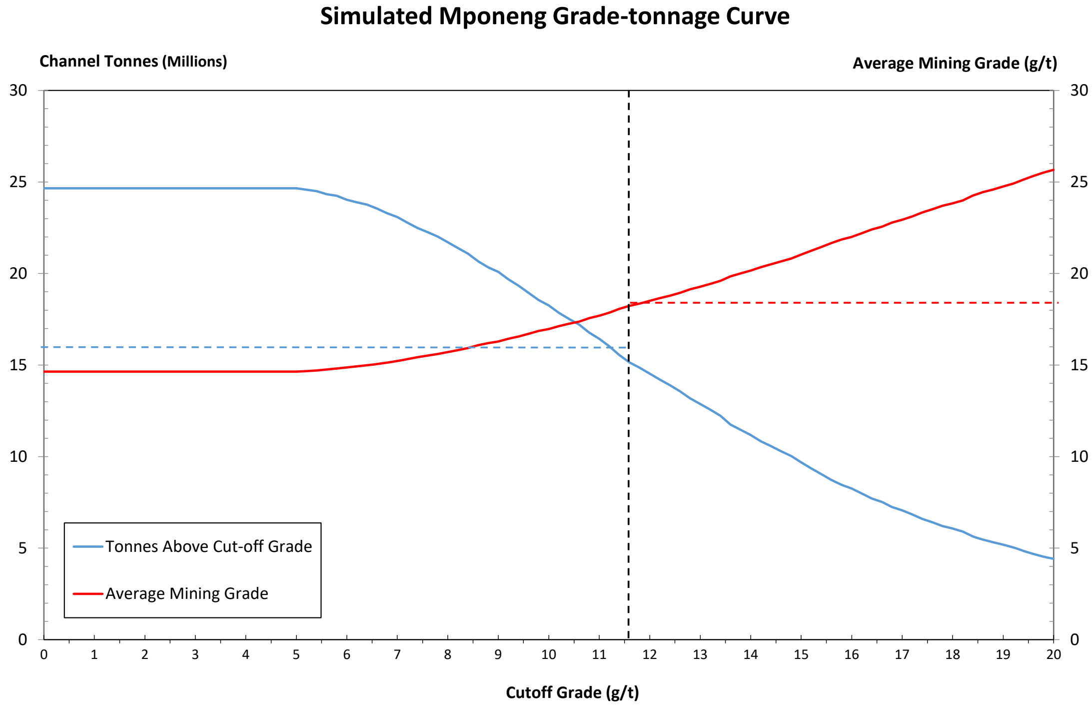


**FIG 13** – Simulated grade-tonnage curve for Mponeng Mine (lognormal distribution).

In the simulated grade-tonnage curve for Mponeng (Figure 13), it can be observed that for a break-even cut-off grade of 11.6 g/t (from Table 1) there are approximately 15.2 Mt at an average grade above cut-off grade of 18.2 g/t. Considering the published grade-tonnage curve in Figure 2 (approximately 16 Mt at approximately 18 g/t), these appear to be fairly close considering the resolution of the figure and the lack of intermediate markers.

Figures 14 and 15 show the simulated grade-tonnage curves for Kusasalethu Mine created using lognormal and exponential distributions respectively. The break-even cut-off grades determined in Table 1 are indicated, along with the corresponding tonnes and average grades above the cut-off grade.

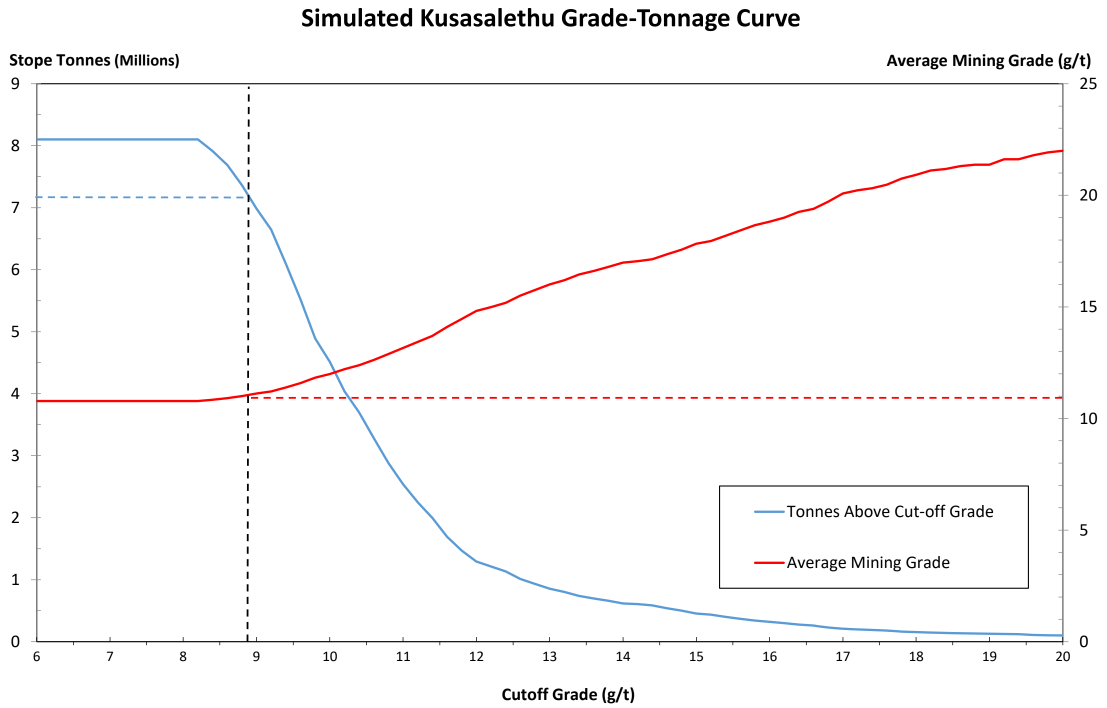


**FIG 14** – Simulated grader-tonnage curve for Kusasalethu Mine (lognormal distribution).

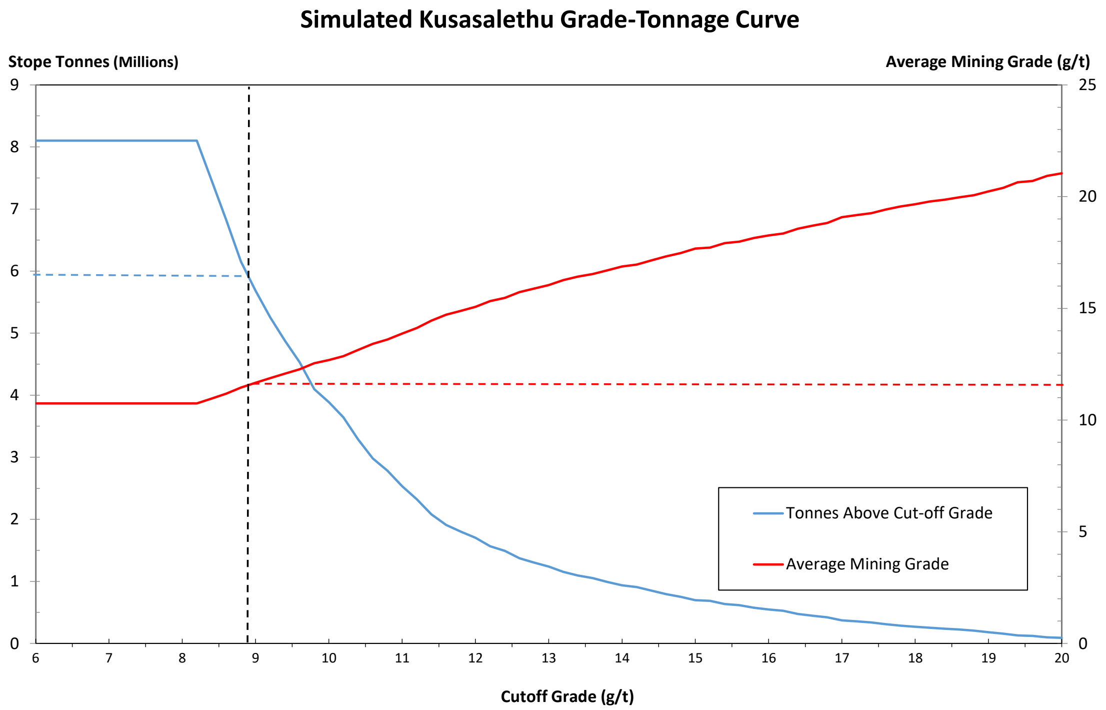


**FIG 15** – Simulated grade-tonnage curve for Kusasalethu Mine (exponential distribution).

It can be observed in Figure 14 that the tonnages above the break-even cut-off grade of 8.9 g/t result in 7.2 Mt. The average grade above cut-off grade is 11 g/t. The tonnages are higher than expected from the published grade-tonnage curve (6 Mt), whilst the grade is lower (12 g/t). As a result of these differences, the exponential distribution was also tested and this is displayed in Figure 15.

Using the exponential distribution, the break-even cut-off grade of 8.9 g/t results in 5.9 Mt above the cut-off grade, with an average grade of 11.6 g/t. This compares favourably with the estimates from Figure 3 (6 Mt above cut-off grade at an average of 12 g/t).

Figure 16 shows the differences in percentages for the various grade categories for Mponeng Mine.

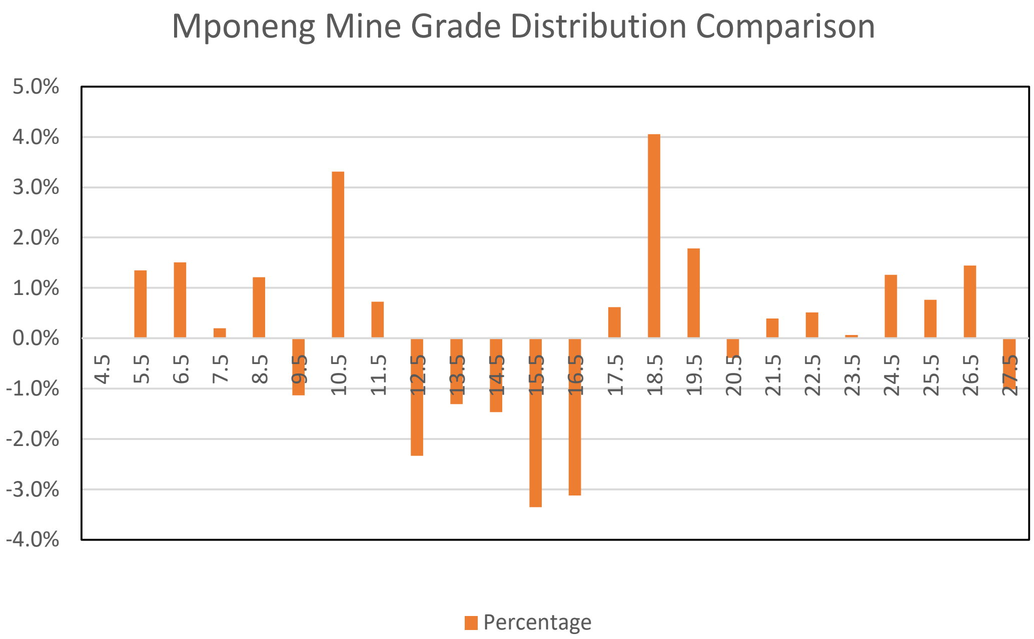


**FIG 16** – The tonnage distribution differences for the various grade categories for Mponeng Mine.

Figure 16 shows the effect of the bimodal distribution with the simulation generally allocating more tonnage in the range from 5.5 to 10.5 g/t, whilst less tonnages in the range from 12.5 to 16.5 g/t. However, the differences are small, mostly 2 per cent. The greatest difference is 4 per cent in the 18.5 g/t category.

Figures 17 and 18 show the tonnage distribution differences for the Kusasalethu Mine using the two distributions tested.

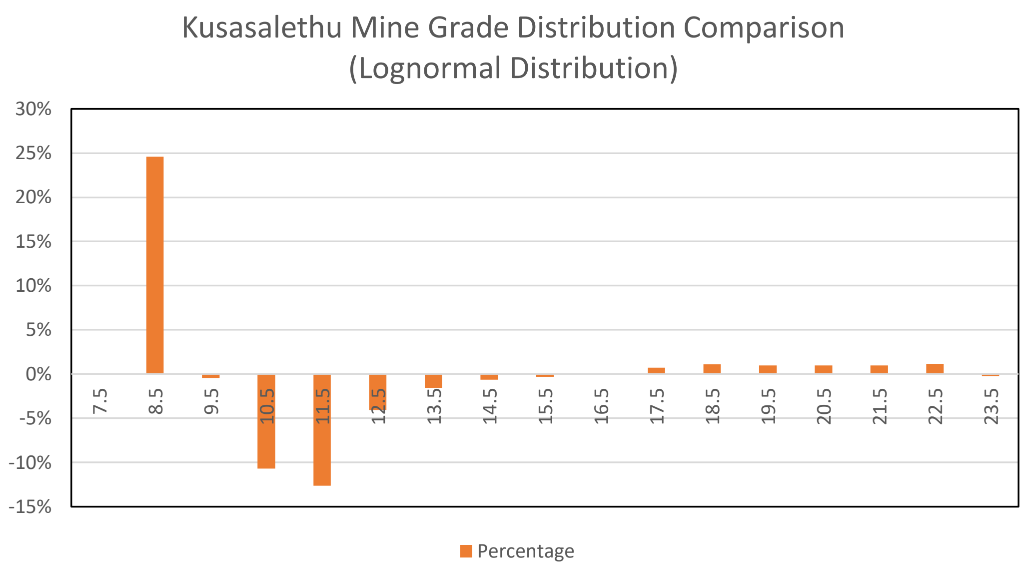


**FIG 17** – The tonnage distribution differences for the various grade categories for Kusasalethu Mine (lognormal distribution).

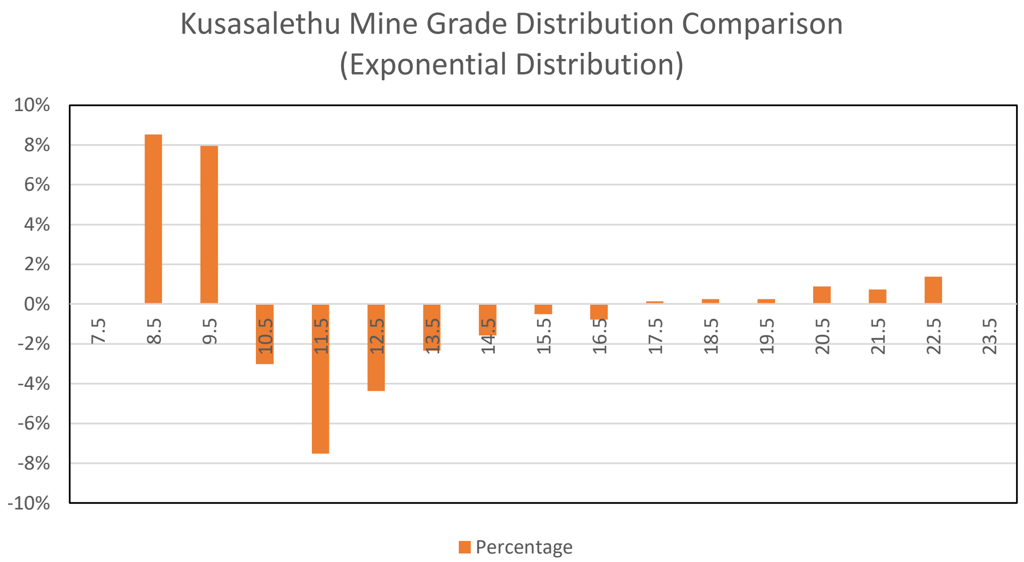


**FIG 18** – The tonnage distribution differences for the various grade categories for Kusasalethu Mine (exponential distribution).

The tonnage distribution differences for the various grade categories when using the lognormal distribution support the differences noted in Figure 14. There are too many tonnes allocated in the 8 to 9 g/t category (almost 25 per cent) which alters the average tonnes and grade above cut-off grade when a break-even cut-off grade of 8.9 g/t is applied.

Although the overall results for the exponential distribution compare better to Figure 2 than the lognormal distribution, there are still some differences when considering the tonnage distributions. The simulation allocates more tonnage in the 8.5 to 9.5 g/t range, while less in the 10.5 to 14.5 g/t range. Considering that the break-even cut-off grade (11.6 g/t) falls within this portion of the distribution curve, differences of up to 8 per cent could be significant if using the simulation for mine planning and financial optimisation research. Utilising software that allows greater control over the shape of the distribution curve could provide a solution to this. Risk Simulator 2023 only allowed the lambda to be altered for the exponential distribution curve. Software used previously for this type of modelling exercise by the author, Palisade @Risk, generated more accurate distribution curves, and the resultant simulations better matched the published grade-tonnage curves.

## CONCLUSIONS

The author encountered a problem when requiring block lists for research purposes. These block lists are used by companies to create their published Mineral Resource tables and their grade-tonnage curves are not available in the public domain. Lognormal grade distributions are typically considered applicable for the gold deposits of the Witwatersrand, and these distributions were applied to create simulated block lists using publicly available information. However, this method did not always yield the best results and required further refinement to better approximate the published grade-tonnage curves. Two South African deep-level gold mines (Mponeng and Kusasalethu) were selected for this paper to highlight some challenges faced when simulating block listings.

The company published the Mineral Resource figures and grade-tonnage curves for the two mines differently. For Mponeng Mine, the VCR and CLR are combined into a single grade-tonnage curve with a mineral resource cut-off grade applied. For Kusasalethu Mine, the grade-tonnage curve represents a single orebody (VCR) without a resource cut-off grade. The Mineral Resources for Mponeng Mine are stated over the channel width, whereas for Kusasalethu Mine, they are stated over the expected stoping width. These differences are noteworthy because the two mines belong to the same company and are reported in the same Annual Resources and Reserves statement in neighbouring chapters. One would expect a company to standardise reporting across similar operations.

The lognormal distribution used for Mponeng Mine approximated the overall grade-tonnage profile published in the public domain fairly closely. However, the bimodal distribution in the grades (likely due to the combination of VCR and CLR) results in some inconsistencies in the distribution of the tonnages into the various grade categories. These inconsistencies are generally minor but would need further investigation if they affect the region of the grade-tonnage curve where the break-even cut-off grade is applied.

The lognormal distribution for Kusasalethu Mine did not yield an accurate block listing compared to the overall grade-tonnage profile published in the public domain. The published grade-tonnage curve included all the blocks below the Mineral Resource cut-off grade (8.2 g/t), totalling 25 Mt. The simulated block list excluded blocks below this grade to ensure the simulated blocks matched the published tonnages in the Measured and Indicated Mineral Resources statement. The truncated nature of the resultant simulated block list resulted in a distribution that the lognormal distribution poorly matched. An exponential distribution was thus selected, which provided a better match. Like the simulated block listing for Mponeng Mine, there are areas where the fit is not ideal, requiring further investigation to determine if the differences are critical to the research outcomes.

When developing the method for his PhD research, the author had access to Palisade @Risk software, which offers more options for fitting distributions than the Risk Simulator 2023 software used for this paper. The author required the block lists for comparing the effects of different approaches in considering the costs of the mineral resource royalty. This method for generating the block lists was deemed acceptable because the errors would be consistent across all approaches being compared. It thus did not affect the overall findings of the PhD project. However, depending on the requirements of the research, this method may not be suitable for all projects requiring block listings. The simulated lists need to be tested against the original grade-tonnage curves, particularly in the grade regions that would significantly impact the final results.

## ACKNOWLEDGEMENTS

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## APPENDIX

### Appendix A – Allocating tonnages to grade categories for Mponeng Mine

| Grades (g/t) | Measure (cm) | Proportion | Tonnage |
|---|---|---|---|
| <5 | 7.6 | 0.0 | 0.00 |
| 5.5 | 7.5 | 0.1 | 0.34 |
| 6.5 | 7.2 | 0.3 | 1.03 |
| 7.5 | 6.9 | 0.3 | 1.03 |
| 8.5 | 6.4 | 0.5 | 1.72 |
| 9.5 | 6.0 | 0.4 | 1.37 |
| 10.5 | 5.2 | 0.8 | 2.75 |
| 11.5 | 4.6 | 0.6 | 2.06 |
| 12.5 | 4.2 | 0.4 | 1.37 |
| 13.5 | 3.8 | 0.4 | 1.37 |
| 14.5 | 3.4 | 0.4 | 1.37 |
| 15.5 | 3.2 | 0.2 | 0.69 |
| 16.5 | 3.0 | 0.2 | 0.69 |
| 17.5 | 2.6 | 0.4 | 1.37 |
| 18.5 | 2.0 | 0.6 | 2.06 |
| 19.5 | 1.6 | 0.4 | 1.37 |
| 20.5 | 1.4 | 0.2 | 0.69 |
| 21.5 | 1.2 | 0.2 | 0.69 |
| 22.5 | 1.0 | 0.2 | 0.69 |
| 23.5 | 0.8 | 0.2 | 0.69 |
| 24.5 | 0.6 | 0.2 | 0.69 |
| 25.5 | 0.4 | 0.2 | 0.69 |
| 26.5 | 0.2 | 0.2 | 0.69 |
| **Total** | | **7.4** | **25.40** |

## Appendix B – Allocating tonnages to grade categories for Kusasalethu Mine

| Grades (g/t) | Measure (cm) | Proportion | Tonnage |
|---|---|---|---|
| 0.5 | 10 | 0 | 0.00 |
| 1.5 | 9.8 | 0.2 | 0.50 |
| 2.5 | 9.5 | 0.3 | 0.75 |
| 3.5 | 9 | 0.5 | 1.25 |
| 4.5 | 8.2 | 0.8 | 2.00 |
| 5.5 | 7.3 | 0.9 | 2.25 |
| 6.5 | 5.7 | 1.6 | 4.00 |
| 7.5 | 3.7 | 2 | 5.00 |
| 8.5 | 2.3 | 1.4 | 3.50 |
| 9.5 | 1.2 | 1.1 | 2.75 |
| 10.5 | 0.7 | 0.5 | 1.25 |
| 11.5 | 0.6 | 0.1 | 0.25 |
| 12.5 | 0.55 | 0.05 | 0.13 |
| 13.5 | 0.5 | 0.05 | 0.13 |
| 14.5 | 0.45 | 0.05 | 0.13 |
| 15.5 | 0.4 | 0.05 | 0.13 |
| 16.5 | 0.35 | 0.05 | 0.13 |
| 17.5 | 0.3 | 0.05 | 0.13 |
| 18.5 | 0.25 | 0.05 | 0.13 |
| 19.5 | 0.2 | 0.05 | 0.13 |
| 20.5 | 0.15 | 0.05 | 0.13 |
| 21.5 | 0.1 | 0.05 | 0.13 |
| 22.5 | 0.05 | 0.05 | 0.13 |
| 23.5 | 0.05 | 0.05 | 0.13 |
| **Total** | | **10.0** | **25.00** |

# Review 70 years of achievements and high-quality development architecture system of open pit coalmines in China

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## ABSTRACT

As an important component of China's coal industry, open pit coalmines have the advantages of large production capacity, low mining costs, and great safety conditions. In recent years, open pit coalmines in China have achieved leapfrog development in construction scale, total production, mining technology, and technical equipment, which strongly guarantees the status of coal as the 'ballast' for the safe and stable supply of national energy. Firstly, the development process of open pit coalmines in China over the past 70 years after the founding of the People's Republic of China was reviewed, which was divided into four stages: the initial recovery stage (1949–1979), the rapid development stage (1980–1999), the comprehensive development stage (2000–2020), and the intelligent primary development (after 2021). A systematic summary was made of the outstanding achievements made in the production and quantity scale, mining theory and technology, mining technology and equipment, and resource development and environmental protection in each stage. Then, four main problems faced by the development of open pit coalmines at the current stage were discussed, including uneven development layout, bottlenecks in sustainable development, key technological problems that need to be deeply researched, and the shortage of talents and imperfect cultivation mechanisms. Finally, this paper proposed to construct a high-quality development architecture system for 'safe, efficient, green, low-carbon, intelligent' as the overall goal, including six academic ideas as the theoretical basis: time-dependent slope theory, mining disturbance coefficient theory, green mining theory, ecological mining theory, zero carbon and carbon negative mining theory, and intelligent mining theory. As well as the five technology systems as the core support, 30 key technologies to breakthroughs, and ten construction tasks of open pit mines. At the same time, the realisation path of high-quality development of open pit coalmines was provided. Ultimately, it provides guidance to promote the sustainable, healthy, and high-quality development of open pit coalmines in China.

## INTRODUCTION

China's open pit coal mining originated in 1914 (the predecessor of the Fushun West open pit mine) 1914, known as the first open pit coalmine in China. It has a history of 110 years. But the real great development of open pit coalmines began with the founding of new China, and the vigorous development began with the reform and opening up (Coal Industry Committee of Technology Association, China Coal Society Open Mining Committee, Coal Industry Planning and Design Research Institute Co., Ltd, 2015a). Since the beginning of the 21st century, China's open pit coal mining output has exceeded that of other coal-producing countries, ranking first in the world. China's open pit coal industry has formed a new situation of leap-forward development. During this period, China's open pit coalmine industry has written a magnificent chapter, from small to large and from weak to strong.

Based on the construction and development process of the open pit coalmine in the past 70 years after the founding of new China, in terms of open mining theory and technology, after initial recovery, integration and exchange between China and the west, western technology digestion, absorption and innovation, and fully independent intellectual property rights, has now been walking in the forefront of the world. In terms of the open pit mining process, completed from the discontinuous mining process to the semi-continuous mining process, the continuous mining process, then to the development of comprehensive mining technology. In terms of open pit mining equipment, realise from a few cubic metres of bucket capacity, more than ten tons of loading capacity of small equipment to nearly 100 cubic metres of bucket capacity, hundreds of tons of load capacity, and continuous mining with high-speed wide tape of large mining and transportation equipment across. In terms of total open pit raw coal production, achieved a leap from one million tons (Mt), ten Mt, ten Mt to one billion tons (Bt). In terms of the open-air development mode, gradually realised from the single coal resource development to sustainable circular economy (Cai *et al*, 2002; Li *et al*, 2019; Liu, Guo and Zhao, 2022; Qian, Xu and Wang, 2018).

In 2022, the production capacity and output of open pit coalmines in China both exceeded 1 Bt for the first time, accounting for about 8 per cent of the number of coalmines, contributing about 23 per cent of the country's coal output, opening a new starting point of open pit coal mining (Ding, 2023). While the production and supply capacity continues to enhance, the intelligent level of an open pit coalmines is also accelerated, and the intelligent application scenarios represented by intelligent, comprehensive control platforms, unmanned driving, intelligent monitoring and early warning, intelligent penetration, and explosion are constantly enriched in (Wang, 2022). However, with the vigorous development of open pit coal mining, it is also faced with some problems, such as environmental problems such as land excavation, air pollution, groundwater loss (Li, 2023b), the low utilisation rate of associated resources in the mining process and the waste of stranded resources also need to be solved urgently.

In conclusion, on the occasion of China's open pit coalmine in twists and turns, development, innovation, and climbing, this paper, the first review of the 70 years of the founding of the new China open coalmine construction history and development, the period of open coalmine production and quantity scale, open pit mining theory and technology, mining technology and equipment, resource development and environmental protection of outstanding achievements in the system summary. Then, the main problems in the development of open pit coalmines are analysed. Finally, according to the overall goal and development trend of open pit coalmine construction in the new period, the high-quality development framework system and realisation path of open pit coalmines are proposed. In order to provide a reference for promoting the sustainable, rapid, healthy, and high-quality development of open pit coalmines in China.

## THE CONSTRUCTION PROCESS OF OPEN PIT COALMINE IN CHINA

After the founding of new China, along with the progress of socialist construction, China's open pit coalmine cause has made great achievements. According to the number of open pit coalmines in different periods, production, mining theory, technology, and process equipment development index, the open pit coalmine construction since 1949 is divided into four stages, including the start recovery stage (1949–1979), rapid development stage (1980–1999), comprehensive development stage (2000–2020) and intelligent primary development stage (2021) four periods.

### Initial recovery phase (1949–1979)

With the reconstruction and expansion of the Fuxin Haizhou open pit coalmine and the later Fushun West open pit coalmine as symbols, the construction of open pit coalmines in China has entered the initial recovery period, which was defined from the founding of the New China to 30 years before the reform and opening up.

After the founding of the New China, after three years of national economic recovery, the state planned the first five-year plan (1953–1957). 'The first five' plan determined a total of three open pit coalmine projects, respectively, Fuxin Haizhou open pit coalmine, Fushun West open pit coalmine, Fushun east open pit coalmine (Xu, 2007). With the steady progress of the 'First Five-Year Plan' and the resumption of the original open pit coalmines, the output of open pit coalmines in China reached 10.08 Mt/a in 1957, accounting for 6.75 per cent of the total coal output in that year, which increased by 213 per cent compared with the output of open pit raw coal in 1949. At the end of the first Five Year Plan, there are more than 20 open pit coalmines in China, with a total design capacity of 10.33 Mt/a. So far, China's open pit coalmine industry has entered the healthy development track.

Based on the construction of the 'five' plan, 'five' plan and three years adjustment period (1958–1965), the national planning and design of Hami Sandaoling, Yima north, Kebao, Yilan, PingZhuang west, Gongwusu, Hegangling north, Buzhaoba open pit coalmine, at the same time to Haizhou open coalmine, Fushun west open pit coalmine for the expansion and technical transformation. Compared with the 'First Five-Year Plan' period, the annual capacity of open pit coalmines increased by about 8 Mt, and the number of open pit coalmines increased to more than 30, with a total designed capacity of more than 17 Mt/a. At the same time, the distribution range of open pit coalmines has gradually expanded from Liaoning to Henan, Xinjiang, Shandong, and other places. With the improvement of open pit coalmines' number and production capacity, China's open pit production capacity reached 24.62 Mt in 1960. Due to the early mining exploitation ratio imbalance, combined with the technical constraints, during the '25' the open coal production for years to the end of the 'fifth' plan (1965), the national open capacity into the lowest peak, state-owned key open pit coalmine production of only 4.22 Mt, open production proportion of total coal production fell to 1.8 per cent.

During 1966–1979, the 'three five' and 'four five' plans were successively completed, along with the completion and operation of Pingzhuang West, Jalainur Lingquan, Yunnan Kebao, Yima North, Hami Sandaoling, Hegangling North, Haibowan Gongwusu and Carboniferous Well Dafeng (Wei, 1989). China's open pit coal production began to rise. From 1966 to 1979, the annual output of key state-owned open pit coalmines increased from 7.6 Mt to 16.56 Mt, an increase of 118 per cent.

At this stage, China's open pit coal production has experienced a 'start development-trough-gradually recover' three processes (Figure 1), the open pit coalmine development in twists and turns, in developing adjustment, recovery in adjustment, consolidate in recovery, improvement in consolidation, in order to enter the rapid development stage laid a good foundation.

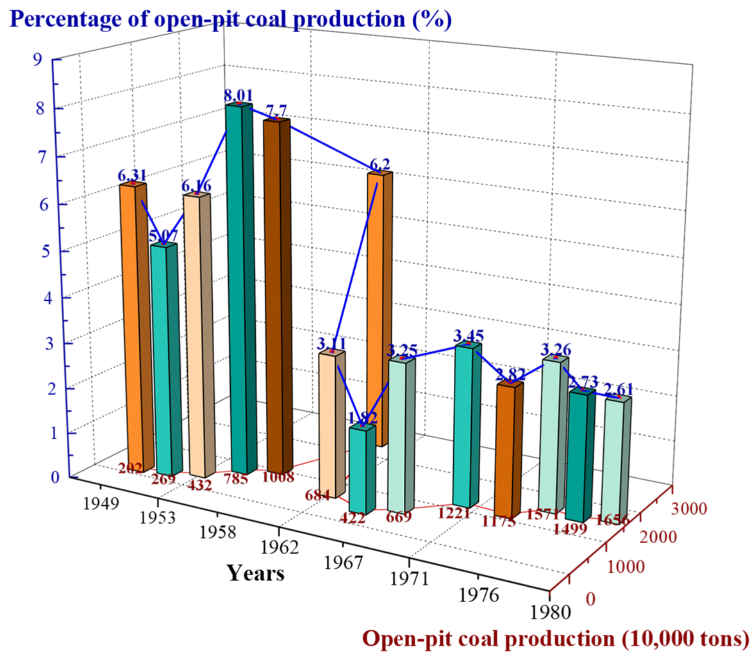


**FIG 1** – Annual production of open pit coalmines and its proportion in total coal production during the start-up rehabilitation stage.

## Rapid development stage (1980–1999)

After the reform and opening up, the construction of open pit coalmines in China entered a stage of rapid development. The construction and operation of five open pit coalmines in Holland River, Yimin, Yuanbaoshan, Heidaigou, and Antaibao was the main symbol of this period, which was concentrated in the 20 years from 1980 to 1999.

Under the birth of the spring breeze of reform, the construction of open pit coalmines in China has entered a period of rapid development, guided by the national policy of 'giving priority to the development of open pit coalmines' and 'opening large open coalmines as far as possible'. Through the introduction of large open pit mining equipment, the cooperative design of five open pit coalmines, and the cooperative development and operation of Antaibao open pit mines, the construction process of open pit coalmines in China has been greatly promoted, and the integration of Chinese and Western technology and construction concepts has been effectively promoted. During this period, China's open pit coal mining has made remarkable achievements in technology and construction scale.

In 1980, there were 18 open pit coalmines with a capacity of 0.3 Mt/a or above, and the total designed production capacity was 21.30 Mt/a. The national open coal production was 16.99 Mt, accounting for 2.7 per cent of the total national coal production; in 198 525.32 Mt, accounting for 2.9 per cent of the total national coal production, officially exceeding the open pit coal capacity in 1995, the national open coal production was 41.53 Mt, accounting for 3.2 per cent of the total national coal production (Figure 2). During this period, the super large open pit coalmine – Pingshuo An Taibao open pit coalmine developed by China, and the eight large open pit coalmines have also been put into operation, with a total design capacity of up to 48 Mt/a.

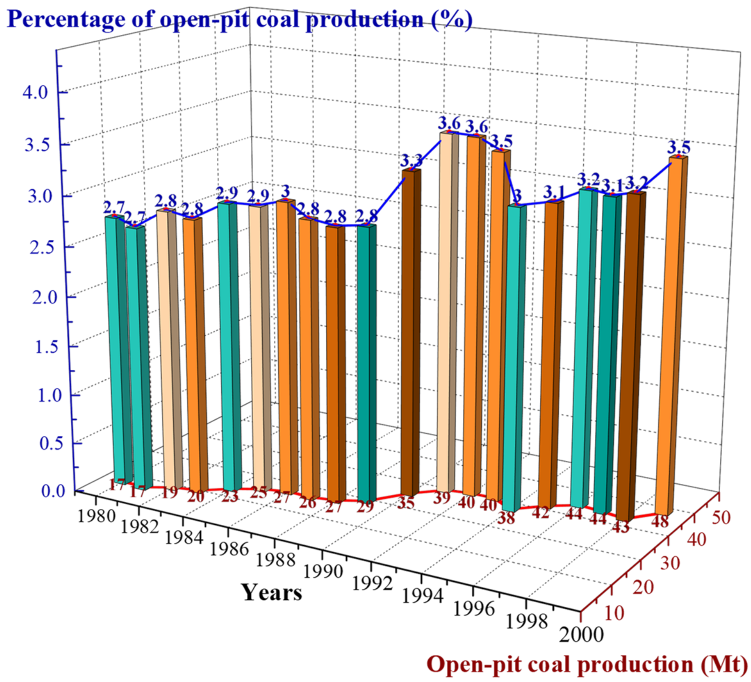


**FIG 2** – Annual production of open pit coalmines and its proportion in total coal production during the rapid development stage.

The great increase of national open pit coal production capacity and output is inseparable from the progress of mining theory and technology and mining technology. During the period of rapid development, the development and transportation system of the original open pit coalmine was optimised, and the single-truck intermittent process gradually replaced the original single-bucket-railway intermittent process and promoted on a large scale. The wheel bucket continuous process, semi-continuous process, and comprehensive mining process gradually began to apply (Ji, 2008). During this period, large-pit mining equipment was mainly introduced from abroad, supplemented by domestic equipment. At the same time, the construction and management mode of open pit coalmines also gradually show the characteristics of the market economy. While taking into account the production capacity, (Song *et al,* 2016a*,* 2018) also begins to pay attention to environmental protection and the effective utilisation of co-associated resources.

## Comprehensive development stage (2000–2020)

Since the beginning of the 21st century, with the deepening of the market economy and reform and opening up, the demand for energy in the development of the national economy has surged, which makes the construction of open pit coalmines usher in new development opportunities. Under the policy background of paying attention to production safety, building large open pit mines, improving coal resource recovery rate and green mining, China's open pit coalmines have made breakthrough achievements in scale output, mining theory, and mining technology, which are concentrated in the 20 years from 2000 to 2020.

By 2020, there are 53 large open pit coalmines of 4 Mt/a or above, with a total capacity of 637 million tons (Mt), of which 2610 Mt coalmines with a capacity of 493 Mt, accounting for 51.9 per cent of the national open-air capacity. In terms of output, the total output of open pit coalmines increased from 500 Mt in 2000 to more than 800 Mt, accounting for the total coal output to 21 per cent (Figure 3); in terms of mining process, the bucket-self-shift crusher-belt conveyor-dump process was greatly developed, and the shovel technology was applied (Cai *et al,* 2009); and the method of determining economic and reasonable exploitation ratio in the mining design of modern open pit coalmine, establishing the theory of open pit green mine, forming the comprehensive evaluation system of open pit coalmine with Chinese characteristics. At the same time, China's open pit coalmine industry has made innovative achievements in market reform, resource integration, safety regulation, construction of large bases, green mining, and other aspects, and formed an open pit coalmine technology system with its own characteristics.

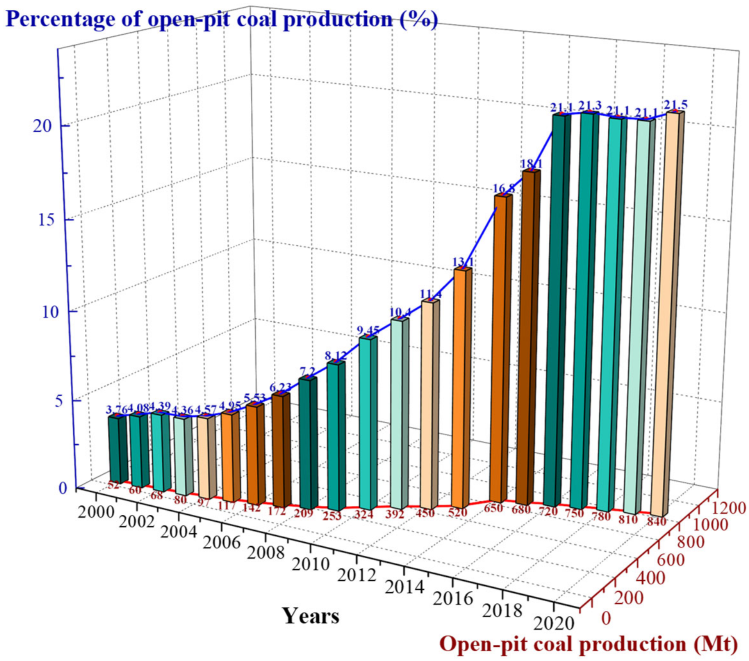


**FIG 3** – Annual production of open pit coalmines and its proportion in total coal production during the comprehensive development stage.

## Primary development stage of intelligence (after 2021)

Since 2020, as the National Development and Reform Commission, energy bureau, emergency department, coalmine safety bureau, and other eight ministries jointly issued 'about accelerating the development of intelligent coalmine guidance', China coal industry association issued the coal industry 'difference' high-quality development guidance, 'energy bureau and mine safety bureau issued' mine intelligent construction guide (2021 edition) and so on a batch of intelligent coalmine construction regulations of (Wang *et al,* 2022), open pit coalmine has entered a new stage of intelligent construction, the goal is to drive the overall improvement of mining technology, process equipment and intelligent level through scientific and technological innovation, to achieve the safe, green, small and efficient development of open pit coalmine.

In December 2021, the National Energy Administration issued the Measures for the Acceptance of Intelligent Demonstration Coalmines (Trial) (National Energy Coal Regulation (2021) No.69), which provided requirements and basis for the acceptance management of the first batch of intelligent demonstration coalmines in 71 countries. In the same year, the major coal provinces (autonomous regions) began to carry out the acceptance of intelligent coalmines. For example, by December 30, 2021, the Inner Mongolia Autonomous Region had completed the intelligent acceptance of 12 large open pit coalmines.

At present, the intelligent open pit coalmine construction work mainly around 5G + network integration, large data acquisition and analysis, intelligent integrated control platform, slope monitoring, 3D geological model construction, vehicle safety monitoring, broken station intelligent control, intelligent belt conveyor intelligent inspection, unmanned, intelligent drilling, intelligent transportation, intelligent loading, intelligent washing, fixed position unattended as the centre construction content, in these directions have made some progress in (China National Coal Association, 2024). Five open pit coalmines were selected as the first batch of national intelligent demonstration coalmines, and about 300 driverless vehicles were carried out to test (Ma, 2023) in more than 30 open pit coalmines. The above series of achievements mark the development of open pit coalmines in China gradually into the stage of intelligent construction.

Although the intelligent construction of the outdoor industry has made many achievements, overall, most of the intelligent construction of open pit coalmine work centre of gravity is focused on the informatisation, visualisation, unmanned etc, and most open pit coalmine intelligent work will not outsource part into the contracted construction category, and outsourcing contracted construction in China open pit coalmine is common and occupies a large proportion. It can be seen that the integration depth of intelligence and business systems is far from enough, and it is still in the stage of display, assistance, and standby. Compared with the intelligent application of integrated and integrated mines, China's open pit coalmine is relatively low, and is still in the stage of exploration and primary development (Yang *et al,* 2023).

Reviewing the construction process of China's open pit coalmine, from the initial recovery stage of 1949–1979 to the intelligent initial development stage after 2021, the production capacity and output of the national open pit coal have increased substantially, showing a whole upward trend (Figure 4). Open pit coal production increased by more than 520 times from 2.018 Mt in 1949 to 1.057 Mt in 2022. The open pit coal mining industry has shown a leapfrog development, which has made outstanding contributions to the development of China's coal industry and even the great development of China's industry.

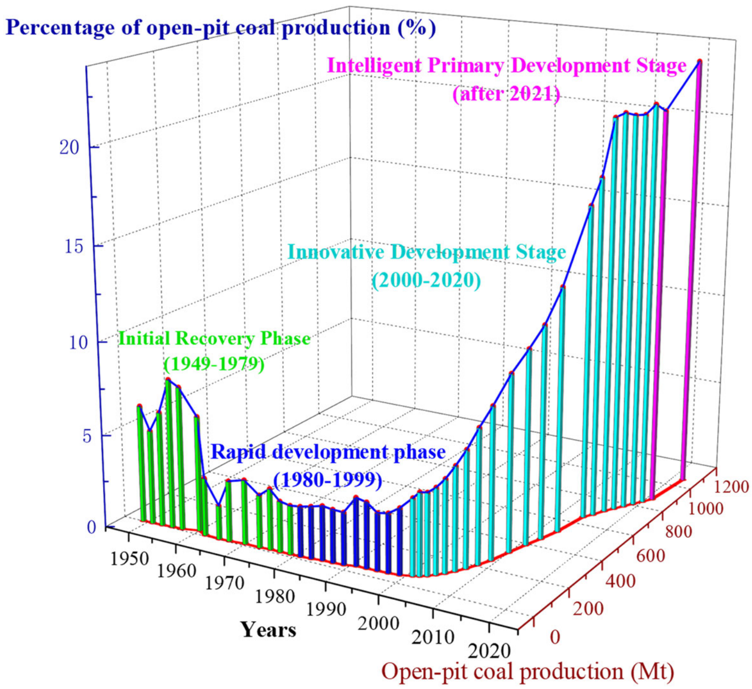


**FIG 4** – Annual production of open pit coalmines and its proportion in total coal production from 1949 to 2022.

## REVIEW OF 70 YEARS' DEVELOPMENT ACHIEVEMENTS OF OPEN PIT COALMINE

### Output and quantity and scale of open pit coalmines

Since the founding of New China, the production and quantity scale of surface coalmines have been developing continuously, and the number of typical surface coalmines built by the five major coal-producing bases of the country at different stages is shown in Table 1.

**TABLE 1**
Distribution of typical open pit coalmines at different development stages.

| Coal-producing base | Initial recovery phase (1949–1979) | Rapid development phase (1980–1999) | Integrated and intelligent primary development stage (after 2000) |
|---|---|---|---|
| Mengdong | 4 | 4 | 4 |
| Jinbei | | 2 | 1 |
| Shanbei | | | 1 |
| Shendong | | 3 | 1 |
| Xinjiang | 1 | | 6 |
| Yungui | 2 | | |

In the initial and recovery stages, after initial adjustment and restoration of the production and construction of open pit coalmines, China's open pit coal industry gradually entered the track of rapid development. During this period, the representative new and expanded open pit coalmines include Fuxin Haizhou open pit coalmine, Fushun East open pit coalmine, Hami Sandoling open pit coalmine, Fushun West open pit coalmine, etc. By 1979, the output of key state-owned open pit coalmines was 16.56 Mt, 8.2 times that of the People's Republic of China in 1949. The open-air industry is constantly adjusting in the development of the country, and the production capacity and output are gradually increasing, and the related industries are developing synchronously and stably, laying a foundation for the rapid development stage of the next period.

In the stage of rapid development, the output of open pit coalmines in 1980 was 16.99 Mt, accounting for 2.7 per cent of the total coalmine output. There are 18 main open pit coalmines with 0.3 Mt/a and above, with a designed production capacity of 21.3 Mt/a. After the reform and opening up, China's rapid economic development, coal demand increase, facing the problem of coal supply and demand, supply, in the original coal industry 'priority to the development of open pit coalmine' and 'to open the open' as soon as possible, under the guidance of the construction of the five open pit coalmine: HuoLinHe open coalmine, Yuanbaoshan coalmine, the open pit coalmine, black adai ditch open pit coalmine and Ann fort open pit coalmine (Tian, Bai and Zhao, 2019). At the same time, also successively built Heidaigou, Wujia Pagoda, Antaibao, Majia Pagoda, Baori Hile, and other open pit coalmines, and the original Huolin River, Xiaolongtan, Bufen Dam, Haizhou, Fushun West and other open pit coalmines for technical upgrading and transformation. Among them, the designed production capacity of the Antaibao open pit coalmine is 15.33 Mt/a; the South open pit coalmine started production in September 1981, and the designed production capacity is 3 Mt/a. The expansion began in 1988, and the second phase expansion project of 7 Mt/a was completed in 1992; the first mining area of the Yimin open pit coalmine was completed in 1984, the designed production capacity is 1 Mt/a, started in 1992, completed in 1998, and the design capacity reached 5 Mt/a in 2000. During the rapid development stage, the output of open pit coalmines has been greatly increased, and the design capacity of a single mine has increased from below 5 Mt/a to the maximum of 15.33 Mt/a. The open pit coalmine has made remarkable achievements in technology, construction scale and quantity.

Entering the stage of comprehensive development, with the rapid development of the economy, China's energy demand is increasing, and the demand for coal also shows a trend of rapid growth. In order to meet this demand, the State has made large investments and supported innovation in the field of coal mining, and the production and quantitative scale of open pit coalmines have continued to expand, with the production of open pit coal resources accounting for an increasing high proportion of the country's total coal output, open pit coalmine development in China also ushered in the 'golden decade', in the construction scale and production output has made remarkable progress. For example, a number of large open pit coalmines, such as Pingshuodong, Halusu, Bai Yinhua, and Shengli, were completed and put into operation; in 2014, the production capacity of Heidaigou open pit coalmine increased to 34 Mt/a, and the production capacity of Halusu open pit coalmine and Baile coalmine increased to 35 Mt/a.

Entering the primary stage of intelligent development, the production capacity of the south open pit coalmine of Xinjiang Tianchi Energy Co., Ltd. has increased to 40 Mt/a, creating a new situation of single mineral energy of open pit coalmine in China. By 2022, China's open pit coal output exceeded 1 Bt for the first time, reaching 1.057 Bt, and the open pit coal capacity and output accounted for more than 20 percent of the country. At present, there are more than 350 open pit coalmines in China, with a capacity of 1.162 Bt, 101 safe and efficient open pit coalmines, and more than 30 000 t. The open pit coal resources are distributed in 15 provinces, mainly in Xinjiang and Inner Mongolia, accounting for 90 per cent of the national open pit coal resources. Open pit coalmines have become an indispensable part of China's coal industry, and their position as a 'buffer warehouse' in the process of capacity adjustment is more and more obvious, which is of great significance to play the role of coal in energy and guarantee the bottom.

## Theory and technology of open pit mining

### *Construction of the geological model of the open pit coalmine*

In the initial recovery stage, the domestic open pit coalmine began in the 1960s. At first, the geological model is basically a two-dimensional model with single information and simple function, polygonal model and grid model.

After entering the rapid development stage, some scientific research institutions and open pit coalmines cooperate to develop geological models suitable for the occurrence of a single coal seam. However, due to difficult data updates, poor accuracy, and complex operation interfaces, the model is only used for scientific research and production technology optimisation and is rarely used in open pit coalmines. In 1986, the Eagles software developed by the Morrison company was introduced into the Antaibao open pit coalmine, and the geological model was first used in the production planning and design of the open pit coalmine. Since then, the domestic scientific research staff in related fields have gradually formed the construction technology of the deposit geological model combined with the existing theory and practice. With the introduction of commercial software for geological modelling abroad, the production planning and design in the field of open pit coalmines. During this period, the VULCAN software introduced by the Antaibao open pit coalmine and Yuanbaoshan open pit coalmine is the typical representative (Song, Bai and Xie, 2000) of the production and design application of foreign commercial software in domestic open pit coalmines.

After entering the comprehensive development stage, with the computer technology and geographic information system (GIS), global positioning system (GPS), remote sensing system (RS), and virtual reality (VR) of spatial information technology mature application and development, open pit coalmine geological model construction gradually realised the refinement of three-dimensional block and three-dimensional entity visualisation. 3D geological model with high precision, large information, complete function, strong computing ability, high degree of visualisation can effectively realise the height of geological terrain, deposit geological data, geological information, reserves management, mining design visualisation, geological forecast, measurement acceptance precision, make the mine geology, measurement, design, safety, and construction management information to share, realise the mining decision overall optimisation, production process optimisation pre-control, improve the modern management level of mining enterprises. At this stage, China has also developed many 3D geological modelling software, such as 3DMine, DiMine, etc.

After entering the primary development stage of intelligent development, the intelligent mining of open pit mines puts forward new and higher requirements for the construction of the geological model. By further improving the exploration accuracy, the high-precision three-dimensional geological model is established, which can accurately reflect the geological status, geological structure, and coal rock characteristics of the coal seam, the transparency level of mine geology is improved, and the precise geological guarantee is provided for the construction of intelligent open pit mine (Peng, 2020; Wang, Zhang and Li, 2023).

### *Planning and design of open pit coalmine*

At the beginning of the initial recovery stage, the new Haizhou open pit coalmine and Fushun west open pit coalmine reconstruction project belongs to the Soviet aid project, design work by the Soviet Leningrad coalmine design institute, using single-railway broken technology, development way for non-work fixed turn pit line and help move turn-back pit line development transportation system. In the late 1950s, on the basis of mastering the design methods of the former Soviet Union, domestic design institutes began to complete the planning and design of a number of open pit coalmines. For example, in 1958, Shenyang Design Institute completed the first engineering design of open pit coalmines in China – Pingzhuang West open pit coalmine with a design capacity of 3 Mt/a. At this stage, the design capacity of China's open pit coalmine has been maintained below 5 Mt/a, and the mining process is mainly based on the single single-bucket-railway intermittent process.

After entering the rapid development stage, related design units learn and digest foreign technologies in the process of 'the construction of five open pit coalmines', the design of open pit coalmine breaks through the traditional mode of railway transportation-pulling-mining-external drainage, start to design partition mining-pressure pressure inner row, and further improve the trench scheme and mining procedures. The design of holin River and Heidaigou open pit coalmine has broken through the scale of 10 Mt. Single-bucket-truck intermittent process and single-bucket-truck-semi-fixed crushing station semi-continuous process in Antaibao, Heidaigou, Yimin and Yuanbaoshan and other open pit coalmine application. The continuous process of wheel bucket was introduced and applied in the expansion process of Xiaolongtan and Buboba open pit coalmine for the first time in China. Experts and scholars have further innovated the design theory of open pit coalmines, Tian (1987) proposed the intersection graph method suitable for the calculation of coal rock quantity. Zhang and Yang (1991) summarised the common problems of various existing optimisation design methods of open pit mining realm, the principle and method of dynamic comprehensive optimisation of open mining state are given. Yang (1993) analysed the limitations of the theory based on static economic analysis, put forward the theory and method of determining the state of open pit mining according to the dynamic economic analysis. Ji and Zhang (1998a, 1998b) Based on the maximum net present value of unit reserves and the reasonable match of the interrelationship between the elements, the comprehensive optimisation model of open pit mine production capacity is established by using system engineering method and scale economy theory. During this period, the standards and specifications of open pit coalmines, such as the 'Mining Design Manual of Open pit Coalmine' and 'Engineering Design Code of Open pit Coalmine,' have been formulated successively, which further improves the design system of open pit coalmine in China.

After entering the comprehensive development stage, the design concept of the domestic open pit coalmine has changed from the stripping engineering technology and balanced production to the feasibility study of resource development, paying more attention to economic benefits, safety benefits, and environmental benefits, showing the characteristics of large scale, intensive production, high yield, and high efficiency. Open pit coalmines began to fully enter the scale era of 20~40 Mt/a. The process of a single-bucket-self-moving crusher was designed and applied for the first time in Heidaigou open pit coalmine and Yimin open pit coalmine, respectively. As the coal industry open pit mine construction project feasibility study report preparation standard, 'coal industry open pit design specification', 'coal industry open pit mine engineering construction project design document preparation standard', 'coal industry open pit mine transportation engineering design standard', 'coal industry open pit slope engineering design standard' and a series of national, industry standard preparation and implementation, domestic open pit coalmine complete construction project design system gradually established.

## *Division and turning of open pit coalmine*

In the initial recovery stage, the single mining area of domestic open pit coalmine is relatively small, and the transport distance has little impact on the production cost of single bucket-railway intermittent process. Therefore, the slow working method and the whole state mining method are mainly used to continuously extend the deep exposed coal.

After entering the rapid development stage, the area of single mining has increased greatly, and the whole state of mining is limited. After the 1980s, Antaibao open pit coalmine first introduced the new concept of zoning mining, which quickly promoted the development of zoning mining and turning technology of open pit coalmines in China. Zoned mining has effectively reduced the amount of initial infrastructure projects, and has obvious advantages in preferentially mining favourable sections, reducing the transport distance, and rapidly realising the internal row. The length of the working line is the basis and basis of the division of the open pit mining area, which directly affects the stripping distance and then affects the production capacity and economic benefit of a coalmine. During this period, Yu and Xi (1986) derived the calculation formula diagram method of the length of the open pit economy from the perspective of the minimum total cost. In order to solve the problems such as the increase in transport distance, the 'flood peak', complex production management, and less coal exposure (Bai, Li and Liu, 2014), Cai and Ji (1996) to Anjialing open pit coalmine to the second mining area as an example to put forward four feasible mining area steering scheme, through quantitative calculation and qualitative analysis, the research methods and conclusions provide important guidance for mines with other similar conditions. Gu, Li and Yu (1997) analysed the characteristics of two intermittent and continuous mining area turning modes, namely, and taking the Hololin River south open pit mine as an example to the technical and economic analysis of different steering modes, it provides a reference for the choice of the turning mode in the open pit mining area under different conditions.

After entering the comprehensive development stage, the experts and scholars have further enriched and optimised the theory of mining area turning. Liu and Duan (2006), Liu, Li and Shi (2001), Xu, Cai and Liu (2006) took Antaibao open pit coalmine as an example to analyse the problems of the contradiction of insufficient operation space and the demand for rapid extension, the insufficient space of internal dump, the increase of transport distance, the difficulty of raw coal production and the complexity of transportation system, the mining procedure optimisation measures such as internal row bypass, reverse high section and 'dritic' transportation system are put forward. Ji (2011) summarised and analysed the characteristics of right-le slow, fan-shaped propulsion and re-pulling in the near horizontal open pit coalmine. Zhou *et al* (2008) took Antaibao open pit coalmine as an example and proposed the use of mining interval bypass, reverse internal row and road building ditch development transportation system to solve the problems of unbalanced internal row space and too long transport distance of large near-horizontal open pit coalmine.

## *Adjustment of stripping ratio in open pit coalmines*

In the initial recovery stage, the domestic open pit coalmine mainly adopts the single-bucket-railway intermittent process. Because the transport distance has little impact on the production cost of the process, the stripping ratio equilibrium method is mostly used to optimise the stripping plan to achieve the purpose of balanced production. However, the stripping ratio equilibrium method is at the cost of advanced stripping; the early investment is large, and the investment recovery period is long. Chen (1988) According to the principle of the economic effect of investment, the early production stripping and stripping ratio, the maximum production stripping ratio, and the maintenance life of large and medium-sized open pit coalmines using the process of single bucket-railway are discussed.

After entering the rapid development stage, the single bucket-truck discontinuous process and the semi-continuous process began to be applied on a large scale in China, and the mining and transportation distance increased with the development of the mine scale. However, the stripping ratio equilibrium method cannot solve the problem of increasing production cost caused by the increase of stripping and stripping distance, and at the same time, there is a contradiction between mining and transportation after stripping the 'flood peak' (Song, Bai and Yi, 2000). Therefore, the optimisation method of stripping ratio considering economic benefits has been applied in the design and production of open pit coalmine, but it still cannot solve the practical problems of stable mine production and the reduction of 'flood peak'.

After entering the comprehensive development stage, the wide application of computer technology makes the open pit coalmine to optimise the production schedule based on the geological model simulation, and the optimisation theory of stripping ratio is further innovated. Yu (2003) proposed the equilibrium method of stripping and transportation work, which combines the stripping ratio with the stripping and stripping distance, which not only considers the balance of mine production, effectively reduces the 'flood peak' of stripping, but also gives full play to the efficiency of the main equipment and improves the economic benefits of the mine. In addition, relevant scholars have also studied the optimisation of production and stripping ratio under special conditions. Bai *et al* (2015) In view of the fluctuation of the stripping ratio of Yuanbaoshan, Zhao *et al* (2014) analysed the production capacity constraint index of the near horizontal to inclined coalmine and proposed the dynamic stripping adjustment method of double pit.

## *Optimisation of the development and transportation system of open pit coalmine*

In the initial recovery stage, open pit coalmines mostly adopt single-bucket-railway intermittent process, and the development transportation mode is mainly non-working fixed pit line, working moving pit line and joint pit line. For example, the Haizhou open pit coalmine adopts the fixed pit line, the moving pit line system, and in the middle of the mining adopts the moving pit line of the bang.

After entering the rapid development stage, the open pit coalmines take measures according to local conditions to explore more suitable for the mine. At the same time, due to the change in mining technology, the railway transportation system is gradually reduced, and the proportion of highway development transportation systems and belt conveyor transportation systems in the open pit coalmine is increasing. For example, the single bucket-truck mining process and multi-access ditch-direct-back mobile pit line, the development method of open pit, and the development and transportation system of double access ditch fixed pit line.

After entering the comprehensive development stage, in order to adapt to various mining conditions and different mining depths, the joint development transportation mode has been widely used, and experts and scholars have also put forward the optimisation method of development of transportation systems under different conditions. For example, Shang *et al* (2004) analysed the characteristics, problems and solutions of developing the transportation system during the transition period of near-horizontal open pit coalmine, and proposed the ideas and methods of optimising the transportation system. Che and Cai (2007) and Che (2007) innovatively proposed the middle step bridge to develop the transportation system. Liu *et al* (2015a) further gave the applicable conditions for the intermediate bypass grafting in open pit coalmines, and determined the key parameters such as the height and width of the intermediate bypass grafting. Liu *et al* (2019) established a numerical calculation model based on the optimisation of road cost. The optimised line cost is lower, which can quickly and effectively solve the routing problem of mine transportation system.

## *Guarantee for the mining safety of open pit coalmines*

At the beginning of the initial and recovery stage, the CPC Central Committee and The State Council attached great importance to the safety production of coalmines. In 1949, the first National Coalmine Work Conference put forward the policy of 'coalmine production, safety first', and multi-level safety supervision institutions were established successively, and a large number of administrative regulations, regulations, and rules on coalmine safety production were formulated and issued successively. By the end of 1952, the national coalmine safety production management system had initially taken shape, ensuring the safe development of open pit coalmines. In 1961, the CPC Central Committee reiterated that 'safety is for production, production must be safe', and put forward the eight-word policy of 'adjustment, consolidation, enrichment and improvement'. In general, the safety management of open pit coalmines in China is in the traditional passive management mode during this period.

After entering the rapid development stage, the former Ministry of Coal Industry has successively issued the 'Coalmine Safety Work Trial Regulations', 'Coalmine Safety Supervision Trial Regulations', 'Coalmine Safety Regulations' and other safety policies and guidelines, and put forward the implementation of the ‘safety first’ policy of ten standards, the safety production situation of open pit coalmine gradually improved. On February 3, 1993; the former Ministry of Energy promulgated the first technical regulations on the safety of open pit coalmines in the history of China–Coalmine Safety Regulations (Open pit coalmines), which provides an important guarantee for improving the safety management level of open pit coal enterprises. At the same time, scholars have studied slope stability, one of the most important problems in the safe mining of open pit coalmines. For example, Bai and Guo (1991) used the finite element method to analyse the influence of Wulong mine mining on the south-west gang stress and displacement of Haizhou open pit coalmine; Zhou (1992) analysed the main deformation types and stability influencing factors of the dump in the open pit coalmine, the measures to ensure the stability of the inner dump are proposed; Cao, Bai and Liu (1997) and Cao, Liu and Bai (1997) analysed the stress change and rock migration characteristics of southern bang with Haizhou open pit excavation by discrete unit method and model test, the slope rock migration mechanism and the potential landslide mode are revealed; Rui *et al* (1999) proposed the general rheological equation of the weak interlayer in the open pit coalmine slope according to the aging theory, the relationship between the long-term shear strength and the time change of the stress action was established, it provides a theoretical basis for the dynamic stability analysis of the peristaltic slope. In general, in this period, the overall safety management of open pit coalmines is still in the transition stage from ‘passive safety’ to ‘active safety’.

After entering the stage of comprehensive development, a system of laws and regulations on coalmine safety production, with the Work Safety Law and the Regulations on Coalmine Safety Supervision as the main body, has been basically formed. With the safety policy of ‘safety first, prevention first and comprehensive treatment’ as the safety production policy, starting with the safety and quality standardisation, summarises the laws and regulations and the experience of safety production management, and establishes and improves the institutionalised management system of safety management. At the same time, the theoretical research of the slope stability of the open pit coalmine is further enriched (Shu, Wang and Zhou, 2004; Shu, 2009). Through theoretical analysis and physical similarity model test to improve the water pressure distribution assumption of rock mass slope plane sliding. Cai *et al* (2008) put forward the theory of aging slope of open pit mine, taking the exposure time of the slope as the index of the slope timeliness evaluation, it provides a safety guarantee for the open pit coalmine to achieve the help mining. Yang *et al* (2011) established the internal damage evolution model of slope rock mass based on the inversion of microseismic monitoring information. Wang *et al* (2014) studied the influence of fault position on the stability of slope of open pit. Chen *et al* (2022, 2023) Considering the effect of circulation and blasting impact of rock, the dynamic mechanical characteristics of slope coal rock mass are studied. Han (2015) proposed the aging stability coefficient of two instability modes, plane and arc, the theoretical model of the stability analysis of slope aging is established. Liu *et al* (2015b) studied the intrinsic causes of the different penetration rates between the compacted and non-compacted regions, some suggestions are made to improve the stability of open pit dump slope. At present, with the further research and development of intelligent construction and safety system of open pit coalmine, open pit coalmine has been developed to fully realise the direction of ‘active safety’.

## Open pit mining technology and equipment

In the initial recovery stage, limited by the domestic equipment manufacturing capacity and mining technology, the single bucket-railway technology is the main process of the domestic open pit coalmine. For example, Fushun West, Haizhou, Pingzhuang West, Sandoling and other open pit coalmines are single-railway mining technology. Peng (1956), and Peng *et al* (1964) summarised the connection and cooperation between the mining and transportation links in the bucket-railway process, and determined the reasonable value of the shovel ratio. Luo and Wang (1982) (Wang and Luo, 1983), studied the steps and methods of computer simulation of open pit production system, which were used to match the number of equipment and train scheduling. At this stage, the domestic open pit coal mining equipment is mainly imported from the former Soviet Union. In 1954, Fushun excavator factory successfully developed an excavator with a bucket capacity of 0.5 $m^3$, marking the transformation of China’s open pit coal mining equipment from import to independent research and development. After that, domestic equipment such as 4 $m^3$ electric shovel, 80~150 t electric locomotive and steam locomotive was gradually applied to open pit mining operations, and the independently developed equipment manufacturing system was gradually improved.

After entering the rapid development stage, Jin (1982) summed up the experience of open pit mining at home and abroad, and pointed out that the research work of new technology, new technology and corresponding exploitation and mining should be vigorously carried out, and each open pit coalmine should develop the comprehensive process system according to the specific conditions. Xi, Peng and Zhang (1988) established a multi-objective planning model for heavy and empty trucks, and derived the 'minimum ratio variance' adjustment criterion. Peng, Zhang and Xi (1991) discussed the calculation method of the reliability of continuous process system in open pit coalmine, which can estimate the annual effective working hours of the system and provide a basis for the selection of equipment specifications in the wheel system.

During this period, Antaibao open pit coalmine introduced the single-truck mining process and complete equipment from the United States, and then the single-truck mining process began to be applied in Yimin, Holin River, Heidaigou and other open pit coalmines. In May 1983, the State Council discussed passed the decision on the development of major technology and equipment, determine the annual output of thousands of large open pit coalmine complete sets of equipment for the national key construction projects, including annual output of 1000 t and 2000 t open pit coal bucket-truck mining process and continuous and semi-continuous mining process of complete sets of equipment. In 1984, Fushun West open pit coalmine put into use the first set of single bucket-truck-semi-fixed crushing station-belt conveyor semi-continuous mining process system, marking that China's open pit coalmine has officially entered the semi-continuous process development stage. In July 1986, the stripping of Xiaolongtan open pit coalmine in Yunnan province first adopted the continuous production process of small wheel excavator, and the continuous mining process of medium wheel excavator after expansion. Subsequently, Yuanbaoshan and Heidaigou open pit coalmine and other wheel bucket continuous process systems have been put into production, which opened the situation for the application of continuous mining process in China. In 1987, the complete set of equipment for single bucket-truck mining process of open pit coalmine with an annual output of 10 Mt of coalmine was fully localised, and put into application in huolinhe open pit coalmine. At the same time, the joint application of foreign technology and domestic technology has given birth to a large number of products of great significance, such as the annual output of open pit coalmine single bucket-truck mining process complete equipment, 23 $m^3$ single bucket excavator and 154 t electric wheel dump truck applied in Pingshuo mining area.

After entering the stage of comprehensive development, Zhang *et al* (2003, 2002a, 2002b), Shang *et al* (2002), Li *et al* (2005) around pull bucket shovel dump process, analyses the large coalfield using dump stripping method and application prospect, puts forward the basic idea of pull bucket shovel selection and method, points out the key to optimise coal system is coal channel setting, and gives the throwing blasting and stripping steps mining parameters. Che (2005), Che and Cai (2004) and Che *et al* (2000) proposed a new type of wheeled soft rock crusher, which formed a semi-continuous mining process system for new open pit coalmine with single bucket excavator and belt conveyor, filling a gap in open pit mining process. In 2007, Heidaigou open pit coalmine introduced the first pulling shovel in China, using the mining technology with the throwing blasting technology, with an annual stripping capacity of 20 million $m^3$. In the same year, Yimin open pit coalmine put in the first set of semi-continuous process equipment of self-shift crusher in China for coal mining, which promoted the prosperity and development of single-bucket-self-shift crusher-belt conveyor in open pit coalmine in China. So far, the world's main advanced open pit coal mining technology can be applied in China.

The use of single mining process mode in open pit coalmine limits the improvement of production scale and economic benefit. According to the occurrence conditions of open pit coalmine, the comprehensive mining process using two or more processes at the same time can obtain high production efficiency and the best economic benefit (Zhang and Lu, 1992). In order to further clarify the application effect of mining process on different scenarios, various scholars have conducted a lot of studies on the applicable conditions and parameter optimisation of various mining processes. Che, Zhai and Zhang (2001) puts forward the determination process and method of setting the step distance of crushing station, and gives the principle and calculation formula of determining the step distance of crushing station. Li, Zhang and Fu (2006) used theoretical calculation combined with the application practice of pull bucket shovel stripping and dump process, further improve and perfect the throwing blasting parameters; (Song, 2007) established the adaptability evaluation index system of open pit mining process system and the applicable conditions model of various common open pit mining process system. Shang *et al* (2010) has optimised the working face parameters of the semi-continuous process system of the self-shift crusher. Ji, Chen and Sun (2014) analysed the production capacity of the semi-continuous process system, the boundary condition model of semi-continuous process application is established. Chen (2011) established the truck optimisation model with the lowest production cost of the system, the crushing station location and setting optimisation model, the semi-continuous process service range model, the combined step mining model and the optimisation model of mining belt width. Hp (Ma, 2015) constructed a comprehensive evaluation model of throwing blasting effect, the application conditions of throwing blasting in open pit coalmine and the matching relationship with the subsequent stripping process are analysed. At this stage, the manufacturing level of supporting open pit mining equipment has also entered a new height. The independently developed 75 $m^3$ mining shovel, 400 t mining dump truck, large self-shift crusher, full hydraulic wheel bucket excavator, high-power bulldozer and so on have been put into use or trial operation successively. China's open pit coalmine equipment has achieved a great leap from dependence on imports to domestic independent production.

After entering the primary stage of intelligent development, the unmanned transportation project of the open pit coalmine began the field test. In 2020, Tianchi Energy South open pit coalmine has put nearly 100 100 tons of new energy driverless mining card. In September, 2021; Baori Xile open pit coalmine runs the world's first extremely cold (-40°C) environment unmanned mine card formation. In 2022, the Shengli No.1 open pit coalmine has completed the unmanned modification of seven 220 t mine dump trucks, and continuously carry out 7243 teams organised without safety officer transport operation, created a new record of transport efficiency without a safety officer. In March, 2023; Juneng Group has completed the first NTE330 type mining truck driverless transformation, it has opened up a new era of unmanned driving with the maximum 330 t load in China.

It can be seen that the open pit coal mining process from the initial single single-railway technology development to the current single-truck intermittent process, single-truck-half fixed crushing station semi-continuous process, wheel bucket continuous process, single-self-shift crusher semi-continuous process, bucket shovel pile process of comprehensive application, on the whole from single to continuous, the development trend of integration. With the reform of mining technology, mining equipment is developing towards the direction of large-scale, localisation and intelligence, as shown in Figure 5.

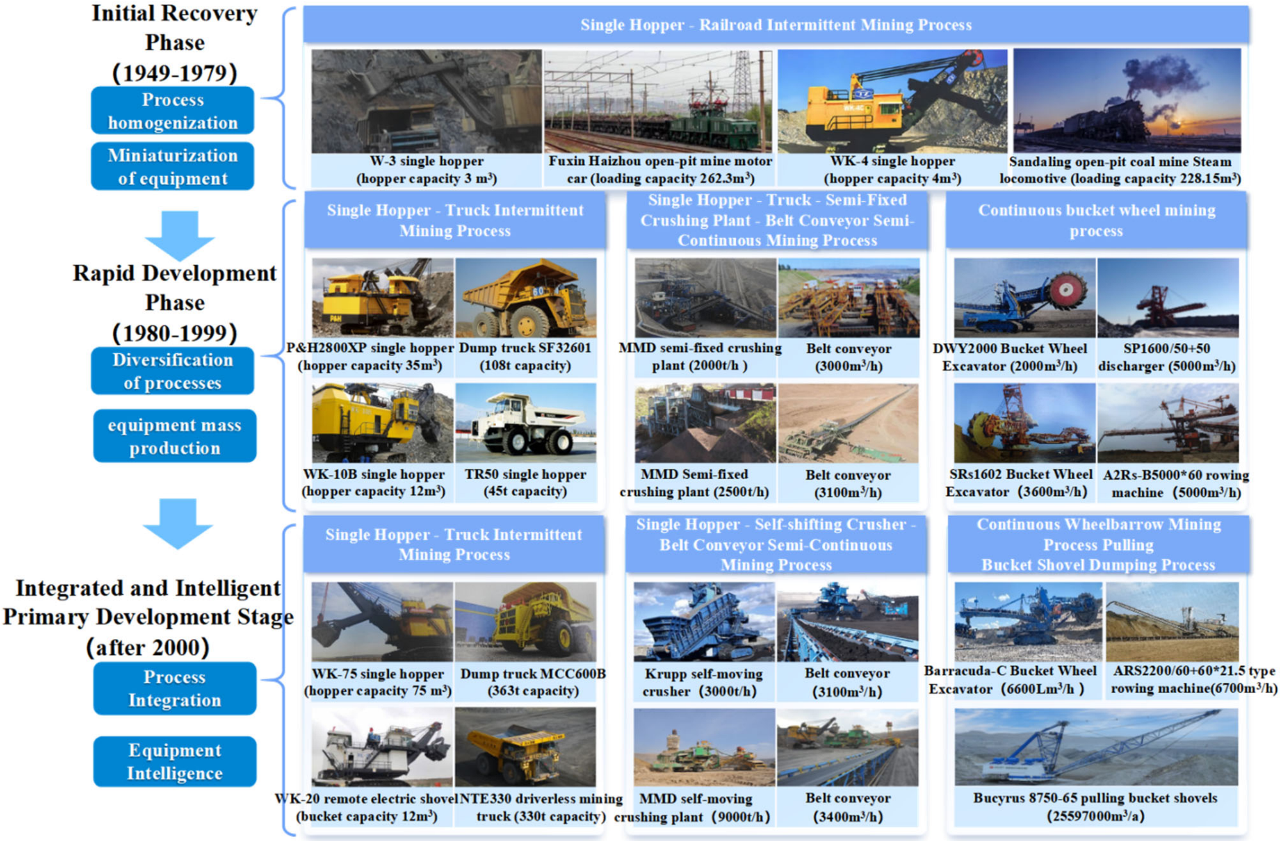


**FIG 5** – Representative mining techniques and equipment at different development stages of open pit coalmines.

## Resource development and environmental protection

With the large-scale development of open pit coal resources, a series of environmental problems are also brought. The discharge of mining and stripping will damage and occupy a large amount of land, destroy the surface soil and vegetation (Gao *et al*, 2021; Zhang, Wang and Li, 2019), accompanied by the migration of water and solutes, resulting in the loss of soil fertility and the accumulation of heavy metals (Cheng *et al*, 2020; Zhen, Zheng and Zhang, 2019). In addition, drilling and blasting, mining, transportation, soil drainage and other links will produce a large amount of dust, resulting in air pollution (Zhou *et al*, 2023; Yang *et al,* 2022), etc. Reviewing the past 70 years, China's open pit coal resource development and environmental protection have mainly experienced three stages: focusing on development over governance, development first and then governance to development and governance, as shown in Figure 6.

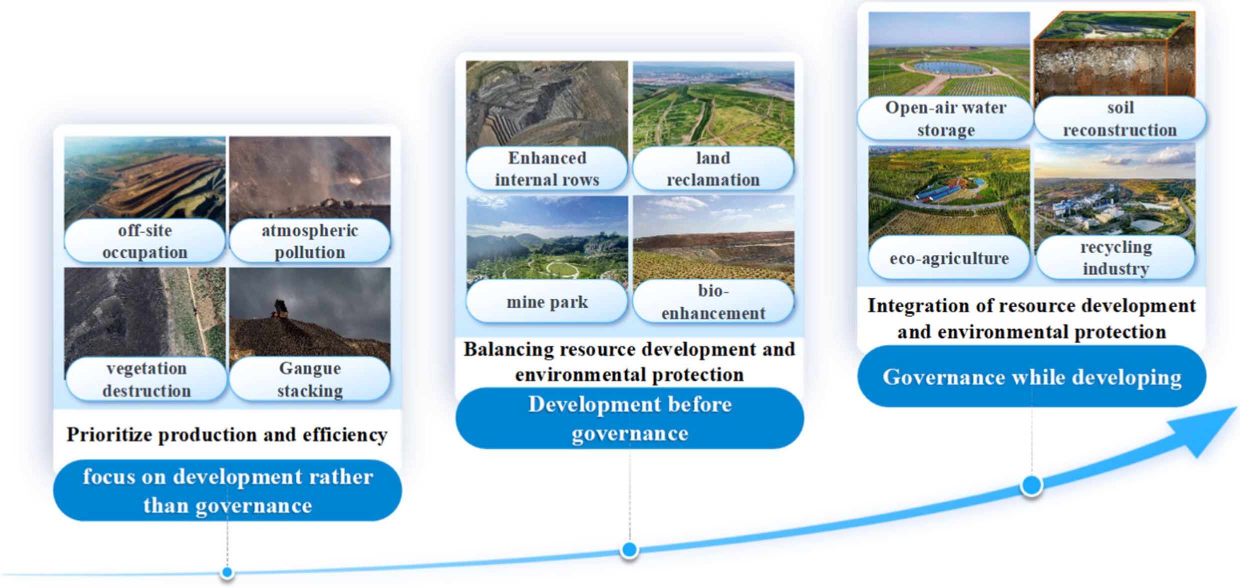


**FIG 6** – Development stages in resource development and environmental protection of open pit coalmines.

### *Emphasis development over governance in the initial and recovery stage*

In the initial and recovery stages, due to the limitations of historical conditions, mining technology, and technical means at that time, the environmental damage caused by open pit mining in this period has not been paid much attention to. In order to pursue higher economic benefits, development rather than treatment. Under this mining mode, the open pit coal mining has caused serious excavation damage and occupation of the land. Statistics show that after the normal production of open pit coalmines in China, about 0.08 $hm^2$ per 10 000 t of coal is mined and about 0.16 $hm^2$ (Coal Industry Committee of Technology Association, China Coal Society Open Mining Committee, Coal Industry Planning and Design Research Institute Co., Ltd, 2015b) per 10 000 t of coal dumped. A large amount of land is stripped and occupied, and the surface ecology of the mining area is seriously damaged. At the same time, the large amount of soil stripping and mining influence also leads to the loss of groundwater resources, which indirectly causes the problems of salinisation, desertification, and impoverishment and seriously damages the ecological environment of the open pit mining area.

### *First development before governance in the rapid development stage*

In the rapid development stage, the mining technology and technology of domestic open pit coalmine develop rapidly, and the mining intensity increases year by year, and the negative impact on the environment becomes increasingly severe. In 1988, China promulgated the Regulations on Land Reclamation, which officially opened the prelude to the ecological management of open pit mines in China. Antaibao, Yimin, Zhungeer and other large open pit mining areas took the lead in responding to the policy call, and designed and implemented the land reclamation plan according to the concept of ecological and environmental protection at the beginning of the mine under construction. At the same time, scholars have also carried out a large number of studies on the ecological protection of open pit mines. Hu (1992) analysed the spatial variation of soil physical characteristics of open pit coalmine reclamation, pointed out that the spatial variability of soil is closely related to the mining direction, the spatial variation in the soil profile is obvious regularity. He *et al* (1996) pointed out the principles, directions, and procedures of land reclamation in the coalmine area and the corresponding main technical measures. Bai *et al* (1997) analysed the characteristics of soil loss in different areas of Antaibao open pit coalmine, and proposed the comprehensive control measures for soil and water conservation in dump.

In this period, the ecological management means of open pit mines are still relatively single, and strengthening the internal drainage and land reclamation are the main measures for the ecological restoration of open pit mines at this stage. This stage open pit coalmine park after resource development, biological improvement of ecological restoration, but not yet according to the conditions of the whole mining area, according to the principle of ecology, economics, science and reasonable, multi-industry, comprehensive, coordination of ecological restoration research, nor will open pit mining and ecological reconstruction integration system, the environmental protection and management is not through the open pit coalmine development planning, design, production process of (Song *et al,* 2016b), the ecological environment improvement is not obvious, ecological restoration did not bring obvious environmental benefits.

### *Development and management after the comprehensive development stage*

After entering the stage of comprehensive development, with the China's attention to environmental protection and the popularisation of the concept of sustainable development, the concept of integration of resource development and ecological restoration has gradually become a consensus. Academic Minggao Qian (Qian, Miao and Xv, 2006; Qian, Miao and Xv, 2007; Qian, Xu and Miao, 2003) pioneered the concept of green coal mining, analysed the necessity and significance of studying green mining of coal resources, and explained the coordinated mining technology system of resources and environment. Bai, Zhao and Zhu (1999) pointed out that mine ecological reconstruction should predict possible environmental problems before mining and mining, and Bian, Xv and Lei (2007) believed that mine ecological planning and ecological protection, and mine ecological construction needs to run through the mining process by systematic engineering.

In 2008, the State Council issued the National Mineral Resources Planning (2008–2015), which put forward the requirements of developing green mining and the construction of green mines. Based on the concept of green mine construction, the concept of integration of resource development and ecological restoration has been put forward. Cai, Gao and Shang (2002) studied the integrated operation methods and related parameters of surface soil stripping and land reclamation in open pit coalmines, it is proposed to use linear planning to optimise and control the flow rate and flow direction of topsoil resources. Song *et al* (2016a, 2019) proposed the green degree evaluation method of open pit coalmines, established the mining area ecological environment evaluation index system. Tian and Wang (2018) put forward the concept and technical method of 'disturbance coefficient', to quantify the comprehensive disturbance degree of open pit mining to the environment. Li (2023b, 2023a), Li and Li (2023) put forward the ecological restoration concept of source loss-process control-end treatment, developed three-dimensional water storage and joint call, mining and land loss reduction, cross-time and space allocation and storage of materials, and 'ecological window period' collaborative restoration and other technologies, the ecological mining theory and technology system of open pit coalmine was established. Bi, Peng and Du (2021) proposed the reconstruction structure model of three layers of topsoil ecological layer-culvert-layer-water-barrier layer of arid and semi-arid open pit mine dump, research and development of geophysical testing technology and equipment, monitoring the pit water source, soil structure and water content of the dump, ensure the effective utilisation of water resources in ecological projects.

At the present stage, with the continuous development of intelligent mining technology, the traditional mining design and process have been unable to adapt to the development of intelligent equipment such as unmanned driving and new energy, and the 'two-carbon' background poses new challenges to the original production mode. Academic Xie *et al* (2021) scientifically studied the evolution trend of energy consumption structure and coal consumption under the goal of carbon peak carbon neutrality, and put forward the path to achieve the dual goal of carbon peak carbon neutrality and energy security and stable supply. Gu *et al* (2023) proposed a new mode of intelligent construction of low-carbon, continuous, efficient and safe open pit mines, and discussed the technical path of this mode from three aspects: building a multi-energy complementary renewable energy system, exploring the low-carbon continuous production process of open pit mines, and developing the carbon storage and ecological carbon sink technology system. At present, the mode of development and management has achieved obvious results. Relying on the rich land resources in the mining area, the land reclamation and ecological reconstruction technology system suitable for different mining areas has been innovatively developed. Meanwhile, the circular industrial economic system suitable for different open pit mining characteristics has been gradually improved, and the associated resources, groundwater resources, gangue and other solid wastes in the coal mining process have produced good economic and social benefits for environmental protection and ecological restoration.

## MAIN PROBLEMS EXISTING IN THE OPEN PIT COALMINE AT THIS STAGE

After 70 years of development, China's open pit coalmines have made a series of outstanding achievements, but there are still four problems at the present stage, including the unbalanced development layout, the bottleneck of sustainable development, the key technical problems need to be deeply solved, and the talent shortage training mechanism is imperfect, as shown in Figure 7.

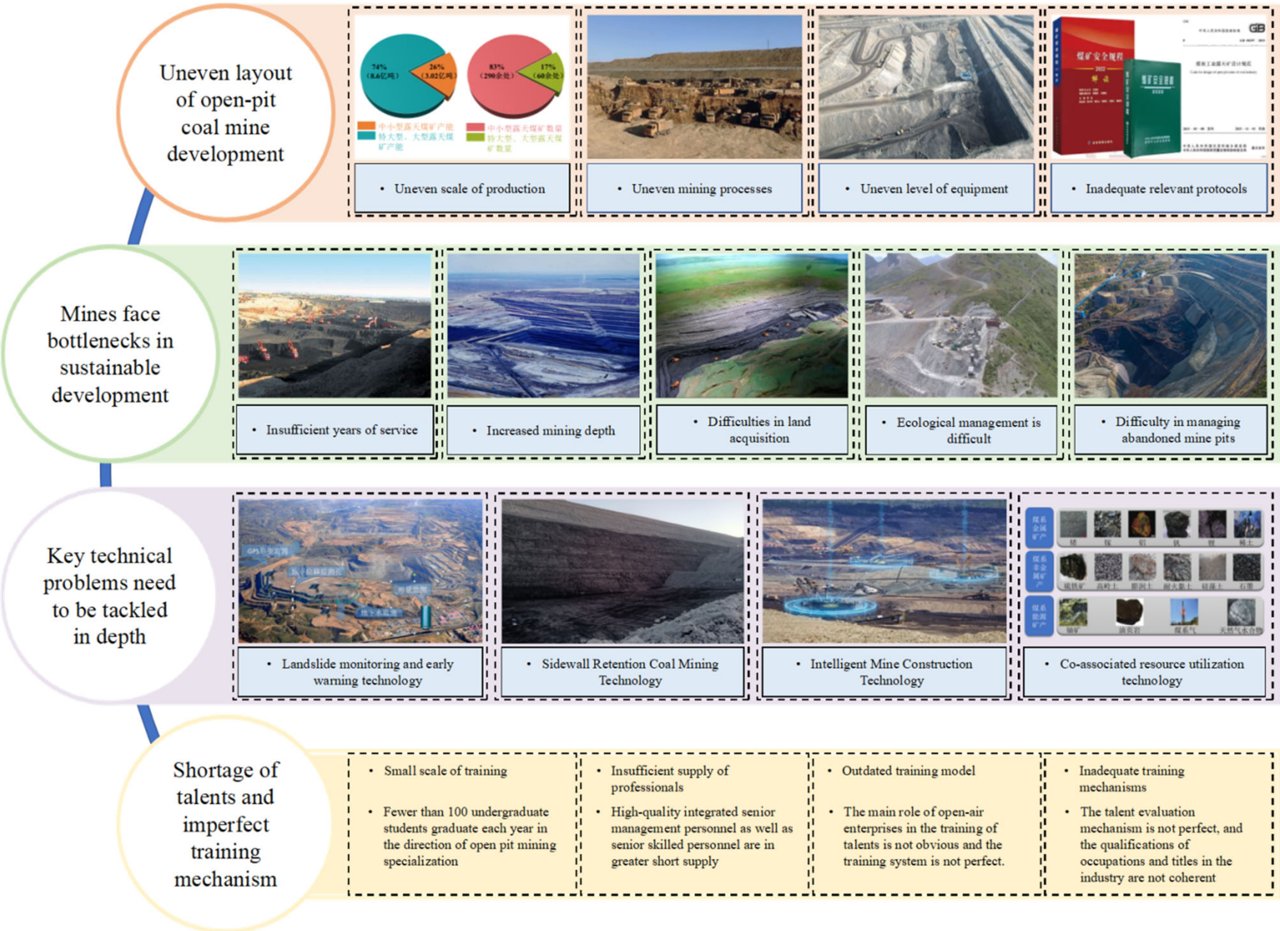


**FIG 7** – Main problems currently existing in open pit coalmines.

### Unbalanced development and layout of open pit coalmines

1. The production scale is not balanced, and the number of super-large and large open pit coalmines is low, and mainly concentrated in ecologically fragile areas, while small and medium-sized open pit coalmines account for a high proportion and are widely distributed. According to data released by the China National Coal Association, by the end of 2022, there were more than 350 open pit coalmines with a capacity of 1.162 Bt, of which more than 60 large and large open pit coalmines with a capacity of about 860 Mt, that is, large and large open pit coalmines contributed more than 70 per cent of the capacity with about 17 per cent of the number of open pit coalmines. However, the super-large and large open pit coalmines are mainly distributed in Xinjiang, Inner Mongolia, Shanxi and other arid Gobi areas with less rain, the alpine grassland areas and the loess Plateau area with serious soil erosion. At the same time, there are more than 170 small open pit coalmines with a capacity of less than 1 Mt, accounting for 50 per cent of the total number of open pit coalmines in China, and they are widely distributed in Inner Mongolia, Xinjiang, Shanxi, Yunnan, Shaanxi, Heilongjiang, Liaoning, Jilin, Ningxia, Guizhou and other provinces and regions.
2. The mining process is not balanced, the single bucket-truck intermittent process is still dominant, and the comprehensive process promotion is insufficient. Due to the high proportion of small and medium-sized open pit coalmines, about 2/3 of the open pit mines in China adopt the single bucket-truck intermittent process, and adopt the outsourcing production and

operation mode, facing the prominent problems of small equipment capacity, large quantity and large fuel consumption, resulting in more operators, great safety risks and high management difficulty. After years of practice, China's extremely large and large open pit coalmine has explored a comprehensive process suitable to the geological conditions of the mining area, which has a good demonstration effect, using a single bucket-truck intermittent process, single bucket-truck-semi-fixed crushing station/self-bucket crusher semi-continuous process, truck-semi-fixed crushing station semi-continuous process. But from the perspective of the national open pit coalmine, the promotion scope of comprehensive technology is far from enough.

3. The equipment level is not balanced, the localisation of some equipment or core accessories needs to be broken through, and the production capacity of high-end and intelligent equipment needs to be improved. Although the equipment manufacturing level of China's open pit coalmine has been in the process of steady development, however, on the whole, the development of the equipment manufacturing industry of the open pit coalmine in China has always lagged behind the reform and development of the open pit technology system, and it is still a difficult task to catch up with the world's advanced manufacturing level. In particular, the localisation of electric shovels, wheel buckets, bucket shovels, mining cards, crushers, and other large equipment or core accessories is in urgent need to be broken through. In addition, the production capacity of fully continuous stratified mining equipment in thick coal seam, frozen soil and hard rock mining equipment in cold area, high-end and intelligent equipment such as large inclination belt conveyor equipment and side help shearer equipment still needs to be improved.

4. The revision speed of relevant regulations and standards is unbalanced. Some terms of the open air part of the Coalmine Safety Regulations are not complete and fine, and cannot cover all kinds of mines in the whole country, including the open pit mining machine, coal areas, coal transport, and unmanned driving in the standardised management system of coalmine safety production are not specific, and many terms require 'design', 'non-design', but no requirements, and the requirements are not specified. Its root cause is that there are too few standards for open pit mine specifications, and the standardised provisions have no support and no basis. It has been more than eight years since the release of the Design Code for Coal Industry GB50197–2015. In recent years, new requirements for green mine and intelligent mine construction have not been met, and the design concept is outdated and needs to be revised urgently. At present, there are less than 30 national standards and industrial standards involving open pit coalmines, most of which are design standards. There are too few standards and specifications for production technology and safety management, which seriously restrict the development of high quality and safety of open pit coalmines (Zhao, 2022).

## The sustainable development of mines faces a bottleneck

1. High-intensity mining leads to a significant shortening of the service life. In recent years, the coal market of supply and demand tight, under the background of high coal price fluctuations, part of the open pit coal production capacity, continuous high strength mining, not only caused the open pit coalmine production in the tension, remaining service length of serious shortage, will lead to disaster management does not reach the designated position, safety risk accumulation, for mine late continuous construction increase difficulty, to open pit mine safety production brings huge hidden trouble. At the same time, high-intensity mining will also cause the destruction of mining ecology, directly affecting the sustainable development of open pit coalmines.

2. The increase of mining depth exacerbates the risk of high slope instability. With the increase in the output of open pit coalmines, the mining depth is increasing day by day. At present, the average mining depth of an open pit coalmine is nearly 200 m, and the deepest mining depth of Shengli East No.2 open pit coalmine is 623 m, which is the highest mining depth of an open pit coalmine in the world. With the deepening of the mining depth, the slope height of the open pit coalmine keeps increasing, which is easy to form a high and steep slope. Once the exposure time is too long, the strength of the rock layer will be further reduced, which is not conducive to the stability of the slope. At the same time, the mining depth also limits the

progress of tracking the inner row, which not only increases the transportation cost of the discharge, but also delays the slope protection of the internal row pressure.

3. Difficulties in land acquisition limit the development of mines. In recent years, the production capacity of open pit coalmines has been rapidly released rapidly, leading to the rapid growth of the scale of land requisition for open pit mines, but the current land requisition policy has not been adjusted in time. Because mining land belongs to the category of construction land, coalmines need to go through the procedures of expropriation and transfer, but the index of construction land is uniformly allocated and distributed step by step every year, and the land use index is seriously insufficient. At the same time, under the national requirements of green development, ecological, environmental protection, and keeping the red line of cultivated land, enterprises must strictly go through the procedures of grassland expropriation and occupation and land reclamation, and the procedures require approval by multiple departments, and the procedures are complex and long cycle. Some large and large open pit coalmines have been forced to cut production with no land available, which seriously affects the long-term development of mines.
4. It is difficult to conduct ecological management in the mining area under the constraint of environmental protection policy. Under the background of the gradual improvement of national environmental protection policy and 'double-carbon', China's open pit coalmine is accelerating the development of green and low-carbon direction, so the ecological management of open pit coalmine is urgent. However, ecological governance is a multi-disciplinary and multi-professional systematic engineering. At present, there is still a large number of professional engineering research institutions and professionals, and the ecological restoration technology of mines is not perfect. In addition, although the laws and regulations such as Land Reclamation Regulations, Land Administration Law of the People's Republic of China, and Coal Law of the People's Republic of China have played a certain role in the reclamation work, the reclamation rate of open pit coalmines in China is low, and even the reclamation speed cannot catch up with the speed of damage. In addition, a large number of mines left over from history have ecological damage problems, resulting in huge quantities of ecological management, long restoration cycle, and difficult to meet the requirements of ecological environmental protection in a short time. In addition, the approval procedures of mine ecological restoration construction are complicated, difficult, and the processing time is too long, which leads to difficult construction, which greatly increases the difficulty of ecological management in the mining area.
5. The treatment mode of abandoned open pit still needs to be explored. After experiencing large-scale mineral resources mining activities, a large number of resource-exhausted open pit mining areas (Qian and Xu, 2006; Wang, Kretschmann and Li, 2021) were produced in China. Abandoned open pit mines will bring safety risks, waste of space resources and energy reserve security problems. For the abandoned pit caused by open pit coal mining, the simplest and most direct way is to fill the soil, but it is difficult to obtain backfill, and the amount of huge, long time and high cost problems (Gao, 2017; Song *et al,* 2016a). In China, the management of abandoned open pits mainly adopts ecological restoration and landscape design means (Wu *et al,* 2021), such as Hulunbuir Jalainur National Mine Park, Fuxin Haizhou Open Pit Mine National Mine Park etc. However, at present, the management means of abandoned open pit are relatively single, the transformation and utilisation mode is still limited to ecological restoration, the economic benefits are not obvious, the utilisation value of pit is not fully explored, and the management mode needs to be further explored and innovated.

## Key technical problems need to be solved deeply

1. High side slope deformation monitoring and landslide early warning technology. With the increase of the mining depth of open pit mines, the deformation monitoring and landslide early warning of tall slopes are of great significance to the prevention and control of landslide geological disasters. The slope of large open pit mine is high, steep slope and large drop, with many influencing factors, and has complex, hidden, multi-scale, multi-stage and large deformation characteristics (Liu *et al,* 2020), which brings many difficulties to the deformation monitoring of tall slope and landslide early warning technology. With the continuous

development of modern surveying and mapping science and technology, a variety of new monitoring and early warning means, such as landslide GPS automatic monitoring and early warning system, GNSS monitoring, microseismic monitoring, landslide monitoring based on the beidou system, radar differential interferometry (D-InSAR), wireless sensing online monitoring system, long-distance 3D laser scanning (TLS) (Liao *et al*, 2012; Liu *et al*, 2010; Sheng, Yan and Song, 2003; Wu *et al*, 2005; Xu *et al,* 2016). Slope and landslide monitoring and early warning are gradually developing from the traditional point monitoring to surface and body monitoring. However, different monitoring methods have different applicability and limitations due to their own inherent defects. At present, the slope and landslide monitoring and early warning model is mainly based on the historical data statistics and analysis, through the analysis and analysis of the slope monitoring data to conduct the slope stability early warning (Wang *et al,* 2023). In view of the existing landslide early warning technology high failure rate, warning error, limitations, landslide early warning model development needs to consider the slope geological characteristics, evolution process, landslide mechanism and other key characteristics, combined with slope stability analysis method, build multi-platform, more means joint empty-day-to-ground-deep collaborative intelligent monitoring and early warning method and technology system, improve the accuracy of landslide early warning and universality. Therefore, further clarify the tall slope rock mechanical parameters change with time rule and landslide creep mechanism, implementation of tall open pit mine key areas, key link major landslide risk identification monitoring and precision, to promote open pit mine landslide monitoring early warning to remote, visualisation, intelligent way, become the key technical problems to solve.

2. Safe and efficient mining technology for stranded coal. According to relevant statistics, in the 40 open pit mining areas in China, more than half of the coal areas with more than 50 Mt is more (Ding, 2022), and the total amount of coal trapped in China is more than 10 Bt, accounting for about 10 per cent of the total resources of open pit mines. The abandonment of stranded coal not only causes a huge waste of a large number of high-quality coal resources, but also leaves major safety risks such as spontaneous combustion of coal seam and slope instability. In view of the stranded coal mining, many open pit coalmines have practiced mining technology. ① Open-well joint production technology (Ding *et al*, 2013; Lan, 2008; Liu *et al*, 2008; Wu, 2020; Xu, 2015; Zhu *et al,* 2010a, 2010b). Based on the occurrence conditions of near horizontal coal seam, the mining technology of well level roadway mining and open pit mining are conducted simultaneously by arranging the mining space distance and order scientifically. ② Paid mining technology (Cai *et al*, 2008, 2007; Han *et al*, 2013; Shang *et al,* 2019). Based on the spatial and temporal variation characteristics of the mine, the exposure time and service period of the side slope theory and the mining technology are proposed. In the case that the short time exposure has little impact on the overall stability of the side slope, the slope Angle of the end side is raised, and the coal resources are extracted through rapid mining and internal pressure relief. ③ Coordinated mining technology of adjacent open pit mines (Bai *et al*, 2014; Liu *et al*, 2016; Zhang *et al,* 2013). For the adjacent open pit coalmine in the same mining right, the recovery of the stranded coal is realised through the optimised mining parameters and the coordinated control of the engineering position. ④ End help shearer mining technology (Wu *et al*, 2022; Chen and Wu, 2016; Ding *et al*, 2021; Wang *et al,* 2017). When the strip-out mining ratio reaches the prescribed economic threshold, the end support shearer is arranged on the side of the stranded coal seam, and the remaining coal resources at the end of the coalmine of the open pit coalmine are explored remotely. The supporting coal pillar is formed between the mining pit to support the overlying rock layer and prevent landslides and other disasters. Although part of the open pit coalmine for different stranded coal resources mining technology was successfully applied, with the deepening of safe and efficient mining concept, the thick coal seam in the mining process and the slope stability control have higher requirements, at the same time, also need to process between time and space and existing open pit production planning coordination mechanism for in-depth research.

3. Intelligent mine construction technology. The intelligent development of open pit coalmine in China started late and the construction time is short, but a series of achievements have been

made. ① The drilling and blasting link is intelligent. Apply drilling technology for automatic detection of rig state, automatic navigation and drilling control, formation lithology identification, and apply new-generation information technologies such as 5G, artificial intelligence, big data and cloud computing to realise information depth perception and accurate control and self-execution. ② Intelligent mining, installation and transportation links. The remote operation intelligent shovel project of HuolinSouth Open pit Coalmine has been delivered, Xiwan Open pit Coalmine, Pingshuo East Open pit Coalmine and Yimin Open pit Coalmine have realised the normal operation of 5G + mine card, and the large and large open pit coalmines have gradually carried out intelligent exploration of mining, installation and transportation. ③ Ground production system is intelligent. Based on big data and artificial intelligence technology, Shengli Energy open pit mine has realised the new mode of intelligent transportation and maintenance based on robots, scientifically completed the task of high and low voltage stop and power transmission, and realised the intelligent unattended of power distribution room. Wucaiwan No.1 open pit coalmine has set-up an intelligent logistics platform to accurately control the information of social vehicles in and leaving the mining area, and the intelligent ground production system has officially opened. Although many achievements have been made in the intelligence of open pit coalmines in China, the intelligent construction of open pit coalmines is mostly reflected in 'single component, single equipment, single link,' and there is still a lack of (Zhang *et al,* 2019) in the information sharing and efficient utilisation of cross-equipment, cross-process link, cross-process system and cross-business category. At the same time, the industry has insufficient understanding of the path of intelligent construction of open pit mines, the planning content and implementation approaches of the intelligent construction of open pit mines have not been systematic, and the evaluation system standards of intelligent construction of open pit mines also need to be solved through scientific and reasonable planning.

4. Co-associated resources and waste resource utilisation technology. In view of the comprehensive utilisation of coal system associated resources, many open pit mines are explored. ① Comprehensive utilisation technology of coal system metal mineral resources. Based on the grade of coal system metal, raw coal with recycling value is selected, and according to different metal types, different processes are selected to refine germanium, gallium and aluminium associated metal elements, such as isometals. ② Comprehensive utilisation technology of coal system and non-metallic minerals. According to the different types of coal system non-metallic minerals, different treatment processes are selected to treat non-metallic minerals, such as coal gangue power generation technology. Through crushing, sorting, feeding, combustion and power generation processes, the combustible substances in coal gangue are converted into electric energy, which significantly improves the comprehensive utilisation level of coal gangue. ③ Comprehensive utilisation technology of coal system energy and minerals. For uranium and other energy minerals, it is rare to extract and utilise the uranium elements in raw coal through the process of mineral separation, ash, ash leaching and leaching uranium extraction. Although some open pit mines have made recycling of coal line associated resources, there are still low theoretical level and backward mining technology in the mining of coal line co-associated mineral resources such as germanium, pyrite and uranium. Therefore, it is necessary to break through the traditional single coal resources development and utilisation mode, strive to solve the shortcomings of mining chaos and backward technology, extend the coal line industry chain, improve the comprehensive exploration, development and utilisation level of coal line co-associated mineral resources, and promote the industrialisation and industrialisation of coal line associated resources utilisation (Guo *et al,* 2022).

## The talent shortage training mechanism is not perfect

1. The supply of open mining professionals is insufficient. With the rapid development of information technology and intelligent technology, the problem of the lack of open-air professionals is becoming more and more prominent. At the level of advanced talent training, only a few universities, such as China University of Mining and Technology and Liaoning University of Engineering and Technology, and less than ten universities offer open pit mining majors. The total number of fresh undergraduate and graduate students graduating every year

does not exceed 100, resulting in a serious shortage of the supply of open pit mining professionals. At the same time, there is also a great shortage of leading talents in the urgent development of the industry and professionals in high-end fields of intelligent mine construction, and there is a larger gap in senior management talents such as modern enterprise management, capital operation, technology management and risk control, as well as highly skilled talents.

2. The talent training mechanism is not perfect. At present, open pit mining is mainly trained through colleges and universities, vocational colleges and training institutions, but the discipline system of the intelligent construction of open pit coal mining enterprises is not complete; the cooperative training links between professional colleges and professional personnel training programs and professional practice have not been fully completed. At the same time, the main role of open pit coal mining enterprises in personnel training is not obvious, the training system is not perfect, and there are few ways to update knowledge and train skills for on-the-job employees. In general, the talent team construction mechanism is lacking, the management talents of high-quality comprehensive enterprises and ‘advanced talents are scarce’, the training of skilled talents has not been valued; the talent evaluation mechanism is not perfect, the professional qualifications and professional title qualifications have not been completed, there are barriers to cross-regional and cross-enterprise title recognition work, and the talent assessment and evaluation system is not perfect.

## OUTLOOK FOR THE HIGH-QUALITY DEVELOPMENT OF OPEN PIT COALMINES IN CHINA

### High-quality development framework system for open pit coalmines

In different historical stages, the main goal of the construction of open pit coalmine has been constantly changing with the development of China’s economic construction. In the initial recovery phase (1949–1979), the national economy is in a stage of recovery and steady development. The main goal of the construction of open pit coalmine is ‘production capacity recovery’. During the rapid development phase (1980–1999), the national economy is in a period of rapid growth. The main goal of open pit coalmine construction is also gradually transformed into ‘high-yield and high-efficiency mining’. During the comprehensive development stage (2000–2020), as China pays more and more attention to environmental protection, the main goal of open pit coalmine construction has also gradually been transformed into ‘safety, high efficiency and environmental protection’. Since entering the primary stage of development of intelligence (after 2021), under the guidance of the national ‘double-carbon’ strategy, coal, as the main energy source in China, according to the direction of green and low-carbon development. To achieve carbon peak, carbon neutral and target tasks, we will promote the transformation and upgrading of coal consumption. At the same time, with the continuous progress of the construction of open pit coalmines, it is expected that by the end of the ‘14th five-year plan’, the total output of open pit coalmines will account for more than 25 per cent of the national total coal production, and by the end of the ‘15th five-year plan’, it will reach more than 30 per cent (Association). Therefore, under the new national development concept of innovation, coordination, green, open and sharing, China’s open pit coalmine should also actively build a new system of full-chain, full-cycle and high-quality development with the overall goal of ‘safety, efficient, green, low-carbon and intelligent’.

1. Adhere to the bottom-line thinking, and promote the safe and efficient development of the whole chain of open pit coalmines. After years of development, the safety guarantee ability of China’s open pit coal mining enterprises has been significantly improved. The 101 safe and efficient open pit coalmines named in 2022 have all achieved ‘zero death’ in safe production. But at the same time, it also faces practical problems such as safety production concept is not firm, safety management system is not perfect, safety technical measures are not perfect. With the contradiction between complex conditions and multiple disasters and safety production as the primary position, it is necessary to strengthen the safety monitoring and early warning of open pit coalmine, improve the disaster prevention and relief ability; strictly implement the safety production regulations of open pit coalmine, effectively prevent and resolve the ecological environment risks of landslide, land damage, water pollution, air pollution and

geological disaster in the production process; strengthen the safety production and risk control in the whole chain of coalmine mining, strengthen the environmental safety and geological disaster management, and effectively improve the coalmine safety guarantee ability.

2. Promote ecological civilisation and practice the whole-cycle green and low-carbon development of open pit coalmines. We should strengthen the integrated scientific and optimised design of mining and exploitation, transportation, abandonment and reclamation, improve the ecological compensation mechanism in mining areas, focus on ecological management in the whole life cycle system such as planning and design, development and utilisation, and pit transformation, and focus on the ecological management of ecologically fragile areas and important ecological function areas such as the Yellow River basin. We will accelerate the clean and efficient development of coal and realise the use of high carbon energy and low carbon energy. Based on the actual situation of China's coal consumption structure, we should promote coal washing and processing and the cascade utilisation of coal, strengthen the quality tracking, testing and management of the whole process of commercial coal, and strengthen the research on the efficiency of coal utilisation and transformation. We will implement the new development philosophy and promote coordinated carbon reduction, pollution reduction, green expansion and growth. We will improve the standards for energy conservation and emission reduction in mining areas, encourage the development of energy conservation projects for the comprehensive utilisation of waste heat, pressure, water saving and electricity saving, strengthen the green transformation of production and living areas, and explore the formulation of an energy consumption budget management system.
3. Stimulate the innovation power and drive the intelligent development of open pit coalmines. The open pit coalmine is currently in the primary stage of intelligent development, and the intelligent equipment represented by unmanned mining trucks is developing rapidly, but it is still in the stage of technology exploration and pilot test, and has failed to form large-scale application. In the future, we should continue to increase the investment in scientific research, strengthen the technological innovation, and further enrich the intelligent application scenarios. At the same time, the intelligent mine construction is still in the independent module intelligence, and the intelligent operation of the mine lacks systematic. As an emerging professional cross-field, intelligence lacks a knowledge system for business related information under special mining scenarios and experience sharing in cross-professional disciplines such as mining, computer and automation.

## Realisation path of high-quality development of open pit coalmines

### *Planning guidance is the basis of high-quality development of open pit coalmines*

The open pit coal resource endowment conditions in China are relatively complex, and the unbalanced development and unreasonable layout are relatively prominent, so it is necessary to strengthen the planning guidance and top-level design, which is the basis for the high-quality development of open pit coalmine.

1. We will optimise the construction and layout of open pit coalmines and strengthen the top-level design of industries. Taking into overall account the national mining layout planning, infrastructure construction and development layout of related industries, define the development focus and development direction of the open pit mining areas in each region. Based on the coal demand and resource distribution in different regions, optimise the layout of mining rights setting, reasonable distribution of mining rights, reduce the loss of coal resources caused by human demarcation, ensure the efficient use of open pit coal resources. Focusing on the two major tasks of building quality production capacity and eliminating backward production capacity, to reduced displacement and optimise the layout, strictly control the access to new coalmines, priority to the construction of super-large and large open pit coalmines, we will intensify efforts to eliminate backward production capacity, supporting the orderly withdrawal of resource-exhausted open pit coalmines. Deep understanding of the distribution, quality and mining conditions of open pit coal resources, scientific assessment of the recoverable reserves of the open pit coal resources, identify the production potential of large open pit mining areas. We will adjust production plans according to changes in market

demand, regulate the production capacity of open pit coalmines, establish a flexible production mechanism for open pit coalmines, and ensure the flexible supply of coal resources and the balance between supply and demand in the market.

2. Adjust the industrial structure of open pit coalmines and deepen the reform of coal mining enterprises. We will accelerate the optimisation and upgrading of the industrial structure of open pit coalmines and increase the proportion of high-quality and advanced production capacity. Give full play to the advantages of coal resources, focus on the fields of coal power, coal chemical industry and coal-based new materials, further promote the chain, improve the development level of the open pit coal industry and deepen the reform of state-owned coal enterprises, strengthen and improve, and expand the quality and efficiency of the connotative growth of open pit coal enterprises.
3. Improve the regulations and standards of open pit coalmines, and standardise the healthy development of the industry. According to the elements of open pit coalmine from preliminary design, construction, production operation, until the withdrawal of pit, comprehensive evaluation of the current relevant regulations and standards for the construction of open pit coalmines, clarify the existing problems and deficiencies, comparative analysis of the differences of foreign regulation and standards of open pit coalmines, drawing on advanced ideas and technologies, clarify the direction and focus of improving the procedures and standards. Through the revision and improvement of the relevant regulations and standards of the open pit coalmine, to realise the full coverage of regulations and standards in the whole life cycle of open pit coalmine construction. During the implementation of the protocol standards, to continuously track and monitor the actual results, timely adjustment and improvement, ensure the applicability and effectiveness of the procedures and standards. At the same time, we will continue to pay close attention to the dynamic changes and new technological development in the open pit coalmine industry, timely adjustment and optimisation of standards and specifications, to adapt to the changing market demand and industry development trend.

### *Scientific and technological innovation is the driving force for the high-quality development of open pit coalmines*

The double pressure of low-carbon transformation and high-quality development of the coal industry has put forward higher requirements for the scientific and technological innovation of the open pit industry. Strengthening the original scientific and technological innovation characterised by informatisation, big data, greening, and intelligence is the driving force for the high-quality development of open pit coalmines.

1. Improve the mechanism and system of scientific and technological innovation, and build the institutional atmosphere of scientific and technological innovation. Strengthen the market-oriented mechanism of scientific and technological innovation, establish a scientific and technological innovation system oriented by the deep integration of industry-university-research and application to solve the actual production needs of open pit coal mining enterprises; optimise the decision-making mechanism of scientific and technological innovation, give full play to the decision-making role of scientists leading innovation; improve the management mechanism of scientific research projects, and actively explore the new management mode of scientific research projects, such as ‘taking the list’ suitable for the healthy development of open-air industry.
2. Give full play to the role of enterprises as the main players in innovation and increase investment in scientific research. Open-air enterprises should establish a development mechanism oriented by scientific and technological innovation, constantly strengthen their own innovation ability construction, actively develop global industrial innovation layout, and manage scientific research and innovation as an important asset in the process of enterprise development; change the innovation mode from a single technological innovation mode to a collaborative sharing mode of imitation innovation and independent innovation. At the same time, open pit coal mining enterprises should also increase the investment in scientific research funds, continue to strengthen the construction of scientific research platform and operation

funds support, establish a long-term and stable support for original basic research, applied basic research, research on industrialisation preliminary research, technical standard revision and other research and development direction.

3. Strengthen the coordination and linkage of industry innovation, and accelerate the research of key and core technologies. Focus on major disaster prevention and control of open pit mining, efficient intelligent mining, core equipment manufacturing, green low carbon development in the field of major basic theory, application basic theory and the urgent needs of the key core technology, fully strengthen the innovation of the open-air industry coordination linkage, scientific layout key research direction, comprehensive research direction of policy, capital, talent, facilities, support, focus on the implementation of a batch of original innovation and strategic prospective long cycle, high risk, the consensus, subversive major basic research projects, delineated basic research team, build the original technology.

### *Talent cultivation is the guarantee for the high-quality development of open pit coalmines*

In view of the current problems of talent shortage, low talent quality and unbalanced development in the open-air industry, expanding the training scale, innovating the training mode and improving the training mechanism are the necessary guarantee to realise the high-quality development of the open-air industry.

1. Expand the scale of training and increase the number of open-air professional and technical personnel. From the national level, we should increase the support for the higher education of open pit mining, and strengthen the faculty and teaching platform; from the level of the competent department of education, deepen the reform of the education system, pay attention to interdisciplinary integration, optimise and adjust the setting of open pit coalmines, expand the enrolment scale, increase the enrolment of undergraduate and graduate students; from the social level, actively guide the typical and advanced deeds of outstanding talents in the open pit coalmine, and create a good atmosphere to attract more outstanding talents to join the open pit industry.
2. Innovate the training mode and improve the quality of professional and technical personnel. Enhance the training function of innovative talents in colleges and universities, encourage colleges and universities to fully understand the talent needs of open pit coal mining enterprises, with the new engineering construction as the carrier, to further improve the discipline construction work, promote schools and enterprises to jointly formulate talent training programs, strengthen the integration of production, teaching and research, innovative training mode, construction of school-enterprise cooperative education platform and operation mechanism. Enhance the training function of skilled personnel in vocational institutions and training institutions, fully mobilise resources such as vocational colleges and training institutions, serving the personnel training of open pit coalmine. Enhance the training function of enterprise practical talents, promote the open pit coal mining enterprises to improve the training system, relying on the enterprise innovation and training mode, knowledge updating, professional skills and practical skills training for on-the-job personnel through various channels, improve the quality of personnel training.
3. Improve the training mechanism to promote the sustainable development of high-level talents in the industry. Improve the construction of the talent evaluation standard system in the open pit coalmine industry, promote mutual recognition of cross-regional and cross-enterprise professional titles and integration of professional titles and professional title qualifications, establish standards for the ability and quality of various talents, establish the assessment and evaluation methods of various talents by stratification and classification, we will optimise the compensation distribution and incentive mechanism for talents, guide enterprises to form effective incentive measures, stimulate talent motivation and release talent vitality. The whole outdoor industry should strengthen the awareness of high-level personnel training, in active response to the national implementation plan for major scientific and technological personnel, fully implement the supporting support policies for national talents, cultivate a group of open-air industry leading talents with international influence, thus driving the construction of the

talent team of the whole industry, to provide a strong talent guarantee for the high-quality development of open pit coalmine.

## CONCLUSIONS

1. Reviewing the construction process of open pit coalmines in China after the founding of new China, namely, the initial recovery stage (1949–1979), the rapid development stage (1980–1999), the comprehensive development stage (2000–2020) and the primary development stage of intelligence (after 2021).
2. The outstanding achievements of China's open pit coalmines in the past 70 years are systematically summarised from the output and quantity scale of open pit coalmines, open pit mining theory and technology, open pit mining technology and equipment, resource development and environmental protection.
3. Put forward four main problems in the development of open pit coalmines at the present stage, including the unbalanced development layout of open pit coalmines, the bottleneck of the sustainable development of mines, the key technical problems to be solved, and the imperfect training mechanism of talent shortage.
4. Put forward to build a 'safe, efficient, green, low carbon, intelligent' as the overall goal of the whole chain, whole cycle, total elements of open coalmine high quality development architecture system, summarises the connotation of the architecture system, illustrates the planning lead, scientific and technological innovation, talent cultivation is the basis of open pit coalmine high quality development, drive and guarantee.

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# Study of how industry-university research collaboration can solve long-lasting research problems for the mining industry

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## ABSTRACT

Mining in Australia is a significant primary industry and contributor to the Australian economy. In 2023, mining industry earnings grew to $54.3b, the most significant contribution to the country's economic growth (Australian Bureau of Statistics). The mining industry has recently reported increasing corrosion failure of rock bolts and cable bolts from hard rock mines, which have become a concern that could affect the safety and productivity of their operations. The corrosion failure of rock and cable bolts has been a long-lasting problem for the Australian mining industry. The newly installed bolts could sometimes fail within a few months up to a few years without any clear sign of overloading the material. Therefore, it is difficult for university researchers to focus on such unexpected problems without support from the industry. For the industry, without substantial research input from the university, the cause of such failure is also challenging to investigate, especially since this is a very multidisciplinary topic involving mining engineering, material science, chemistry, and microbiology. In the past few years, the collaboration between UNSW and the mining industry has successfully determined the root cause of the stress corrosion problem in underground mines.

Moreover, through the long-term collaboration between the university and industry, our research team has received many samples and information from different underground mines. According to this information, the research team has finally developed several anti-corrosion methods for the underground mining environment. This collaboration between companies and the university has created much knowledge for both the mining industry and the university researchers. This knowledge has then been turned into a powerful engine to lead the development of new technologies and products to solve problems for the industry. Therefore, this collaboration experience has successfully determined how long-term collaboration between industry and university can benefit researchers' innovation and economic growth for the industry.

Another benefit of the long-term collaboration between the industry and the university is the transformation of research outcomes into a product that can be commercialised. Due to the long-term support from the industry, all researchers in the UNSW multidisciplinary team have a good awareness of the actual problem that the industry is concerned with and what kind of solution is suitable for the industry. The research project focuses on developing the most suitable methods and products for the current industry and quickly making the product available to the market. As a result, several coating methods and materials were developed at the end of the project, and the commercialisation of the technology has already started.

# A trajectory towards the green mineral industry in Namibia

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## ABSTRACT

The global community has committed itself to net zero emissions by 2050 in order to prevent excessive global warming and hence unsustainable climate change. Mining has been estimated to contribute 4 to 7 per cent of the greenhouse gas emissions globally and efforts are required to decarbonise the industry. Namibia produces a variety of mineral products including diamonds, uranium, gold, zinc, lead, gemstones, lithium, tin, copper and salt. The country also has an abundance of renewable energy sources in the form of solar or wind energy and has undertaken to generate green hydrogen at Lüderitz, a location with a mean wind speed of over 9 m/s at 100 m above ground level, in line with the Africa-EU green energy initiative. This paper explores the role being played by the Namibia University of Science and Technology (NUST) in promoting the drive towards decarbonisation of the mineral industry. It also analyses the success factors and the progress achieved so far and charts the way forward not only in the country but the southern African region as well. A strategic decision has been taken to establish a campus in the town of Lüderitz, to focus on postgraduate research and development of renewable energy and green hydrogen. Partnerships have been established with European, mainly German, institutions to facilitate collaboration in this respect. The mineral industry is set to benefit from the research and the postgraduates produced from this campus. In another development of global significance in terms of mineral industry decarbonisation, an international investor who is collaborating with researchers from NUST, is embarking on the development of an iron ore mine and steelmaking plant that will use green hydrogen both as a source of energy and as a reductant in the Erongo region. Ongoing research on sustainable mine closure and the rehabilitation of abandoned mine sites is also expected to curtail fugitive emissions from the discontinued mines, thus contributing to the advances in decarbonising the mineral industry in the country.

## INTRODUCTION

Most developed countries have committed to the net zero emissions target and put in place policies to promote the uptake of renewable energy, electric cars, heat pumps, and other clean energy technologies. Global total energy demand increased from around 630 exajoules in 2022 to 670 by 2030 in the Stated Policies Scenario (IEA, 2023). However, the contribution of solar Photovoltaic (PV) has been revised upward since the Net Zero Emission Scenario 2021, underpinned by a surge in global manufacturing capacity, but a range of low-emissions technologies is required to ensure balanced and secure decarbonisation of the power sector. Since the signing of Paris Agreement in 2015, almost one terawatt (TW) of solar PV capacity has been added to the global system, which is equivalent to European Union total installed electricity capacity (IEA, 2023). However, the global energy mix remains unchanged and is mainly composed of oil, natural gas, coal, bioenergy and clean energy technologies (solar photovoltaics, wind, electric vehicles, heat pumps, hydrogen and carbon capture, utilisation storage) and fossil fuels in the world account for close to 80 per cent of total energy supply (IEA, 2023). On the other aspect electric vehicles have made significant impact on the industrial strategies to combat the carbon emissions. Notably, India has adopted the electric 2/3 wheelers and buses in her policies to deal with climate change. In sub-Saharan Africa 2030 targets are meeting diverse national energy demands with 85 per cent of new power generation plants being developed based on renewables. In tandem with the world, Namibia has also forged ahead in combating the carbon emissions through a number of ways which include the application of heat pumps, planned adaption of green hydrogen and steel manufacturing using green hydrogen.

The global mineral industry, which contributes 4 to 7 per cent of the greenhouse gas emissions, is undertaking a critical transformation driven by the imperative need for sustainability and environmental responsibility. Namibia produces a variety of mineral products including diamonds, uranium, gold, zinc, lead, gemstones, lithium, tin, copper and salt. The country also has an abundance of renewable energy sources in the form of solar or wind energy and has undertaken to generate green hydrogen at Luderitz, a location with a mean wind speed of over 9 m/s at 100 m above ground level, in line with the Africa-EU green energy initiative. As concerns over climate change, resource depletion, and pollution escalate, there is growing consensus that the traditional extractive model must evolve towards a greener and more sustainable future. This paper explores the pathways and strategies adopted by Namibia as it positions itself on a trajectory towards a green mineral industry, and examines the role being played by Namibia University of Science and Technology (NUST) in promoting the drive towards decarbonisation of the mineral industry. It focuses on key aspects such as renewable energy integration, technological innovation, responsible sourcing, and stakeholder collaboration (OECD, 2016).

## METHODOLOGY

The research was conducted by undertaking a desktop study and also by visiting and interviewing various people at the different departments, centres and institutes of NUST, and other stakeholders in the mining industry and the community. A questionnaire was developed to guide the interviews and the outcome of the interviews was summarised. The responses to the interviews led to a number of strategies namely renewable energy, technological innovations and adaptation, capacity building and collaborations.

## PATHWAYS AND STRATEGIES TO A GREEN MINERAL INDUSTRY

Namibia has engaged on a trajectory towards a green mineral industry by adopting strategies which focus on key aspects such as renewable energy, technological innovations, capacity building, and stakeholder collaboration. The country is endowed with renewable energy sources, particularly solar and wind energy, which present a significant opportunity to embrace sustainable energy generation and contribute meaningful strides towards decarbonisation. By harnessing these resources, Namibia does not only meet its own energy needs but also positions itself as a key player in the emerging green hydrogen economy. The decision to generate green hydrogen at Luderitz, a location with favourable sunshine and wind conditions, aligns with the Africa-EU green energy initiative and offers several strategic advantages such as those discussed hereafter. To provide the necessary support, the NUST has made a strategic decision to set-up a campus that will focus on renewable energy systems and green hydrogen research (NUST Green Hydrogen Vision 2030).

### Renewable energy integration

According to Nampower, Namibia has power generation capacity of 488 MW, with the bulk coming from hydropower at a capacity of 330 MW, while coal and thermal contributes 120 MW. Namibia has a low installed capacity of 489.5 MW (of which 465.5 MW is available) against a peak demand of about 690 MW (617 MW in 2021). It imports the balance from its neighbours via Power Purchase Agreements (PPA's) amounting to 380 MW as shown in Table 1. In terms of Namibian power generation, 24 per cent is contributed by fossil fuels, and this may be regarded as acceptable in terms of its contribution to greenhouse gas emissions, but this fossils contribution rises to 40 per cent of the power demand when the import source is factored in. One primary pillar of transitioning towards a green mineral industry is the integration of renewable energy sources into mining operations (Mamat *et al,* 2019). Traditional mining processes are energy-intensive and thus heavily reliant on fossil fuels, contributing to greenhouse gas emissions. By harnessing renewable energy technologies such as solar, wind, and hydroelectric power (Husin and Zaki, 2021), mines can reduce their carbon footprint and mitigate environmental impact. Investing in renewable energy infrastructure not only promotes sustainability but also offers long-term cost savings and energy security for mining operations. The Namibia Energy Institute, which is hosted under the NUST Faculty of Engineering and the Built Environment (FEBE) has made renewable energy integration one of its focus areas. This drive has been adopted by several mining companies, notably B2Gold Namibia which transitioned from heavy fuel oil (fossil) fired power generation to renewable energy sources, generating 7 MW from solar panels (Madziwa, Dzinomwa and Musiyarira*,* 2023; B2Gold, 2018).

**TABLE 1**

Power generation in Namibia.

| Energy source | Percentage |
|---|---|
| Import Power Purchase Agreements | 64% |
| Nampower | 24% |
| Independent Power Producers | 9% |
| Southern African Power Pool | 3% |
| **TOTAL** | **100%** |

- **Exploiting Renewable Energy Potential:** Namibia's vast expanses of desert terrain receive abundant sunlight and strong winds, making it an ideal location for solar and wind energy projects. Namibia has a renewable energy production capacity of above 250 GW. This capacity is competitive on a global scale, making Namibia a leading low-cost green hydrogen potential producer and exporter at 1.5 USD/kg (NIPDB, 2022). Solar photovoltaic (PV) panels can efficiently convert sunlight into electricity, while wind turbines can harness the kinetic energy of wind to generate power. By tapping into these renewable resources, as some mines in Namibia have done, the mineral industry aims to reduce its reliance on fossil fuels, mitigate greenhouse gas emissions, and enhance energy security.
- **Green Hydrogen Production:** Green hydrogen, produced through electrolysis using renewable energy sources, is emerging as a clean and sustainable fuel with diverse applications in sectors such as transportation, industry, and energy storage. According to Namibia Power Corporation (NamPower, 2018), Lüderitz's mean wind speed of over 9 m/s at 100 m above ground level provides optimal conditions for wind power generation, which can be used to power electrolyzers for hydrogen production. Namibia has already engaged its first investor, awarding Hyphen Energy preferred bidder status for US$4.4 billion (Financial Times, 2023; Republic of Namibia, 2021). The project is planned to have a cost *of US$9.4 billion and will employ 3000 people with 15 000 construction jobs necessary for the four-year build*. The construction, operation, and maintenance of solar and wind farms, as well as hydrogen production facilities, require skilled labour and local expertise, generating jobs across the value chain as well as diversifying Namibia's economy.

NUST has made a strategic decision to set-up a research centre at Luderitz and appointed a champion to spearhead the development. Under this initiative staff and student exchange programmes have been established with a number of European (mainly German) institutions. The first cohort of 21 Masters' degree students focusing on research in this area, was sent to German by NUST during the first semester of 2024. Research projects are focused on generation and application of green hydrogen.

## Capacity building and training

Namibia has invested and continues to invest in capacity building and training programs to empower stakeholders with the knowledge, skills, and resources necessary to engage effectively in the transition towards a green mineral industry. Namibia plays a proactive role by employing supportive policies and enforcing regulations to hold companies accountable for their environmental and social performance (Tanimoto, 2019; Paton, 2006). Capacity building initiatives include provision of technical training on sustainable mining and mineral beneficiation practices, environmental management, community engagement, governance (ESG) and conflict resolution (Chen, 2022). NUST has taken a leading role in this direction through the establishment of undergraduate and postgraduate programmes in Mining, Metallurgy and related programmes, and also setting up specialised research and development centres such as the NEI and CEMMB. The NEI focuses on renewable energy and energy efficiency while the CEMMB provides applied research and consultancy services as well as technology development in mining and mineral beneficiation. Both centres also provide continuous professional development and other short courses to large corporates and small scale enterprises. Such initiatives such as Southern African Solar Thermal training and demonstration Initiative (SOLTRAN) undertaken by NEI has managed to train tens of technicians in Namibia and have also managed to install heat pumps at state hospitals. By building local expertise and empowering stakeholders, Namibia can strengthen its ability to manage and regulate mineral extraction in a responsible and sustainable manner.

## Technological innovation and adaptation

Technological innovation and adaptation play a crucial role in driving Namibia's transition towards a green mineral industry by enhancing sustainability, efficiency, and environmental responsibility in mining operations. By embracing sustainable mining equipment, water recycling and treatment technologies, and renewable energy integration, Namibia is unlocking the full potential of its mineral resources while minimising environmental impact and promoting long-term socio-economic development. Innovations such as automation, electrification, and digitalisation are revolutionising mining processes, making them more efficient, environmentally friendly, and safer for workers (Jämsä-Jounela, 2019). For instance, the adoption of electric vehicles and battery-powered equipment in mining operations reduces emissions and eliminates the dependence on fossil fuels. Similarly, the use of advanced data analytics and artificial intelligence enables predictive maintenance, optimised resource utilisation, and enhanced environmental monitoring, leading to improved sustainability performance across the entire value chain.

- **Artificial intelligence in mining and process monitoring**: Significant advances have been made by Namibian mines in this area. For instance the application of drone technology in monitoring tailings storage facilities and other areas by Dundee Precious Metals Tsumeb, Rosh Pinah Zinc and other mines has enhanced safety and environmental monitoring. The NUST School of Engineering, in collaboration with its Finnish partners, has engaged in drone technology application, research and development in the soon to be established Aviation centre in Keetmanshop.
- **Green hydrogen as a reducing agent in direct reduction of metal oxides:** Green hydrogen can be used as a clean fuel in the steelmaking process, replacing traditional fossil fuels such as coal and natural gas. Hydrogen-based direct reduction processes, such as direct reduction of iron (DRI), offer higher energy efficiency and lower greenhouse gas emissions compared to conventional blast furnaces. By incorporating green hydrogen into steel production, the plant can optimise energy usage and reduce overall environmental impact.

In the process shown in Figure 1, renewable energy is utilised to (1) electrolyse water and generate hydrogen which its (2) transported to the (3) reduction furnace where it reacts with iron ore to form (4) steam according to reaction (i) which condenses to water. After heat recovery the water is recirculated to electrolysis.

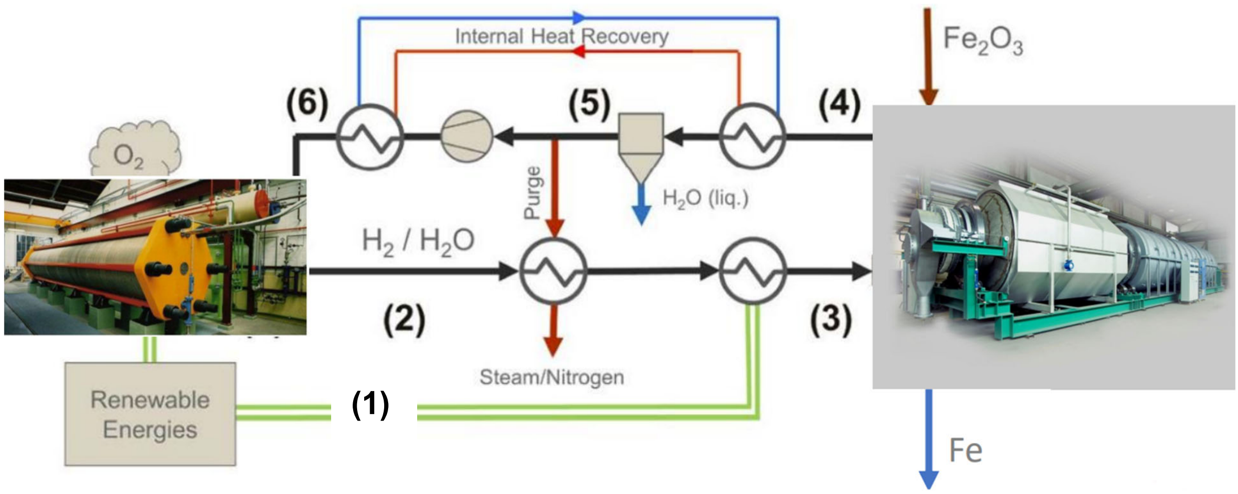


**FIG 1** – Production process for Green Iron/Steel (After $CO_2$Grab, 2022).

$$Fe_3O_4 + 4H_2 = 3Fe + 4H_2O \quad (1)$$

The Centre of Excellence for Mining and Mineral Beneficiation (CEMMB) under the NUST FEBE, is engaged in collaborative research with industry stakeholders such as HyIron Namibia to support the DRI production using green hydrogen at Oshivelo and other iron mines, thus eliminating the need to use fossil fuels like coke or coal.

- **Water recycling and treatment:** Water scarcity is a significant challenge in many mining regions, including Namibia, where access to freshwater resources is limited (Musiyarira, Tesh and Dzinomwa, 2015) Innovative water recycling and treatment technologies, such as desalination, membrane filtration, and advanced oxidation processes, enable the efficient use and management of water resources in mining operations. By recycling and treating process water, mines can minimise freshwater consumption, reduce wastewater discharge, and mitigate the risk of water pollution, thereby promoting environmental sustainability and responsible water management.
- **Environmental rehabilitation:** Over the years, over 100 mine sites were abandoned without rehabilitation. In some cases, contamination of local soils by heavy metals occurs depending on the composition of exposed rocks, thus polluting the environment. NUST is conducting research on the best strategy and methods to apply on rehabilitating such sites and preventing similar occurrences in the future.
- **Mineral beneficiation strategy (MBS) of Namibia:** NUST developed the Mineral Beneficiation Strategy of Namibia and its Implementation Plan for and on behalf of the Government ministries of Mines and Energy and Industrialisation and Trade (MIT, 2021). The MBS and its implementation plan outline the strategy and methodologies to be followed in ensuring that minerals in Namibia are extracted and beneficiated in sustainable and environmentally friendly ways, thus laying the path for the trajectory towards a green mineral industry in Namibia.

## CONCLUSION

To achieve a sustainable trajectory towards a green mineral industry requires a multifaceted approach that integrates renewable energy, technological innovation and adaptation, continuous capacity, and stakeholder collaboration. By embracing sustainability as a core principle and leveraging the latest advancements in technology and governance, the mining sector can mitigate its environmental footprint, enhance its social impact, and contribute to the transition towards a more sustainable and resilient global economy. As the demand for minerals continues to grow, it is imperative that higher education and industry stakeholders work together towards a shared vision of sustainability and responsible stewardship of the planet's resources. The Namibia University of Science and Technology has committed itself to playing a significant role along this trajectory and has made the attainment of this goal one of its primary objectives. By implementing these measures, Namibia will ensure that its mineral sector contributes to sustainable development, environmental stewardship, and social responsibility thus paving the way for a green mineral industry that benefits both present and future generations. In all these efforts NUST is contributing in the trajectory towards a green minerals industry in Namibia.

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# Strategies for linking artisanal and small scale miners with large scale operators and the market

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## ABSTRACT

Artisanal and small scale miners contribute significantly to the global supply of minerals, and to the livelihoods of several families in the world. This sector, however, is characterised by low capital and low mechanisation, as well as minimal capacity to add value and are thus limited to low unit revenues. In Namibia, artisanal and small scale miners are mainly active in mining and beneficiating gemstones, tin, and copper. Opportunities were identified to link the artisanal and small scale miners with large scale operators for increased value addition, and also to the market. Strategies were thus developed to facilitate linkages between artisanal and small scale miners on the one hand, and large scale miners and the market on the other hand to ensure the achievement of the United Nations sustainable development goals (especially 1, 2, 8, 9 and 10) within Namibia. To develop the strategies, it was essential to assess the quantities, qualities and distribution of mineral ores available as well as the capacities of the different operators. Depending on the need, options for value addition through pre-concentration of ores on-site by the small volume producers were evaluated for implementation in order to reduce transportation costs to access the large scale beneficiation facilities. Educational institutions developed and/or provided tailor made training courses in order to build the capacities of the artisanal and small scale miners, and to boost their confidence as well as to assure the large scale and market buyers of high and consistent product quality. Platforms for communication, collaboration and ongoing support were created between the parties and the benefits accruing to each party were evaluated. It was noted that artisanal and small scale miners benefited and continue to benefit through skills development, regular and consistent markets for their products, and higher revenues through value addition while the large scale operators and market buyers benefited through reliable supply volumes and quality, as well as their environmental care, social and governance (ESG) profiles. The role players as well as Government also realised gains in terms of increased safety, incomes and environmental protection. This paper summarises the development, application and the benefits of strategies created to link artisanal and small scale miners with large scale operators and the markets. It is a progress report on the ongoing work on the development and application of the strategies on different mineral commodities.

## BACKGROUND AND INTRODUCTION

The artisanal and small scale mining sub-sector contributes significantly to the global supply of minerals, and to the livelihoods of several families in the world. Overall, 150 million people across 80 countries depend on these types of largely informal mining operations to survive. Generally, the mining sector is divided into formal and informal, and further categorised into large scale and small scale respectively. The large scale category may also be further sub-divided into large and medium scale depending on level of mechanisation and production while small scale may also be sub-divided into artisanal and small scale. According to Aryee *et al* (2003) the artisanal and small scale (ASM) sub-sector is defined as individuals or small groups who depend upon mining for a living and who use rudimentary tools and techniques (eg picks, chisels, sluices and pans) to exploit their mineral deposits. According to the World Bank-funded Delve database, India has the largest number of artisanal and small scale miners (ASM) globally with an estimated 15 million people, followed by China with nine million ASM miners. Other countries with significant numbers in the ASM sector include Indonesia (3.6 m), DR Congo (2.0 m), Ethiopia (1.3 m), Ghana (1.1 m), Burkina Faso (1.0 m), Sudan (1.0 m), Tanzania (1.0 m) and Zimbabwe (1.0 m)

Extensive studies were conducted on the small scale sub-sector in Namibia (Nyambe and Amunkete, 2009; Dzinomwa *et al,* 2014; Chirchir, 2017) and it was established that artisanal and small scale miners in Namibia were mainly active in mining and beneficiating gemstones, tin, tantalite and copper. The growth strategy for the Namibian jewellery and coloured gemstones and associated value chains was completed by some of the authors of this study and the strategy is currently in the process of implementation (Ministry of Industrialisation and Trade (MIT) and SME Development, 2016). In recent years, the importance and demand for copper, with its high electrical conductivity, has increased on the back of a growing electric vehicle production industry. Global copper production has seen steady growth over the past decade, rising from 16 million metric tons in 2010 to total worldwide copper mine production amounting to an estimated 22 million metric tons in 2023 (Statistica, 2024).

This study focused on developing strategies for linking the copper ASM sub-sector in Namibia to large scale operators and or the market.

## METHODOLOGY

The methodology used in this study was based on a review of past work conducted on this subject, identification of stakeholders, consultations with the Government particularly the Ministry of Mines and Energy, consultations with large scale industry players as well as artisanal and small scale miners and local community leaders. The study included field visits to the north-west province of Kunene, where copper ASM activity was identified as prevalent through literature survey and stakeholder consultations. Specific areas visited were Sesfontein, Opuwo, Kamanjab and Khorixas. A questionnaire was designed for use in the survey of the ASM sub-sector to identify ownership of mining claims, quantities and qualities of product and the market, challenges experienced, and suggested remedies. Some samples were collected during the field trips to determine the potential for the level of contribution from the sector.

In order to develop strategies to link ASM with large scale mining, the logical framework analysis (LFA) approach was used, and the problem tree was drawn up and subsequently followed by the objectives tree.

## FINDINGS

### Government

Interviews with Namibia Government officials revealed that the ASM sub-sector was well regulated through various permits and licences required before and during mining. Record keeping, however, by the sub-sector was rather poor and sometimes they did not get fair value from their customers who would on-sale or export the products. The Government had limited resources when it came to providing exploration, mining and processing facilities or equipment. Also, concerns were raised on health and safety, as well as environmental care in this sub-sector.

### Large scale operators

While there is recognition of the sub-sector's contribution and its potential for even more deliveries in terms of both quantities and quality, the large scale operators were not confident of the sustainability of these supplies. They would like the capacity in terms of skills and equipment of this sub-sector improved. The environmental, social and governance (ESG) reputation of the large scale operators is contingent upon issues relating to the sub-sector, particularly health and safety and environmental care. At least one major client for the copper produced by the ASM sub-sector is readily available to purchase as much of the copper (of good quality) as possible.

### Artisanal and small scale miners

The artisanal and small scale miners, as well as the community leaders in which they operate, identified challenges in terms of lack of:

- requisite skills
- appropriate equipment, as well as
- adequate funding.

It is important to note, however, that there was a ready market for the copper produced by the ASM operators. This scenario created an opportunity for independent suppliers of equipment, or toll/contract services in both mining and processing of the copper.

## Field trips and quality analyses

Figure 1 shows some mined pits and hand-sorted products in one of the areas visited.

(a) (b)

**FIG 1** – (a) hand-sorted copper ore; (b) mined pit.

It was clear that there was a shortage of mining expertise as no due consideration had been given to proper mining standards. A variety of copper oxide and sulfide minerals including chrysocolla, cuprite, chalcopyrite, were identified in different parts of the region.

Table 1 summarises the chemical analyses of some samples collected from the hand-sorted stockpiles. The quality of the samples in terms of copper was fairly high at levels above 30 per cent, and also some precious metal content. However, there was inadequate to no quality control measures other than visual inspection and control in some cases, rendering the product quality unreliable over long-term periods.

**TABLE 1**

Chemical analyses of samples collected in the field.

XRF Analysis of copper ore 21-05-2024

| | Cu | Co | Au | Ag |
|---|---|---|---|---|
| Sample A (ppm) | 301185 | 258 | 4.902 | 416 |
| Sample B (ppm) | 342672 | 306 | ND | 440 |
| Sample C (ppm) | 329020 | 277 | ND | 429 |
| ***Average (ppm)*** | ***324292.3*** | ***280.3333*** | ***4.902*** | ***428.3333*** |
| **Concentration (%)** | 32.4 | 0.028 | 0.0004 | 0.0428 |

ND = No Detection

Mechanised ways and methods to upgrade the different kinds of ores found were evaluated and the most cost-effective ones selected for trials.

## STRATEGY FOR LINKING ARTISANAL AND SMALL SCALE MINERS WITH LARGE SCALE OPERATORS AND MARKET

### The strategy – small scale to large scale operator linkages

Based on the findings of this research, the Logical Framework Analysis approach was adopted for the development of the strategy to link artisanal and small scale miners to large scale operators and simplified strategy is shown in Figure 2. The main goals to be attained included:

- Availability of adequate reserves, which would be achieved through exploration.
- Appropriate processing facilities to upgrade the ore.
- Reliable supply of copper concentrate of consistent quality to the large scale processing plants or market.
- Capacity building for ASM sub-sector in terms of skills, equipment and working capital.

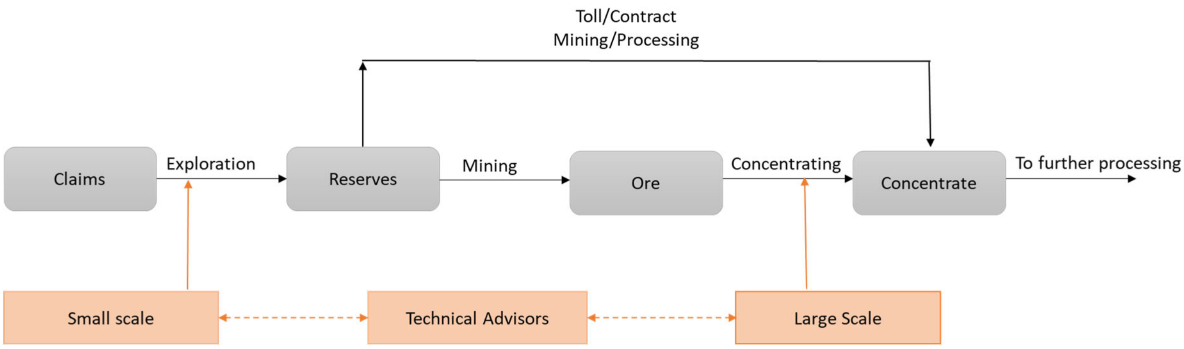


**FIG 2** – Simplified strategy for linking ASM sub-sector with large scale operators and/or market.

### Benefits of the strategy to the parties involved

The benefits of the summarised strategy are adequate geological services, safe and efficient mining and processing, and consistent product for further processing or the market. The ASM operators are assured of regular and consistent income resulting in socio-economic development in the areas that the minerals occur. Adequate environmental care will be realised and urban migration will be reduced.

## CONCLUSIONS AND RECOMMENDATIONS

There is a vibrant artisanal and small scale copper mining sub-sector in identified parts of Namibia, which has the potential to contribute significantly to socio-economic development in the areas and also to contribute towards reducing the growing demand for copper. However, this sub-sector is characterised by lack of skills and facilities or equipment for exploration, mining, processing and logistics to transport their product to the market. In this ongoing study, a strategy for linking artisanal and small scale sub-sector with the large scale operators and/or the market was developed, which is expected to provide sustainable solutions to the challenges confronting the sub-sector. Further refinement of the strategy is recommended to ensure that any loopholes are closed.

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# Acceptance and participation of the community in mining projects

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## THE NINGALOO PROJECT

The acceptance of the community is essential to realise mining projects. Otherwise, demonstrations against these projects can take place. Some protests are widespread. So there were demonstrations even in Germany against the mining project in Ningaloo. A group demonstrated against this project in front of the headquarters of Kali and Salz (K+S) (Atif, Küster and Löwe, 2024). In Australia there were also protests against this (Ilschner, 2024).

## PROTESTS IN GERMANY AGAINST COAL AND WIND POWERPLANTS

In Germany there were large protests against coal mining which lead to police operations and negative headlines (see for example Lützerath and Hambach). Meanwhile the end of coal mining is decided. But there are also protests against wind powerplants. They are not so heavy. But local residents often feel disturbed by noise and light spectacles (disco-effect with the sun). The population wants to enlarge the part of wind electricity but if a project shall be realised nearby it is often refused. To increase the public acceptance, there is the possibility of taking a financial stake in wind turbines and thus making a financial profit from the sale of wind energy.

## ECONOMIC PARTICIPATION

This participance could also be a template for mining projects which affect the neighbourhood or even the houses and farmland of the inhabitants. A possible economic participation could have a positive impact on the realisation of mining projects, but it is difficult to force the enterprises to guarantee such a financial participation. It must be compatible with the freedom of property and the professional freedom. It could be justified by the necessity to extract raw materials for climate protection and for the essential needs of community.

## THE IMPORTANCE OF RAW MATERIALS

Is it in contrary possible to refuse mining projects without acceptance by the population? The protest of parts of the population could prevent mining even if the raw materials are indispensable for basic needs of society and the climate change by electrical cars and a higher energy efficiency of buildings. But how to evaluate whether there is a significant protest of the community and not only of single persons? The missing acceptance can be part of the assessment whether the arguments for a mining project are more important than the arguments against it, but protest cannot prevent a mining project automatically. Often it is necessary to take the protest into account instead of renouncing a project, above all, if this project is necessary for basic needs of society such as power supply and climate protection.

## THE RELEVANCE OF ACCEPTANCE

The acceptance serves the German Federal Constitutional Court (BVerfG) as a reason to limit the professional freedom (BVerfG, 2022). It is true that concerns have been expressed about the classification of acceptance as a legal concept (Erbjuth, 2023). However, the Federal Constitutional Court has at least identified acceptance as a possible starting point for state measures, at least in the area of green electricity expansion – ie also in the energy sector – and climate protection (Rheinschmitt, 2022). It can then all the more be a relevant part of a consideration, even if the German Federal Administrative Court (BVerwG) has denied the importance of acceptance as a legally relevant concern (BVerfG, 2013).

In the Garzweiler decision, the BVerfG explicitly focuses on the general effects of resettlement, ie the concrete significance for all those affected. This can also include profound alienation, which then leads to a lack of acceptance (BVerfG, 2013). If the effects for the entirety of those affected are only named in the case of large-scale resettlements, the subsequent formulations of the Federal Constitutional Court show that, in terms of approach, the concerns of other kinds to be included are not limited and should also be extended comprehensively to expropriations. In addition, developments have moved on and the acceptance of projects is much more in question than at the time of the Garzweiler decision of the BVerfG, which was issued over ten years ago on December 17, 2013. Ultimately, a lack of acceptance can also stand in the way of a project because it is then difficult to implement. This depends on the circumstances in the case, so if the need of raw materials is very high. Thus the BVerfG combines improving acceptance with promoting the expansion of wind power and ultimately climate protection (BVerfG, 2022). If the raw materials are necessary for climate protection and for covering essential needs, the acceptance has a minor importance. Then the assessment is in favour of raw materials.

## RESULT

Mining projects are essential for climate protection and for covering essential needs. They must be realised also if there are protests. But the enterprises have to get in contact with the population and have to try to convince the majority. It is not obligatory to realise an economic participation if it is not normatively fixed like in some parts of Germany concerning the expansion of wind craft powerplants. But it is a possibility to encourage (perhaps financially) the neighbourhood to acquire shares of the mining companies. So these persons are not only involved in the admission of the project but also in the economic benefit.

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# Comparative analysis of the effect of economic parameters on cut-off grade optimisation

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## ABSTRACT

Material mined for profit is defined using a cut-off grade (COG) that is based on geological, operational, and economic factors. Cut-off grade is used to distinguish ore material sent to the mill for processing from waste material sent to the waste dump. Therefore, the cut-off grade affects the overall cash flow and net present value (NPV) generated by a mining operation. To generate maximum economic value, the cut-off grade must be optimised by considering several mining parameters that are broadly categorised into economic, geological, and operational parameters. These parameters have a significant effect on influencing the cut-off grade selected in mining operations at any given period. Uncertainty is inherent in some of the parameters that are stochastic in nature having a random probability distribution that may not be predicted precisely. When selecting cut-off grades in a mine operation, the mining engineers must consider the dynamic nature of the operational parameters to maximise the net present value (NPV) of the project. Lane's cut-off grade approach can be modified to incorporate the stochastic parameters in the approach helping improve the resultant NPV. Recently, machine learning and computer applications have been utilised to explore this stochasticity. The selected economic parameters (metal price, operating costs, and discount rate) in this paper are varied by a specified percentage per annum. The results show a significant increase by a percentage difference of 9.38 per cent between the NPVs generated by varying the price, and 2.07 per cent, 1.12 per cent, 1.28 per cent, and 0.08 per cent difference when varying discount rate, mining, milling, and refining costs respectively in the NPV generated. This shows that uncertainty in these economic parameters has a significant impact on mine planning and hence the need to do stochastic mine planning as opposed to deterministic planning.

## BACKGROUND INFORMATION

Considering the economic, operational, and geological factors in selecting the cut-off grade (COG), the quantity of ore and waste material within a given orebody can be differentiated with accuracy. Using the geo-metallurgical factors incorporated in cut-off grade calculation, cut-off grade can differentiate between various ore types before processing takes place for different metallurgical processing options. The main objective of mining companies is to maximise the net present value (NPV) throughout the mine life. The NPV expected throughout the mine life from an operation is dependent on interrelated parameters such as mining, milling and refining capacities, extraction sequence, and cut-off grade selected at any specific period. These interdependent parameters interact in a complex manner in defining the NPV of a project as depicted in Lane's cut-off grade theory (Lane, 1964, 1988). Consequently, various approaches are used to explore this complex interdependent including machine learning and computer applications tailored for the task.

The selected cut-off grade distinguishes the quantity of ore material sent to the processing plant for processing while the waste material is sent to waste dumps. Some of the ore material mined can also be stockpiled for later processing according to the strategic mine plan. The sequence of extraction of the mineable material shown in Figure 1 is dependent on the rates and capacity of production, grade distribution of the deposit, and the selected cut-off grades. The selected cut-off grade directly affects profits generated hence the need for its optimisation depending on the extraction sequence and mining operation capacity. The two components in the mine value chain: production capacities, and extraction sequence are directly related to COGs. This is incorporated in Lane's COG approach by factoring these components with economic, operational, and geological factors when selecting the optimum COG (Lane, 1964, 1988). The selected COG generated from this approach is then applied in mine operations to maximise the NPV of the project.

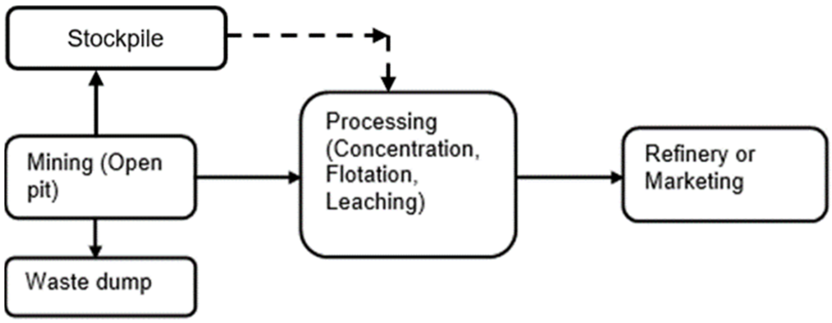


**FIG 1** – Extraction sequence for an open pit mining operation (Githiria, 2018).

Metal mined for profit such as gold would have a typical mining operation that consists of a mine, processing plant, refinery/marketing facility, stockpile area and waste dump. The mine produces ore with different metallurgical composition such as sulfide and oxides ore types mixed with waste material in specified quantities based on the production capacities. The ore undergoes processing to remove impurities through various steps such as gravity concentration, flotation, and leaching. Lastly, the ore is refined to extract metal from the processed material while the waste material is sent to the waste dump (Githiria, 2018).

The cut-off grade theory used in this study is based on Lane's cut-off grade approach. The approach generates higher cut-off grades than breakeven grades in the early years of mining for higher rate of return on capital invested and increased annual cash flows (Lane, 1964, 1988; Githiria, 2018; Githiria and Musingwini, 2019). As indicated, the approach incorporates geological information in its calculation process and makes sure that the production constraints are satisfied. It applies the specified economic and operational factors to generate the dynamic cut-off grades that maximises NPV. The dynamic cut-off grades will therefore decrease with the depletion of mineral reserves. This outcome is because the policy tends to mine higher-graded ore during the early years and lower-graded ore in the later years. The objective of maximising NPV in the early years of operation is to payback the capital invested in the project as quickly as possible. This is referred to as the time value of money where the maximum economic return is achieved by generating the highest NPV of the future cash flows (Githiria, 2018; Githiria and Musingwini, 2019).

There are several approaches proposed by other researchers in their work on cut-off grade optimisation. The main objective is to encompass the variable mining parameters that affect the mine value chain in maximising NPV by selecting the optimal cut-off grade. Some of the techniques used in these studies are based on operation research techniques such as linear programming, dynamic programming, mixed-integer programming, integer programming, binary integer programming, greedy method, and heuristic methods such as genetic algorithms. Machine learning approaches are also being explored in recent works as indicated in a review done by Jung and Choi (2021). The work done on cut-off grade optimisation is listed in the Appendix for a better understanding of the topic.

Mining companies are currently embracing optimisation techniques in planning, evaluation, implementation, and monitoring of their operations. They are using statistical and mathematical models, artificial intelligence techniques and machine learning methods in optimising their daily operations. This embodies the use of data analytics in mineral exploration, extraction, beneficiation, and mine reclamation stages of mining operations. The need to use computer applications in optimisation of these stages helps to manage the intensity of the computational work required. The main objective of most mining-related problems is based on maximising profits and minimising costs or losses in the mine value chain.

The major factor that affects most mining operations is the fluctuation of the prices of most commodities which has led to the closure of some mid-sized mines around the world. Investment in the mining sector has become limited due to this uncertainty brought abought by economic factors. Hence the need for mining companies to embrace optimisation methods to improve their evaluation process before and during the mining operations. For instance, in South Africa, there are several potential mining projects that stopped their exploration activities and feasibility studies due to fluctuations in gold and platinum prices.

Variability in the two precious metals as shown in Figures 2 and 3 has also been affecting the current operations. A report done by Johnson Matthey on the platinum group metals (PGM) market indicated that the global platinum supplies in 2017 declined from the previous year by 2 per cent amounting to 6 million ounces (Matthey, 2018). In South Africa, there were two mines that closed in 2017. Maseve mine which is owned by Platinum Group Metals Limited ceased operations in mid-year while Bokoni mine owned by Atlatsa Resources closed at the end of September (Matthey, 2018). Later, COVID-19 virus pandemic disrupted the supply and demand chain during the year 2020 as seen in Figures 1 and 2. There was a surplus in the market in 2021 as supply levels recovered from the COVID-19 disruption and processing outages. These unpredictable situations need to be accounted for when planning mining operations (Matthey, 2021; Goldhub, 2022).


**FIG 2** – Historical gold price chart (Mining.com, 2024a).


**FIG 3** – Historical platinum price chart (Mining.com, 2024b).

Likewise, the gold mines in the world have suffered the same fate with mines closing in the past years due to fluctuating gold prices. The profitability in the gold sector in the early 21st century started declining as mines started experiencing the effects of the global recession. South Africa's gold industry has been leading globally in gold production, but it has declined considerably due to rising costs, sustained low rand gold price, falling grades, old and deep mines, and declining productivity. This has led to several mines closing such as Evander mine owned by Pan African Resources, which was shutting its underground mine in 2018 retrenching about 1600 people (Seccombe, 2018). Another mine that closed is the Cooke Mines owned by Sibanye-Stillwater mine company which shut its three mine shaft complexes (Cooke Number 1, 2, and 3 Shafts) (Seccombe, 2018). According to the Minerals Council of South Africa, 75 per cent of the gold mines are unprofitable due to the weak rand price of gold (Seccombe, 2018).

Consequently, this paper applies variability in the cut-off grade calculation by introducing varying metal prices, discount rate, and operational costs. This approach ensures that the varying parameters are used to generate more realistic NPVs since variability is inherent to mining operations. In this way, the COG optimisation policy generated using the approach presented in this paper closely relates to variable conditions as encountered in actual mining practice.

Economic evaluation methods are conventional approaches used in the mining industry to evaluate the economic benefits of mining projects. Currently, the widely used include the cash flow method, discounted cash flow method (DCF), financial internal rate of return analysis method, net present value, and breakeven analysis method. Some of the tools used in assessing the economic value and risk of mineral projects in these approaches include sensitivity analysis, probabilistic analysis, scenario analysis, and conditional simulation.

The most common way of evaluating a mining project is the Net Present Value (NPV) criterion. This criterion considers the discounted cash flow of the time value of money. The discounted cash flow (DCF) method uses NPV, Internal Rate of Return (IRR), and profitability index (PI) to evaluate the feasibility of the project. The NPV criterion applies the concept of the time value of money by subtracting the cash outflow from cash inflow and then discounting the present value. This is expressed by the following equation:

$$NPV = \sum_{i=1}^{N} \frac{P_{w_i}}{(1+d)^i} \quad (1)$$

$$\text{Cash flow}, P_{wi} = \left(\sum_{i=1}^{N} s_i - r_i\right) * Qr_i - c_i * Qc_i - m_i * Qm_i - f_i \quad (2)$$

Subject to: ($Qm_{wi} \leq M$ for *i*=1…N), ($Qc_{wi} \leq C$ for *i*=1…N), and ($Qr_{wi} \leq R$ for *i*=1…N)

Where P represents cash flow generated from the mining operation over period(*i*), d represents the discount rate on the present value generated and N represents the life-of-mine (LOM).

The cash flow equation *($P_i$)* represented in Equation 2 incorporates the uncertainty of the economic parameters. The uncertainty (w) is incorporated by introducing a probability distribution of the parameters. The notation in Equations 1 and 2 are represented in Table 1.

**TABLE 1**

Notations of parameters in the COG algorithm (Githiria, 2018; Githiria and Musingwini, 2019).

| Notation | Explanation | Unit |
|---|---|---|
| s | Selling price | US$/oz |
| m | Mining cost | US$/ton |
| c | Milling cost | US$/ton |
| r | Refining or Selling cost | US$/oz |
| d | Discount rate | decimal |
| $Qm_{wi}$ | Quantity of material to be mined for grade-tonnage curve *w* during period *i* | ton/annum |
| $Qc_{wi}$ | Quantity of material mined sent to the concentrator for grade-tonnage curve *w* during period *i* | ton/a |
| $Qr_{wi}$ | Quantity of the final product for grade-tonnage curve *w* during period *i* | ton/a |
| f | Annual fixed costs | US$/a |
| M | Mining capacity | ton/a |
| C | Milling capacity | ton/a |
| R | Refining capacity | ton/a |
| y | Recovery | decimal |
| i | Period (year) indicator | - |
| N | Mine life | Years |
| w | Grade-tonnage curve indicator | - |

An economic evaluation for a project can be done in a variety of ways through point estimation, interval estimation, and probability estimation methods. The point estimation method, a deterministic analysis method, is a simple and easy analysis method that relies on the NPV and IRR. It involves the estimation of the mean value of the single value closest to the dependent variable. However, this method has a disadvantage in that it ignores interdependencies of the mining parameters (Li *et al,* 2023). The interval estimation method applies sensitivity analysis on the mining parameters or constraints by calculating the average, minimum, and maximum values of the objective function. It generates a range estimate of the value of the dependent variable.

Sensitivity analysis involves varying one or more mining parameters in the model to understand their effect on the output. The optimal NPV generated from the COG policy is evaluated with respect to the varying economic parameters. The parameters are analysed to determine the most critical parameters that has significant effect on NPV. The critical parameters considered in this paper include the metal price, mining, milling and refining costs and discount rate. Variation of the economic parameters is done in this study to check if the project is at risk for better planning or optimistically maintaining the optimal input parameters in the cut-off grade policy.

The other method used in economic evaluation is the probability estimation method or probabilistic analysis such as Monte Carlo simulation. It is a stochastic analysis method that incorporates both the scenario analysis and sensitivity analysis mentioned above. Scenario analysis clusters values of key mining parameters by scenarios and then analyses how the project value changes under different scenarios. This is illustrated by Rolley and Johnson (1997) on how different resource models can have an impact on the estimates of project profitability. Probabilistic analysis uses a correlation coefficient to show the changes in the distribution of values and reflects the interdependencies between the variables. The resulting values have the advantage of enabling stochastic decision-making.

Key mining inputs, such as costs, metal prices, discount rates, recovery, and grade-tonnage distribution, are characterised as probability distributions. Monte Carlo simulation is used to simulate the NPV under a range of these key inputs sampled from the primary distributions. In addition to the above economic evaluation methods, conditional simulation method can be used to quantify the grade distribution within an orebody. These distributions are then used in combination with the Monte Carlo based probabilistic evaluation model to understand how grade variation influences the project value. From this study, the NPV is distributed against the varying parameters, and appropriate statistics can be collected to characterise the quantities such as mean, minimum, maximum, standard deviations, and percentage difference.

## CUT-OFF GRADE OPTIMISATION

The NPVMining computer application has a graphical user interface, as illustrated in Figure 4, that allows the user to calculate the optimal COG depending on the cut-off grade method selected. It has two options namely break-even cut-off grade method and Lane's limiting cut-off grade method. It gives the user the choice to manipulate the data depending on the mine or site-specific conditions. It can compute using the COG with parameters that are either in metric or imperial unit system. It has options of using either a deterministic or stochastic approach when calculating the cut-off grade (Githiria, 2018).

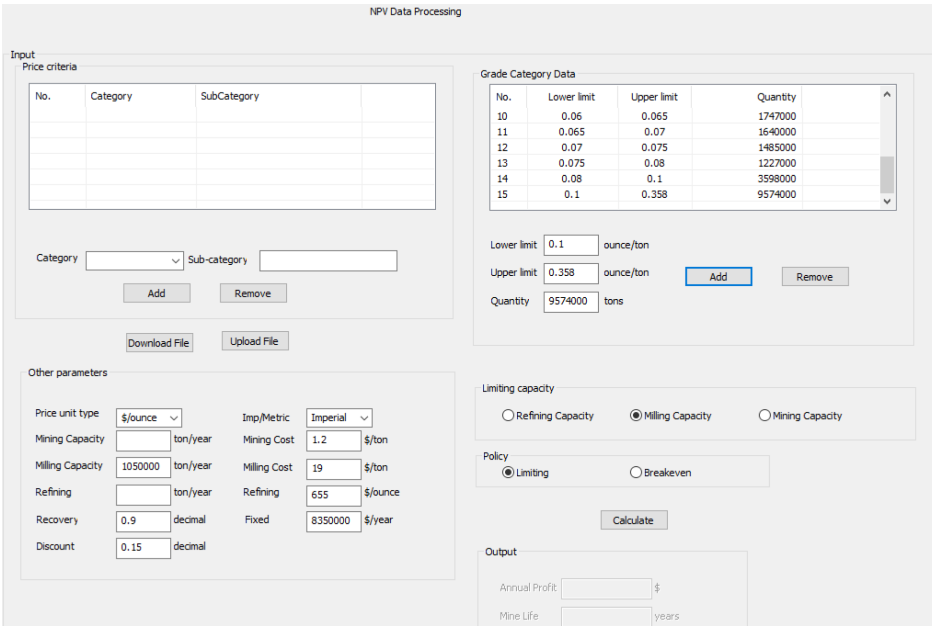


**FIG 4** – NPVMining user interface (Githiria, 2018; Githiria and Musingwini, 2019).

The input parameters for COG model (NPVMining) used in this study are grade-tonnage distribution, metal price distribution, variable operational costs (mining, milling and refining costs), fixed costs, discount rate, recovery, and production capacities. The case study data used in this paper is adopted from Dagdelen and Kawahata (2008), Myburgh, Deb and Craig (2014) and Githiria and Musingwini (2019). The data is used in computation of COGs using NPVMining for further analysis. The mining parameters used in this study tend to depict the parameters based on the McLaughlin gold deposit as shown in Table 2. The economic and operational parameters used in the cut-off grade calculations are based on the operations of the McLaughlin gold mine in Northern California, USA.

**TABLE 2**

Mining parameters used in the study (Dagdelen and Kawahata, 2008; Myburgh, Deb and Craig, 2014; Githiria and Musingwini, 2019).

| Notation | Explanation | Unit | Amount |
|---|---|---|---|
| s | Gold price | US$/oz | 600 |
| m | Mining cost | US$/ton | 1.2 |
| c | Milling/Processing cost | US$/ton | 19.0 |
| r | Refining/Selling cost | US$/oz | 5 |
| y | Recovery | Decimal | 0.9 |
| d | Discount rate | Decimal | 0.15 |
| f | Annual fixed costs | US$/a | 8 350 000 |
| M | Mining capacity | ton/a | Unlimited |
| R | Refining capacity | ton/a | Unlimited |
| C | Milling capacity | ton/a | 1 050 000 |

The range of values used for the economic parameters is assumed to have a uniform distribution along the mine life. The uniform distribution is factored into the calculations. These parameters are varied by a specified range (2 per cent per annum). They are assumed to have a range that is varying in each category as shown in Table 3 to be within the generally accepted long-term values of the parameters in the mining industry. This range is assumed to factor in the volatility that is experienced in the mining industry. In this study, the grade-tonnage distribution, recovery, mining, milling and refining capacities, and fixed cost are assumed to be constant. The grade tonnage distribution is shown in Table 4.

**TABLE 3**

Variations of the economic parameters used in the study.

| Category Name | Price (US$/oz) | Mining cost (US$/ton) | Milling cost (US$/ton) | Refining/Selling cost (US$/oz) | Discount rate |
|---|---|---|---|---|---|
| Range1 | 600.00 | 1.20 | 19.00 | 5.00 | 0.150 |
| Range2 | 612.00 | 1.22 | 19.38 | 5.10 | 0.153 |
| Range3 | 624.24 | 1.24 | 19.77 | 5.20 | 0.156 |
| Range4 | 636.72 | 1.26 | 20.17 | 5.30 | 0.160 |

**TABLE 4**

Grade-tonnage distribution of the gold deposit.

| Grade (oz/t) | Quantity of material in the orebody ('000t) |
|---|---|
| 0.000–0.020 | 70 000 |
| 0.020–0.025 | 7257 |
| 0.025–0.030 | 6319 |
| 0.030–0.035 | 5591 |
| 0.035–0.040 | 4598 |
| 0.040–0.045 | 4277 |
| 0.045–0.050 | 3465 |
| 0.050–0.055 | 2438 |
| 0.055–0.060 | 2307 |
| 0.060–0.065 | 1747 |
| 0.065–0.070 | 1640 |
| 0.070–0.075 | 1485 |
| 0.075–0.080 | 1227 |
| 0.080–0.100 | 3598 |
| 0.100–0.358 | 9574 |
| **Total** | **125 523** |

## RESULTS GENERATED AFTER VARYING SELECTED ECONOMIC PARAMETERS USED IN THE MODEL

The stochastic model (NPVMining) used in this study calculated the optimum cut-off grade (COG) with the aim of maximising the NPV in the shortest mine life possible while varying the five economic parameters. The NPV generated from the model is calculated using data in Tables 2, 3, and 4. The effect of major economic factors on cut-off grade optimisation is analysed by determining the following aspects:

- Effect of gold price on selection of cut-off grade.
- Effect of discount rate on selection of cut-off grade.
- Effect of operating costs (mining, milling/processing, and refining costs) on the selection of cut-off grade.

Using the variations on economic parameters in Table 3, NPVMining generated four possible outcomes in relation to the changes in gold price, discount rate, and operating costs. In this case, as one parameter is varied the other parameters remain constant for that scenario. A summary of the results shown in Table 5 indicates the variance of the output generated from the project when the gold price is varied. The results show a positive percentage difference of 9.38 per cent between the minimum and maximum NPV generated by varying the price from the base value (US$ 600/oz). The increase in price increases the annual profit and NPV generated significantly in a continuous trend and the reverse is true when price decreases. The project had a mine life of 9.12 years.

**TABLE 5**

Summary of the output generated from varying the gold price.

| Category Name | Price (US$/oz) | Optimum COG | Material mined, Qm | Ore processed, Qc | Metal produced, Qr | Annual profit (US$) | NPV (US$) |
|---|---|---|---|---|---|---|---|
| Range1 | 600 | 0.26 | 17 934 000 | 1 050 000 | 244 755 | 95 808 425 | 398 601 467 |
| Range2 | 621 | 0.26 | 17 934 000 | 1 050 000 | 244 755 | 100 948 280 | 419 985 325 |
| Range3 | 624 | 0.26 | 17 934 000 | 1 050 000 | 244 755 | 101 741 286 | 423 284 549 |
| Range4 | 636 | 0.26 | 17 934 000 | 1 050 000 | 244 755 | 104 795 828 | 435 992 670 |

Results generated using NPVMining after varying the discount rate used in cut-off grade optimisation are shown in Table 6. Discount rate variance generates NPVs with a negative percentage difference of 2.07 per cent.

**TABLE 6**

Summary of the output generated from varying discount rate.

| Category Name | Discount rate | Optimum COG | Material mined, Qm | Ore processed, Qc | Metal produced, Qr | Annual profit (US$) | NPV (US$) |
|---|---|---|---|---|---|---|---|
| Range1 | 0.150 | 0.26 | 17 934 000 | 1 050 000 | 244 755 | 95 808 425 | 398 601 467 |
| Range2 | 0.153 | 0.26 | 17 934 000 | 1 050 000 | 244 755 | 95 808 425 | 395 043 870 |
| Range3 | 0.156 | 0.26 | 17 934 000 | 1 050 000 | 244 755 | 95 808 425 | 391 555 421 |
| Range4 | 0.157 | 0.26 | 17 934 000 | 1 050 000 | 244 755 | 95 808 425 | 390 336 728 |

A summary of the results generated using NPVMining after escalating the operating costs in cut-off grade optimisation is shown in Tables 7, 8, and 9. The calculation cut-off grade using different mining, milling and refining costs shows evidently that an increase in these operating costs decreases the NPV significantly by 1.12 per cent, 1.28 per cent, and 0.08 per cent respectively.

**TABLE 7**

Summary of the output generated from varying mining cost.

| Category Name | Mining cost (US$/ton) | Optimum COG | Material mined, Qm | Ore processed, Qc | Metal produced, Qr | Annual profit (US$) | NPV (US$) |
|---|---|---|---|---|---|---|---|
| Range1 | 1.20 | 0.26 | 17 934 000 | 1 050 000 | 244 755 | 95 808 425 | 398 601 467.42 |
| Range2 | 1.22 | 0.26 | 17 934 000 | 1 050 000 | 244 755 | 95 449 745 | 397109214.79 |
| Range3 | 1.24 | 0.26 | 17 934 000 | 1 050 000 | 244 755 | 95 091 065 | 395616962.16 |
| Range4 | 1.26 | 0.26 | 17 934 000 | 1 050 000 | 244 755 | 94 732 385 | 394124709.52 |

**TABLE 8**

Summary of the output generated from varying milling cost.

| Category Name | Milling cost (US$/ton) | Optimum COG | Material mined, Qm | Ore processed, Qc | Metal produced, Qr | Annual profit (US$) | NPV (US$) |
|---|---|---|---|---|---|---|---|
| Range1 | 19.00 | 0.26 | 17 934 000 | 1 050 000 | 244 755 | 95 808 425 | 398 601 467.42 |
| Range2 | 19.38 | 0.26 | 17 934 000 | 1 050 000 | 244 755 | 95 409 425 | 396 941 467.42 |
| Range3 | 19.77 | 0.26 | 17 934 000 | 1 050 000 | 244 755 | 94 999 925 | 395 237 783.21 |
| Range4 | 20.17 | 0.26 | 17 934 000 | 1 050 000 | 244 755 | 94 579 925 | 393 490 414.79 |

**TABLE 9**

Summary of the output generated from varying refining cost.

| Category Name | Refining cost (US$/oz) | Optimum COG | Material mined, Qm | Ore processed, Qc | Metal produced, Qr | Annual profit (US$) | NPV (US$) |
|---|---|---|---|---|---|---|---|
| Range1 | 5.00 | 0.26 | 17 934 000 | 1 050 000 | 244 755 | 95 808 425 | 398 601 467.42 |
| Range2 | 5.10 | 0.26 | 17 934 000 | 1 050 000 | 244 755 | 95 783 949 | 398 499 639.52 |
| Range3 | 5.20 | 0.26 | 17 934 000 | 1 050 000 | 244 755 | 95 759 474 | 398 397 811.63 |
| Range4 | 5.30 | 0.26 | 17 934 000 | 1 050 000 | 244 755 | 95 734 998 | 398 295 983.73 |

## RESULTS AND ANALYSIS

Several parameters are varied in the cut-off grade optimisation exercise done in this paper which are then analysed and compared against NPV. The stochastic COG approach applied to the McLaughlin gold mine produced varying NPVs as shown in Figure 5. Using sensitivity analysis, this is demonstrated by varying economic parameters in the COG approach to generate varying NPV. Sensitivity analysis involves varying one or more parameters to determine what effect it has on the NPV. It analyses how uncertainty in the economic parameters (price, discount rate, and mining, milling, and refining/selling costs) contribute to the NPV when undertaking cut-off grade optimisation.

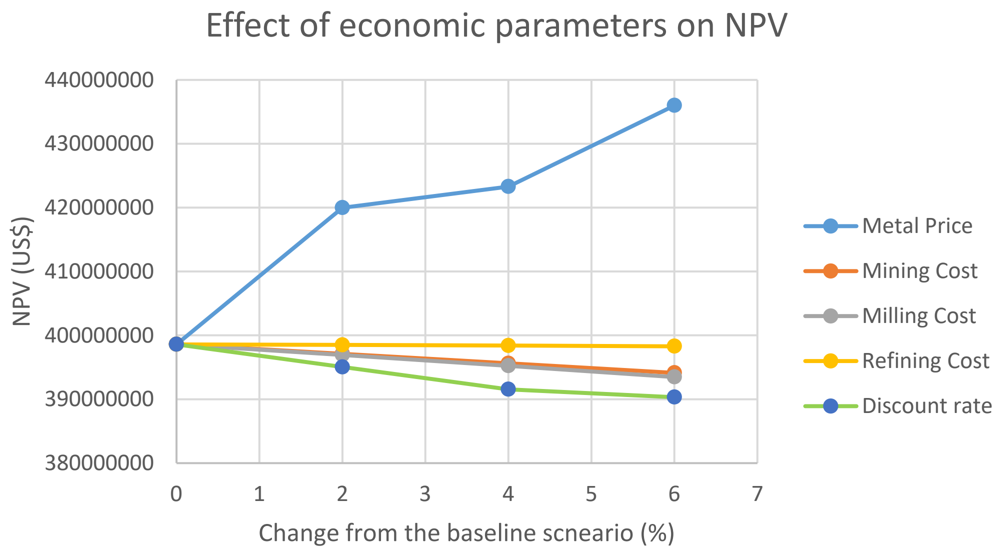


**FIG 5** – Graph showing the effect of economic parameters on NPV in cut-off grade optimisation.

After varying the parameters by the specified percentage as shown in Figure 5, the results indicated that the price of gold and the unit cost of refining gold had more influence on the NPV. The graph in Figure 5 shows that price is the most critical parameter that influences the NPV by a great margin. Other parameters that are significant and critical in this study are mining cost, processing cost, and discount rate. This exercise shows that it is important to evaluate these parameters before the start of mining operations to curb any mishaps in the future. This approach can be used in the mining industry to assess the maximum loss possible over a target time or period at a given level of confidence and plan the mining operations appropriately (Githiria, 2018). Using the sensitivity analysis to assess the output from the COG approach, the optimal NPV generated ranges from approximately US$390 to US$420 million. This shows that this is a moderately stable solution and hence can be accepted with confidence.

## CONCLUSION

Planning of the strategic mining operations should be done using reliable decision-making tools that can assess the probability of success or failure due to the ever-changing market and mining operation conditions. The study done in this paper can be used to measure the probability of any feasible project before and during the actual operations. The results showed a significant increase by a percentage difference of 9.38 per cent between the minimum and maximum NPV generated by varying the price. Varying operational costs generated 1.12 per cent, 1.28 per cent, and 0.08 per cent difference when varying mining, milling, and refining costs respectively in the NPV generated. Discount rate had a significant percentage difference of 2.07 per cent reducing the NPV as it increased. This shows that uncertainty in metal price and costs has a significant impact on mine planning and hence the need to do probabilistic or stochastic mine planning as opposed to deterministic planning.

Out of the four parameters, refining cost had the least significant impact on the NPV generated with the lowest percentage difference in the output generated. The variation of the four economic parameters in the output generated from the COG model (NPVMining) showed the impact of undertaking a stochastic approach when selecting cut-off grades. The cut-off grade selected should reflect the current market and mining conditions which are uncertain in nature. Instead of using a single commodity price on COG determination over the life-of-mine (LOM) as done in most studies, this paper contributes by presenting an approach that complements Lane's COG theory by ensuring that variable commodity prices combined with other economic parameters are used to generate more reliable NPVs. In this way, the COG optimisation policy generated using the approach presented in this paper closely relates to variable conditions as encountered in actual mining practice.

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## APPENDIX

A summary of studies that have undertaken cut-off grade optimisation are shown in Table 10 indicating the statistical and mathematical programming techniques used to generate optimal COG.

**TABLE 10**

Chronological summary of studies that have undertaken cut-off grade optimisation (Githiria, 2018).

| Researcher | Year | Solution method |
|---|---|---|
| Henning | 1963 | Break-even cut-off grade model |
| Lane | 1964, 1988 | Graphical method |
| Taylor | 1972 | Statistical method |
| Dowd | 1976 | Dynamic programming Stochastic programming) |
| Taylor | 1985 | Statistical method |
| Krautkraemer | 1988 | Stochastic programming |
| Dagdelen | 1992 | Break-even cut-off grade model |
| Dagdelen | 1992, 1993 | Analytical method based on Lane's theory |
| Whittle and Wharton | 1995 | Linear programming combined with search algorithm |
| King | 1999, 2001, 2011 | Analytical method based on Lane's theory Linear programming) |
| Asad | 2002 | Analytical method Linear programming) |
| Cetin and Dowd | 2002 | Genetic algorithms |
| Ataei and Osanloo | 2004 | Combination of Genetic Algorithm and the Grid Search Method |
| Minnitt | 2004 | Graphical method using Linear programming |
| Asad | 2005 | Analytical method using Linear programming |
| Asad | 2007 | Linear programming |

| | | |
|---|---|---|
| Dagdelen and Kawahata | 2008 | Mixed-integer programming |
| Osanloo, Rashidinejad and Rezai | 2008 | Analytical method based on Linear programming |
| Gholamnejad | 2008, 2009 | Analytical method based on Linear programming |
| Cetin and Dowd | 2011 | Dynamic programming |
| Li, Yang and Lu | 2012 | Stochastic programming |
| Cetin and Dowd | 2013 | Genetic algorithms |
| Asad and Dimitrakopoulos | 2013 | Heuristic approach based on stochastic programming |
| Hall | 2014 | Break-even cut-off grade model |
| Thompson and Barr | 2014 | Stochastic programming |
| Myburgh, Deb and Craig | 2014 | Genetic algorithm: Evolutionary algorithm Combined with both local search and linear programming) |
| Cetin and Dowd | 2016 | Genetic algorithms, grid search method and dynamic programming |
| Githiria, Muriuki and Musingwini | 2016 | Analytical method based on Linear programming |
| King and Newman | 2018 | Mixed-integer programming optimisation framework |
| Githiria and Musingwini | 2018 | Stochastic programming |
| Ahmadi and Shahabi | 2018 | Genetic algorithm |
| Ahmadi and Bazzazi | 2019, 2020 | Meta-heuristic algorithms Imperialist competitive algorithm ICA) and particle swarm optimisation PSO)) |
| Paithankar *et al* | 2020 | Genetic algorithm GA) based framework |
| Biswas *et al* | 2020 | Dynamic programming |
| Khan and Asad | 2021 | Mixed integer programming |
| Biswas, Sinha and Sen | 2023 | Multi-sequential decision algorithm based on dynamic programming |

# A review of machine learning application in the mining sector

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## ABSTRACT

The mining process has several stages along its value chain such as exploration, development, extraction, production, and beneficiation to produce valuable products for the market. The main objective of any mining operation is to maximise the net present value (NPV) of the mining project. In this regard, the development of computer algorithms fulfills the need to solve large and complex mining problems to generate solutions that maximises profit, performance, or yield and minimises loss, risk, or cost in the entire mining value chain. These objectives have been demonstrated to also be achievable using machine learning (ML), a component of artificial intelligence that uses data and algorithms to generate solutions without explicitly stated instructions but rather using knowledge learned from data in the form of patterns, parameters, and trends. Therefore, this paper reviews studies that have applied machine learning approaches along the mining value chain to meet the mining objectives. It illustrates the benefits of machine learning along the value chain in generating solutions to problems that occur due to uncertainty in mining projects. This paper provides a review of the usage of machine learning in mining sector for ten years from 2014 to 2024. It showcases the different machine learning algorithms that have been used in solving mining problems and discuss popular algorithms by problem category. The results show that supervised learning is the most common ML paradigm used, computer vision and image processing are the most common problem category, and random forest an ensemble learner, and convolutional neural networks are the most commonly used algorithms used across the mining value chain.

## INTRODUCTION

Mining is the extraction of valuable minerals or other geological materials from the earth, usually from an orebody, lode, vein, seam, reef, or placer deposit. The minerals can either be mined through two distinct mining methods: open pit and underground mining. A typical mining system will involve three major stages: exploration, mining, processing, and refining/marketing. Mining related problems involve a conventional sequence that is involved in these stages to generate the finished product. The business side of mining ensures that the entire operation maximises profit and minimises losses and costs along the value chain. Hence, there is a need for optimisation using advanced computer application techniques (Githiria, 2020). Machine learning and computer automation have emerged as some of the key applications of ICTs across the mining value chain. However, the focus of this paper is on machine learning and its usage across the entire mining value chain to solve various problems to maximise mining outputs.

Mining business is capital intensive with high risk on the return of investment. Therefore, there is a need for proper planning and optimisation of the entire mining operation. This planning process is iterative to ensure optimum output from the entire operation. Re-evaluation and creation of alternative plans employ optimisation techniques that incorporate mathematical modelling and in recent times artificial intelligence techniques such as machine learning. This is done to ensure that the mining operation generates the optimum outputs across the entire mining value chain.

Undertaking intensive Mineral Reserve estimation and subsequent mine planning process is crucial when mining companies are assessing the feasibility of a project. These are two important aspects considered to achieve the objectives of the entire operation. For instance, strategic mine (long-term) plans are guided by maximisation of net present value (NPV) while operational (short-term) plans are guided by minimisation of deviations from targeted grade and ore tonnages so that customer specifications can be met without incurring losses. The strategic mine plan's scope is the entire life of the mining operation with respect to the resource/reserve, mining method, equipment access, economic and environmental factors. Based on these dynamic factors, a strategic plan is complex in nature and inhibits inherent risks which need to be accounted for.

An optimal mine plan outlines expected production outputs from a mine during a specified period to maximise economic benefits while enabling the planning of future operations. These plans should be optimised to maximise the NPV of future cash flows generated from a mine in the long-term. Short-term mine planning is considered to be the basis on which the daily operation is governed from. It is important to achieve the short-term objectives without deviations in order to accomplish the long-term objectives. Mathematical modelling is employed in achieving these objectives in order to undertake this exercise optimally. Programming and development of software tools using information and computer technologies have been applied in mining related problems since 1960s (Githiria, 2018, 2020).

The fourth industrial revolution (Industry 4.0) has embraced the application of artificial intelligence techniques in achieving robust and optimum solutions for engineering-related problems. The extractive industry especially the mining sector has also embraced these techniques in generating solutions for mining-related problems. The machine learning approach has been applied mostly in incorporating uncertainty of mining environment such as metal price volatility and irregular geological features. Several studies have applied ML approaches in mine planning and optimisation, exploitation of mineral resources, and mine closure activities. These studies have used neural network techniques to generate optimal production schedules that will sequence the tasks along the mine value chain (Levinson and Dimitrakopoulos, 2023). It has been applied in mineral exploration and estimation of the mineral reserve to generate and predict results that will be used in the valuation of mining projects accurately. There are other various mining-related problems such as block economic evaluation, slope design, pushback design, pit design and optimisation, and production scheduling. Blending and product mixing, fleet management and optimisation of transport systems are some of the other applications in the industry that can apply the ML approach.

## Machine learning

Machine learning (ML) can be viewed as creating a computer application that learns from experience or data (D), corresponding to the performance of a certain task (T) so that it improves its performance (P) on the task using the data (Alpaydın, 2010). ML is a branch of artificial intelligence that uses different learning algorithms to simulate human learning by identifying and acquiring knowledge from the real world to improve the performance of specific tasks using the acquired knowledge from data (Jung and Choi, 2021). Essentially, developing an ML system therefore does not require a complete of algorithms to define all possible actions that the system will do but rather it creates a dynamic application that can use learned patterns to handle a completely new problem or task. ML algorithms include supervised learning algorithms, unsupervised learning algorithms, semi-supervised, active learning, and deep learning algorithms. The components of ML include data sets made up of features or variables and data points or observations, and of course, the learning algorithms that generate the solution. The main attraction of ML is the aspect that they have that they can use these data and learning algorithms to generate solutions without being given explicit instructions on how to find a solution for a novel problem.

Some of the ML algorithms that reviewed in this paper include the categories of ML cited above such as supervised learning algorithms, unsupervised learning algorithms, semi-supervised, active learning, and deep learning algorithms. Under each category of ML, different sets of learning algorithms belong to that learning paradigm. For example, supervised learning algorithms include linear regression, support vector machines, ensemble learners, decision trees, and, artificial neural networks; unsupervised learning algorithms include k-means, expectation maximisation, and hierarchical clustering; and deep learning algorithms which are artificial neural networks, recurrent neural networks (Huynh *et al,* 2023; Alpaydın, 2010). The components of machine learning include data sets, features or variables, and algorithms that generate the solution. Most computer models or algorithms used to solve the problem/task at hand have an objective function that describes the goal of the task, the decision variables and constraints that define boundaries, and the solution path in which the objective function will be used, and the data set that informs the algorithm.

The data sets include texts, numbers, images, and other forms of data that are required for training the machine learning algorithm to draw patterns and correlations. The features or variables of the data set used highlight key pieces of data that the algorithm should focus on. In order to train the algorithm or software to make the right decisions and generate accurate results, the right features should be selected properly. For instance, when considering mineral prices, the most important feature is time which causes the prices to fluctuate due to market factors. When it comes to time series data, the patterns inherent in their time series character make the features in such data set much richer because every price value is linked to a specific date in time and whatever market forces that prevailed at that time. The data set has these main features embedded with patterns such as trend, seasonality, cyclical behaviour, or irregularity. This process of selecting the right features is crucial in training the software to make the right decisions. The quality of the data set affects the accuracy of the results. Thus, collecting accurate data aids in achieving the desired outcomes.

Machine learning involves the identification of patterns, trends in data, and the relationships between the various features in such data sets and thereafter uses these learned patterns and parameters to subsequently make decisions and predictions on data that is novel to the ML models ie data not used in training the ML models. One of the application areas of ML in mining is optimisation in the different processes in the mining value chain. These optimisation ML models should focus on strategies under dynamic economic situations by considering alternative economic approaches that consider a wide range of parameter changes. This will create a global and strategic approach that generates better results for the problems compared to deterministic approaches.

Lastly, ML algorithms are used in analysing the data. Different algorithms applied for the same task may provide similar solutions and have different solution speed and different accuracy of obtained results. Identifying the correct ML algorithm is the first step after the formulation of mathematical framework for the optimisation of mining operations. The algorithms form a basis of knowledge of the problem which can be used to solve the existing problem. They identify whether there are special cases in the algorithmic problems that will allow manipulation of the input parameters. Changes made in such algorithms to simplify the problem must be accounted for. Identify the standard algorithm design paradigms relevant to the problem. A simple algorithm is applied to correctly search through all subsets or arrangements and pick the optimal one. The problem needs to be defined correctly in the algorithm to enable the identification of a solution in good time and capability is adequately sufficient. A heuristic algorithm is applied when the problem is defined in such a way that the algorithm searches for random subsets in the defined path. They are mostly applied to optimise the entire orebody and provide a 3D analysis of the problem (Skiena, 2008).

## SYSTEMATIC REVIEW OF MACHINE LEARNING IN MINING SECTOR

The increasing research output in recent years in mining has produced a lot of publications, especially on the use of computerised systems in solving mining-related problems. However, the research problems and solutions in mining are heterogenous and complex in nature hence the need for a systematic review of the literature to indicate the research trends, gaps, and future recommendations (Bello *et al,* 2015; Tawfik *et al,* 2019). Moreover, the production of research output is not homogenous across the world and there is a need to increase research output or showcase the gap in knowledge production. Figure 1 shows the global research output on ML application in mining sector.

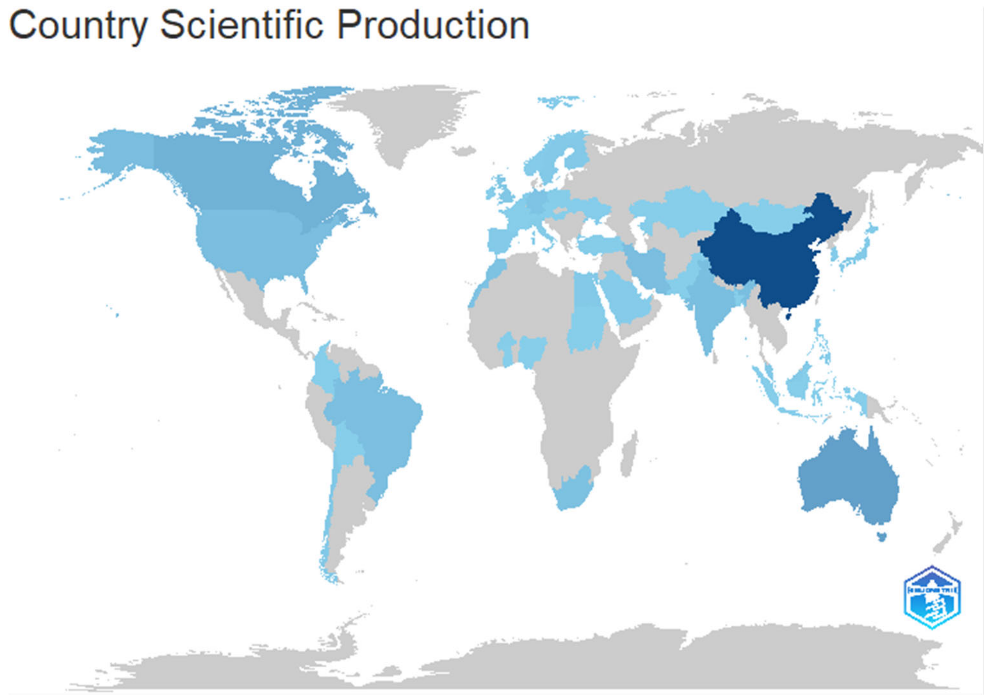


**FIG 1** – Scientific research production by region (Concentration of publication is shown by the depth of the blue colour in that region or country).

Systematic review and meta-analysis (SR/MA) is a review that uses a systematic review methodology to summarise evidence on research questions with a detailed and comprehensive study plan (Tawfik *et al,* 2019). On the other hand, unsystematic review tends to be descriptive and is based on the authors point of view when selecting the frequently cited articles, leading to poor quality review work. The major steps applied in a SR/MA involves framing research questions, developing selection criteria, searching of articles using existing search engines and databases, appraise the quality of articles or studies to include using the selection criteria, interpret and summarise results (Khan *et al,* 2003; Rys *et al,* 2009; Tawfik *et al,* 2019).

There are several systematic reviews of the literature undertaken on the applications of ML in mining sector. Since 2018, ML has been applied in different stages of the mining value chain with great success. There are several review papers that did a research survey in the last five years illustrating the application of ML and its trends in the mining sector. They include studies done by McCoy and Auret (2019), Fu and Aldrich (2020), Jung and Choi (2021), Mahboob, Celik and Genc (2022), and Chimunhu *et al* (2022).

McCoy and Auret (2019) reviewed the applications of ML approaches applied in mineral processing by analysing the mineral processing problems in three categories namely: databased modelling, fault detection and diagnosis and machine vision. Fu and Aldrich (2020) illustrated the application of deep learning algorithms in mining and metallurgical operations. The review showed the application in different stages of the mine value chain such as drilling, blasting, hauling, and processing. Mishra (2021) reviewed the existing works that have explored the application of ML and AI algorithms in mineral processing. The paper proposed some of the future work on applications of ML and presented a generic approach to be used when investigating the potential use of ML and AI in mineral processing. However, the two review papers done by Fu and Aldrich (2020) and Mishra (2021) only looked at ML applications in mineral processing without considering the previous mining operations.

Jung and Choi (2021) did a systematic review and illustrated the application of ML techniques in three major stages in mining operation: exploration, exploitation, and reclamation. The evaluation showed the relevant research areas and their machine learning model application. The paper classified the ML models using research trends and evaluation metrics. However, the study did not look at the application of ML in mineral processing. Chimunhu *et al* (2022) reviewed and summarised the application of predictive data analytics and machine learning in underground mine planning and scheduling. The study looked at how to enhance optimisation model prediction capability through machine learning. This is though incorporation of mathematical and statical models with machine learning.

Mahboob, Celik and Genc (2022) undertook a review looking at the application of machine learning in Mineral Resource estimation to predict the actual orebody models. In this review, the author showed the prowess of machine learning based models over the conventional grade estimation modelling methods in their ability to estimate Mineral Reserves. In summary, the above studies looked at single research areas and their related problems in isolation indicating the importance of applying machine learning in mining. This review study will help connect the current research that has been done in the application of ML in the mining sector and propose potential future directions.

## Search methodology

The study used a systematic literature review methodology proposed by Page *et al* (2021) to conduct a review by identifying the articles published in the specific area of interest and screening to remove the illegible articles. This step-by-step procedure as illustrated in Figure 1 is based on the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) technique. The database used in this exercise included Scopus and Web of Science search engines. The output from this exercise was presented using Scopus and R-Biblioshiny bibliometric software to help in visual interpretation of the results. The major steps applied in this exercise involved the following:

- Developing the major research questions to help in creating a procedure to follow during the review exercise.
- Developing the selection criteria method by screening eligible publications using keywords based on the goals of this review.
- Conducting a search of eligible publications using search engines and databases.
- Evaluation of the publications obtained using the selection criteria to include certain articles based on their content and suitability.
- Evaluation and interpretation of the results based on the objective of the process.

The objective of this exercise is to illustrate the current application of ML in the mining sector by showing the ML approaches used, articles published, prominent researchers, and countries that are actively addressing this research area. This will consequently define the path for potential future research directions in the mining industry. Hence, the major question that this study is attempting to answer is whether the ML application has a significant impact on the mining value chain and indicates the specific areas of interest in the application of the same.

Specifically, the following search terms were used to identify the set of papers used in this study:

- Search term 1: "machine learning", OR "artificial intelligence" OR "deep learning" OR "supervised learning".
- Search term 2: "mineral extraction", OR "mineral exploration".
- Search term 3: "mineral refining" OR "mineral processing".

The results obtained from conducting this search were analysed and revealed a number of topics using Bibliometric analysis such as:

- The current research trends with respect to the application of ML in the mining industry. This will be defined by yearly publication, source of journal publication, subject area of application, authorship, country, and university in which the research was applied.
- The ML models applied in mining-related problems for both surface and underground mining. This indicated the research areas in the mining sector along the mine value chain (exploration, exploitation, production, reclamation) and the ML model applied and its benefits. The evaluation metrics for the ML models applied in mining.

Figure 2 shows a presentation of the PRISMA methodology and a summary of the steps that were taken in this review.

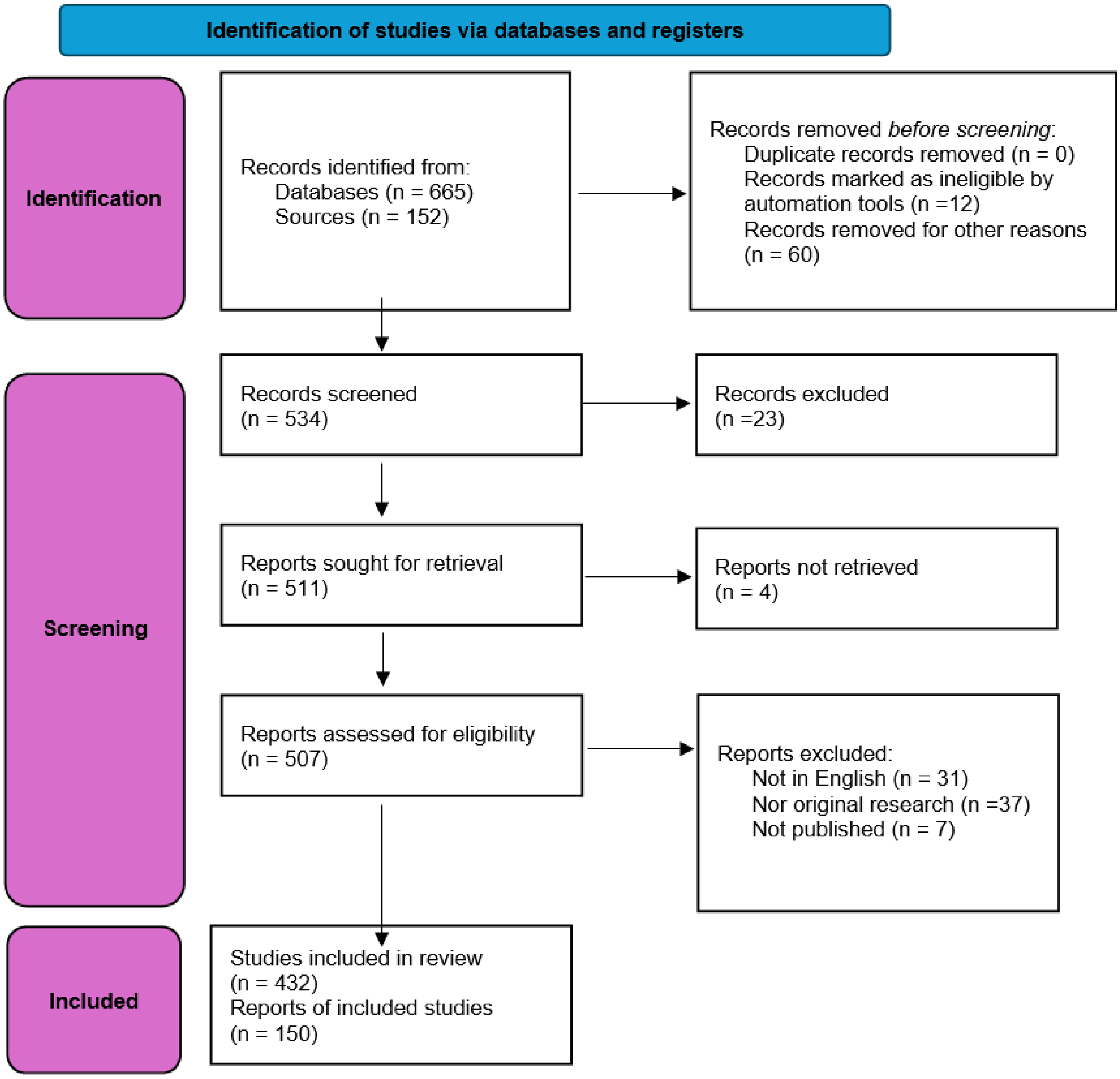


**FIG 2** – Step-by-step procedure in undertaking a systematic literature review (Page *et al,* 2021).

## Selection criteria method

This section analyses the output from the search engine by undertaking a quality assessment, extraction of relevant data, and analysis based on the research question. The search was conducted using the available databases Google Scholar, Scopus, and Web of Science. In this searching process, the keywords used in generating the publications from the databases are ‘machine learning’, ‘artificial intelligence’, ‘deep learning’, ‘mining’, ‘mineral’, ‘open pit’ and ‘underground’ in line with the search criteria, the total number of papers retrieved was 665.

The selection criteria used for conducting this systematic review filtered the results by specific subject areas related to mining and mineral engineering. By focusing the search on these subject areas closely tied to mining operations, processes, materials, and related fields, the systematic review aims to identify relevant research and applications of machine learning specifically within the mining domain. This targeted approach helps narrow down the search results to the most pertinent literature, ensuring a comprehensive review of machine learning applications tailored to the mining sector. The subject areas that were included in the search criteria are Earth and Planetary Sciences, Engineering, Environmental Science, Computer Science, Mathematics, Materials Science, Energy, Multidisciplinary, Chemical Engineering, Decision Science Thermodynamics, and Energy.

## Inclusion exclusion criteria

The criteria used selected only the articles where research is reported on the usage of ML in mining. Specifically, the use of ML in different mining stages along its value chain, such as exploration, development, extraction, production, and beneficiation, which produce valuable products for the market. Therefore, any article not meeting this requirement was removed from the list of papers used in this review.

# RESULTS

## Current research trends

Bibliometrics analysis was first employed to ascertain the key insights on the research work done on ML application in mining sector. Figure 3 shows the publications that have been done in the mining sector that utilised machine learning worldwide from the year 2014 to 2024. This helped to showcase specific analysis of results.

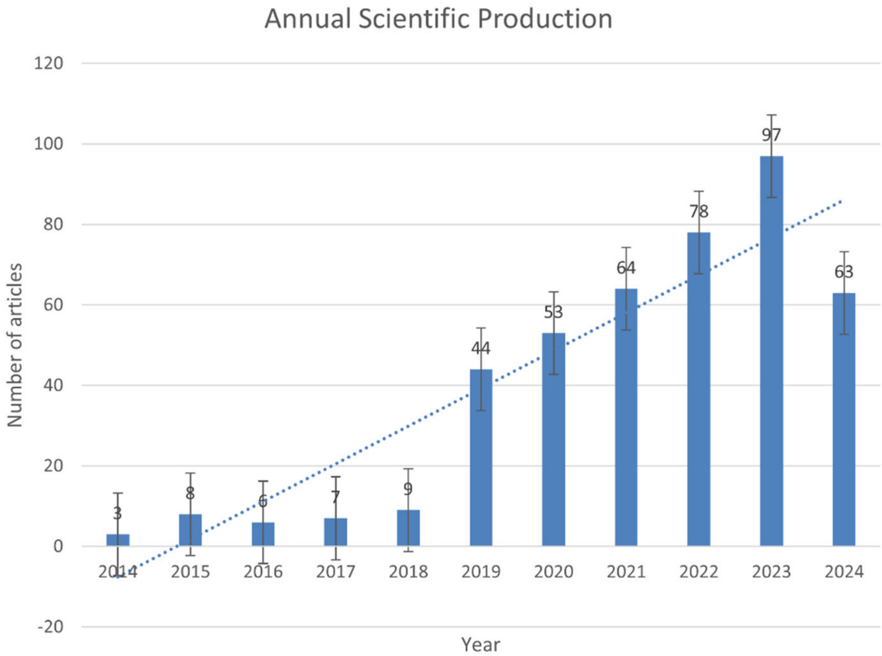


**FIG 3** – Annual Scientific Production from 2014 to date of publication showing both trend and error bars.

### *Annual scientific production*

Figure 3 shows the distribution of research papers by year in the general mining value chain where machine learning was applied to address different problems in the mining sector.

From the data, the following observations can be made:

- 2014 to 2017 might be considered the inception or early stages of research in this field as indicated by the number of publications in that period.
- Since 2013 there has been a gradual increase in the number of publications, suggesting steady growth in research activity. This is also shown using the dotted Trend line in Figure 2.
- A significant spike occurred in 2020, with the number of publications reaching its peak, implying a surge of interest or breakthroughs in the field during that year. This is a reasonable expectation since the interest had begun more than six years earlier in 2013/2014.
- After the peak in 2020, the publication increase has dropped though the upward trend has remained which might suggest saturation or maturation of the research topic.

- Overall, the graph illustrates the typical pattern of an emerging field, with an initial gradual growth, and a rapid surge of activity around a specific period (2020 in this case), followed by a tapering off as the field matures, saturates, or research interest shifts elsewhere.

### *Common keywords, methods, and application areas*

The next area of interest was to assess the trends in terms of the prevalence of keywords that were employed in the research papers that were considered in this review. Keywords reveal many aspects of a study such as methods, algorithms and other pertinent information. This information is summarised in Figure 4.

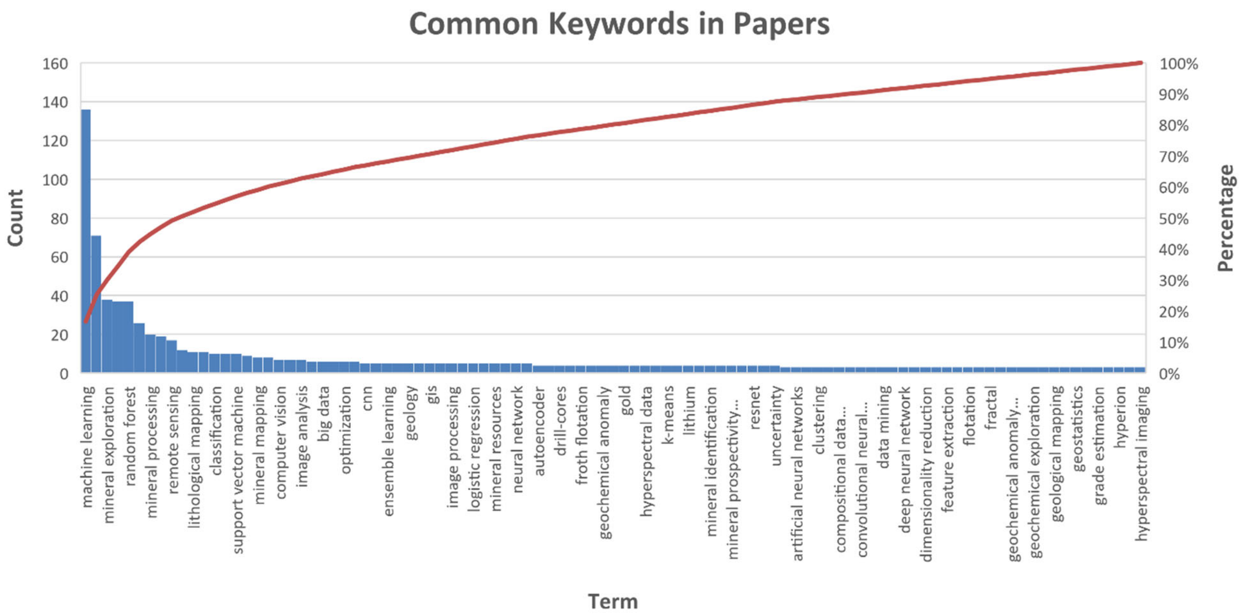


**FIG 4** – Common keywords used in the literature.

The information in Figure 4 gives a synopsis of the common ML methods and application areas that have been used in mining research using the prevalence of keywords utilised. It is important to note the following:

- Random forest and other ensemble learners are the most preferred methods in mining followed by support vector machines, neural networks, autoencoders, and k-means clustering approach.
- The most preferred ML paradigm is the supervised machine learning approach which includes classification and regression analysis. There is also some work that employs unsupervised learning specifically clustering.
- The most common types of problems that the studies tackle fall under computer vision, image analysis, image processing, and optimisation. These have been used mostly in exploration studies.
- Finally, the most common types of deep learning algorithms used are convolutional neural networks which are very suitable for the analysis of image data sets.

### *Common paper sources by year of publication*

This subsection reviews the year of publication and the journal in which such information was published. Figure 5 presents the distribution of research papers related to ML applications in the mining sector across various sources or journals over the years. The following was deduced from the publication trends by source:

- 'Natural Resources Research' appears to be one of the earliest sources publishing on this topic, with a steady increase from 2015 to a peak in 2020.

- 'Minerals' and 'International Journal of Mining Reclamation and Environment' show a similar pattern, with publications starting around 2017–2018, peaking in 2020, and then decreasing.
- Sources like 'Remote Sensing', 'Energies', 'Journal of Mining and Environment', and 'Engineering with Computers' have a relatively lower but consistent number of publications throughout the years.
- 'Journal of Rock Mechanics and Geotechnical Engineering' and 'Journal of The Southern African Institute of Mining and Metallurgy' exhibit a more recent surge in publications, starting from around 2021–2022.
- 'Engineering Applications of Artificial Intelligence' stands out as a source with a significant number of publications, particularly in the later years (2022–2024), suggesting a growing focus on applying artificial intelligence techniques in mining applications.

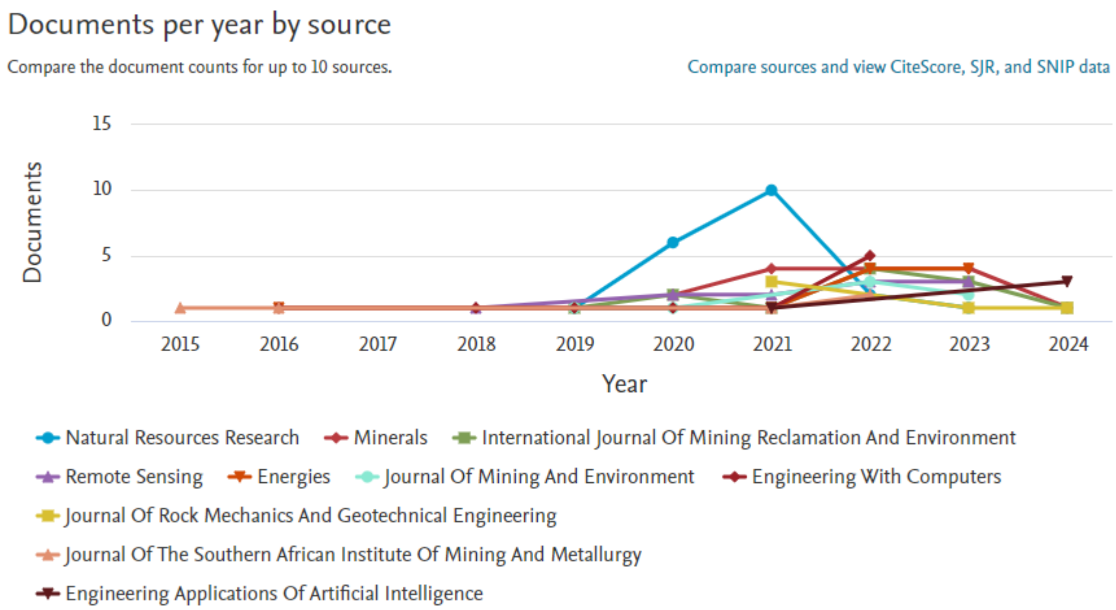


**FIG 5** – Distribution of publications or research papers related to machine learning application in mining sector since 2014.

Overall, the distribution across sources indicates that the field of machine learning applications in mining has garnered attention from a diverse range of journals and publications, with different sources playing a more prominent role during different time periods. The peak in publications around 2020 across multiple sources suggests a concentrated research effort or breakthroughs in that specific year.

### *Publications according to subject area clusters on Scopus*

Based on the pie chart in Figure 6, the distribution of publications related to machine learning applications in the mining sector can be analysed across various subject areas as follows:

- Earth and Planetary sciences (27.8 per cent): This appears to be the largest subject area, likely encompassing topics related to earth sciences, geology, and planetary studies, which are highly relevant to the mining industry.
- Engineering disciplines (20.7 per cent): this includes mining engineering, mechanical engineering, and others, constitute a significant portion of the publications, reflecting the technical and practical aspects of applying machine learning in mining operations.
- Computer Science (12.0 per cent): as expected, a significant portion of publications originate from computer science and related fields, focusing on the development and application of machine learning algorithms and techniques in the mining context.

- Environmental sciences and related fields (11.2 per cent): make up a notable portion, indicating the importance of addressing environmental concerns and sustainable practices in mining through the application of machine learning techniques.
- Materials science and related areas (5.8 per cent): are represented, suggesting research on the characterisation, processing, and optimisation of materials used in mining activities.

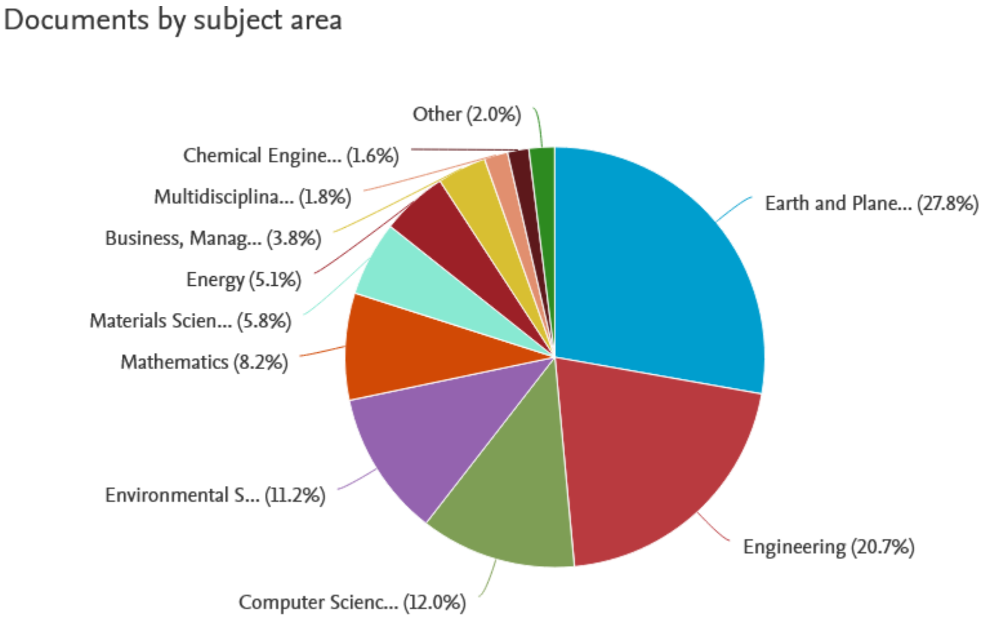


**FIG 6** – Distribution of publications on machine learning application in mining sector by subject area.

The distribution highlights the diverse range of subject areas contributing to research on machine learning applications in the mining sector, reflecting the multifaceted nature of the industry and the potential for machine learning to impact various aspects of mining operations.

### *Publication patterns per author, affiliation and country*

The bar graph in Figure 7 displays the distribution of publications related to machine learning applications in the mining sector across various authors. Each bar represents the number of documents published by a specific author or research group. The author represented by the longest bar is the most published in this field, with around 21 documents. This suggests they or their research group have made significant contributions to advancing machine learning techniques for mining applications.

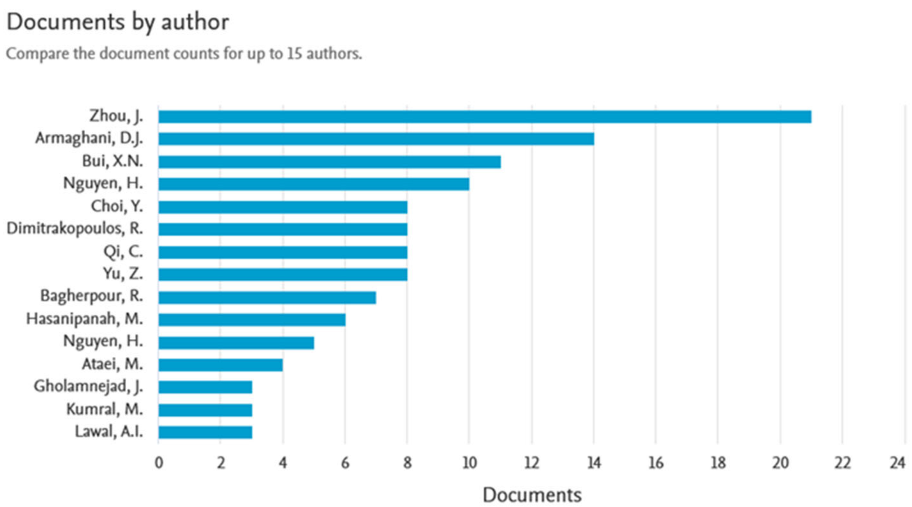


**FIG 7** – Distribution of publications by authors on machine learning application in mining sector.

The next few authors, with bars ranging from around 15 to 10 documents, also seem to be prominent figures in this research area, having published extensively on the topic. Beyond the top few authors, there is a larger group of researchers who have published a moderate number of documents, typically ranging from five to eight publications each. Lastly, there are several authors with fewer publications, possibly indicating more recent or peripheral involvement in this specific field of study. Overall, the distribution reflects a common pattern in academic research, where a small number of highly active and influential authors or research groups drive a significant portion of the published work, while a broader community of researchers contributes to a lesser extent. The distribution of this pattern is also shown in Figures 8 and 9 indicating the specific academic institutions they are affiliated and their location globally. The concentration of publications among the top authors suggests the existence of established leaders and pioneers in applying machine learning to mining applications.

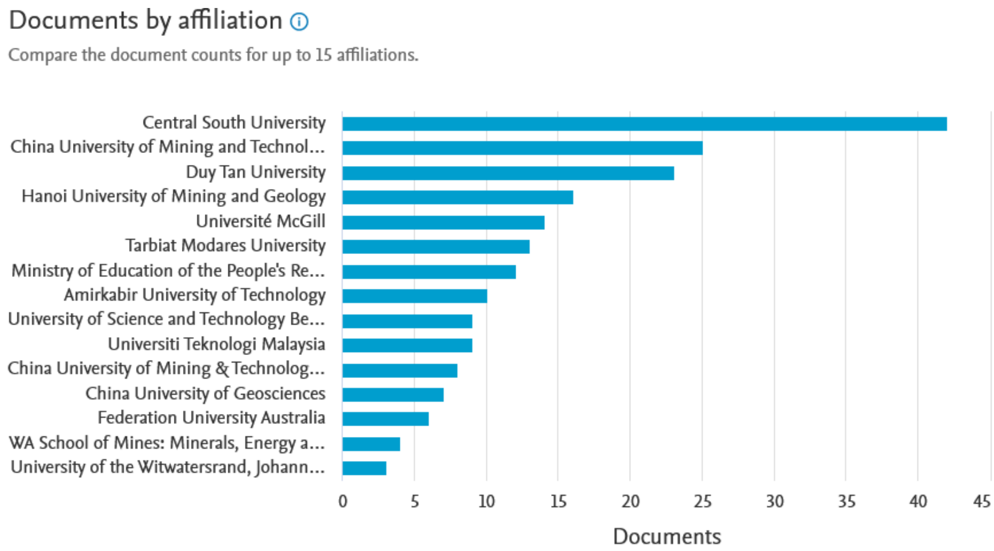


**FIG 8** – Distribution of publications by institution affiliated with research on machine learning application in mining sector.

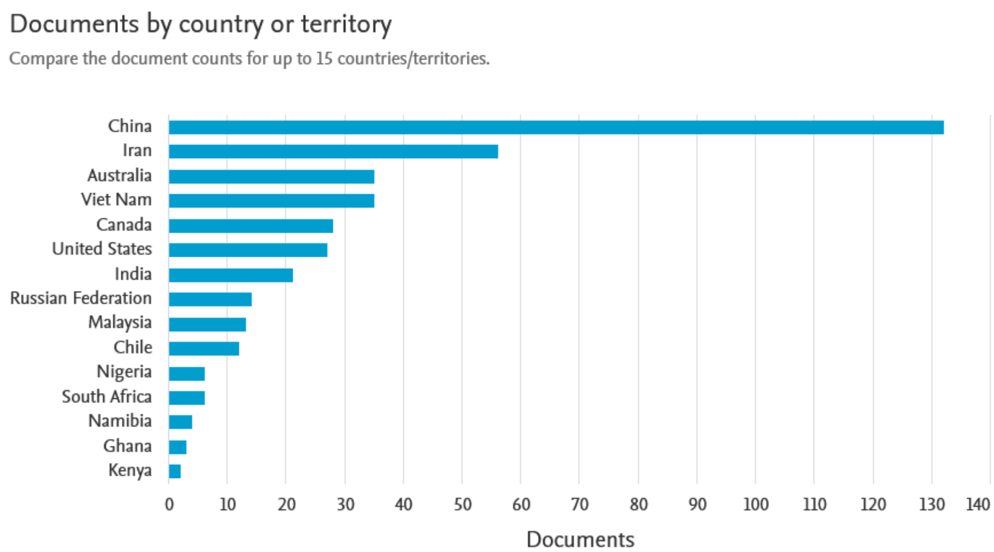


**FIG 9** – Distribution of publications by country on machine learning applications in mining sector.

The horizontal bar graph shows the distribution of publications related to machine learning applications in the mining sector across different countries or territories. Each bar represents the number of documents published by researchers or institutions from that particular country or territory. China stands out with the longest bar, indicating it has produced the highest number of publications in this field, significantly more than any other country shown in the data. Iran and Australia comes in second and third respectively, with a substantial number of publications, though notably less than

China's output. Several other countries, including the Viet Nam, Canada, United States, India, Russia, Malaysia, and Chile also have a considerable number of publications, forming the next tier of active research communities in this domain. Lastly, there are a few countries in Africa with a relatively smaller number of publications, such as Nigeria, South Africa, Ghana, Namibia, and Kenya, suggesting a more limited research focus on machine learning applications for mining in these regions.

Overall, the distribution highlights the global nature of research in this field, with contributions coming from various countries and regions. However, it also reveals a concentration of activity in certain nations, particularly China, Iran and Australia, which appear to be leading hubs for research and development in applying machine learning techniques to the mining industry.

## ML applications, models, and metrics used in mining

Machine learning application in the mining sector is illustrated in Table 1 to show the current research areas that have applied ML models. ML models have been applied in the exploration and mineral resource management due to the availability of data that can be modelled using these tools. The summary in Table 1 shows the application in exploration, exploitation/production, excavation/rock engineering, and reclamation stages along the mine value chain.

**TABLE 1**

Summary of the current research on ML applications in mining sector.

| Mining stages | Application type | ML algorithms used | Authors |
|---|---|---|---|
| Exploration | Computer vision, image processing, image analysis | CNN, ANN, LSTM, RF | Zhao *et al* (2024)<br>Zhao *et al* (2020)<br>Bachri *et al* (2020) |
| | Mineral prediction based on prototype learning | Meta-learning | Ding *et al* (2024) |
| | Geochemical exploration data | Ensembles of decision trees | Guo and Chen (2024)<br>Shayilan and Chen (2024) |
| | Digital ore deposit models | Deep learning | Xiao *et al* (2024) |
| | Mineralisation and Interpretability | Deep learning | Zhang and Zuo (2024) |
| | Geochemical anomalies | Variational autoencoder | Luo, Xiong and Zuo (2020) |
| Extraction/ Exploitation | Rock type prediction | Random forests | Sarantsatsral *et al* (2021) |
| | Mine planning/production scheduling | ANN, reinforcement learning and stochastic programming | Levinson and Dimitrakopoulos (2023) |
| Excavation/ Rock engineering | Rock strength prediction and variable selection with aid of log data | Deep learning | Miah *et al* (2020) |
| | Physics-constrained geomechanical logs | Deep learning | Chen and Zhang (2020) |
| | Rock properties and operational performance | Genetic algorithm, AutoML | Suriadi *et al* (2018) |
| | Predicting rock type and detecting hydrothermal alteration | Support vector machines | Bérubé *et al* (2018) |
| Mineral Processing | Intelligent monitoring and optimisation of froth flotation circuits | Artificial Neural Networks and Genetic Algorithms | Hasidi *et al* (2024) |
| | Predicting Flowability at Disposal of Spent Heap | Artificial Neural Networks | Herrera *et al* (2024) |
| | Minerals processing (industrial comminution and flotation models) | Regression | Koh *et al* (2022) |
| Reclamation | Shallow Surface Outcrop Mining, multisource Satellite Remote Sensing Data | CNN | Li *et al* (2023) |

## CONCLUSION

This review has showcased the critical role that machine learning has been playing in the mining sector in addressing goals of exploration, development, extraction, production, and beneficiation of mineral resources. Moreover, specific problem categories and ML algorithms have been identified as being the most popularly used in these mining activities. In contrast to the manual trial and error approach, the application of machine learning approaches in mining research attempts to bring the artificial intelligence capability to improve identification of mineable material, optimisation of the entire mining operation and better decision-making process. Moreover, though numerous algorithms have been developed to aid in decision-making about mining layout, nonetheless, underground mining has been lagging and no known algorithm can guarantee optimal solution in the 3D space aside from deep learning approaches such as CNNs that have predictive power over high dimensional image and visual data.

ML algorithms has brought great progress in the mining sector through generation and application of real-time flow of data from one department to another hence better and informed decision-making. With the use of data analytics by miners to discover useful and right information to predict future events such as prices, geotechnical and geological features in the deposit will help curb any mishap along the mine value chain. The challenge faced by mine planners and engineers when solving mining-related problems is in the design of ML algorithms that solve problems accurately, fast and efficient. These ML algorithms need to be applicable in a real mining environment to enhance and facilitate sustainability in the extractive industry.

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# Understanding a digital tool for the continuous economic valuation of critical raw materials mining projects

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## ABSTRACT

The strategic sectors of decarbonisation, digitalisation, aerospace and defence heavily depend on a secure supply of critical raw materials worldwide. However, several well-known critical raw materials mining projects had to close due to unforeseen costs that resulted in economic instability stemming from a misinterpretation of the features of the orebody and other boundary conditions. In addition to uncertainties with mineral prices, such misinterpretations are related to ground conditions, metallurgical recoveries, and geological consistency. Circumstances occur with unexpected discontinuities, differentiated geotechnical and rock mechanic properties of orebodies, overly optimistic recoveries, and payable products during the operation. Using digital technologies in mining operations has demonstrated advantages in reduced labour and wear component costs and higher production. Nevertheless, the application of artificial intelligence, machine learning, data analytics, predictive analytics, real-time data, and other relevant digital technologies in mine planning and optimisation still needs to be explored. An in-depth study is required to reveal the potential of digital technology applications in mining planning and research domains.

This study aims to present the current application of digital technologies in mine planning and operation and the extent to which such technologies can potentially handle the evaluation and prediction of techno-economic uncertainties during the project evaluation and implementation. Moreover, the study seeks to integrate the findings and define frameworks of a digital tool for the continuous economic analysis of critical raw material projects from the resource evaluation stage through project completion. Text-mining algorithms supported by Python programming are utilised to study insight reports from leading software companies and consulting organisations and relevant published papers in international peer-reviewed journals and conference proceedings. More funding and the interest of academics and software developers would be drawn in if the potential applications of digital technology in raw material sectors are made more apparent.

## INTRODUCTION

A growing global population, more industrialisation and digitisation, rising demand from developing nations, and the move towards climate neutrality—which depends on metals and minerals for low-emission technologies and products—are all expected to put more strain on resources (European Commission *et al*, 2023). Moreover, the future reliance on Critical Raw Materials (CRMs) may eclipse that of the current oil demand, which is considered one of the reasons behind publishing the list of CRMs every three years in the recent decade by the European Union (European Commission *et al*, 2023).

In addition to the European Union, several nations worldwide are devising plans to ensure their supply of CRMs, acknowledging the significance of the resources. For instance, the Australian government maintains the Critical Minerals List and the Strategic Materials List, which aim to identify minerals crucial to the country's defence capabilities, sophisticated industry, and transition to net-zero emissions (Australian Government, 2023). Similarly, the US Geological Survey (USGS) regularly updates its list of CRMs for the United States (USGS, 2022). Consequently, in the coming decades, there could be a significant increase in the competition for material resources among industrialised nations.

In parallel to the resource competition and subsequent strategic efforts, the mining industry faces many other obstacles. The construction of new mining projects worldwide decreased in 2023 due to shifting electric vehicle adoption rates and growing project prices. Even though big mining companies intend to spend more money in 2024, the challenges remain for the lengthy permitting process, resource nationalism, geopolitics, and environmental movement (E&MJ, 2024). From the perspective of natural occurrences, variations in ore geology frequently need drawn-out and expensive purifying procedures, eg high-grade ores (8 per cent rare earth oxides) at Mountain Pass in the United States (Ilankoon *et al,* 2022).

Using digital technologies and similar approaches to effectively handle several unexpected hurdles in mining projects has shown increased trends in recent decades. For example, KGHM Polska Miedź SA and LW Bogdanka SA use advanced geological modelling and mine planning software to provide comprehensive digital representations of geological conditions and planned mine structures, thereby maximising productivity and minimising costs (Malinowski, 2019). Adopting the suggested Artificial intelligence (AI) engine resulted in a 10 per cent increase in production, according to Cory Stevens, President of Freeport-McMoRan Mining Services (McKinsey and Company, 2023). Moreover, an internal report of Deloitte suggests that digital technology integration in mining can improve system-wide decision-making by 20–30 per cent through process automation, increase efficiency by 10–20 per cent through improved work management, and achieve over 50 per cent improvement through value chain-wide technology redesign and optimisation (Deloitte, 2019).

This study has examined how digital technologies are now used in mine planning and operations to better understand and handle the constraints related to techno-economic uncertainty throughout project assessment and execution. The goal is to combine these insights into creating a digital tool framework to enable ongoing economic analysis of CRM projects from resource assessment to completion. Ultimately, the tool aims to contribute to the sustainable handling of current and future CRM projects from an economic point of view.

## METHODOLOGY

### Documents/data collection

Documents have been meticulously gathered from sources found on Scopus, insights reports from top mining consulting firms, and newsletters on mine planning and optimisation software. In order to manage this collection, the Scopus database was searched using the terms 'mine AND planning AND operations AND digital* AND NOT technolog*.' This search was then narrowed down to only English-language documents and those relevant to 125 specific mining-related keywords. After this filtration process, a second layer of screening was conducted by carefully scrutinising the titles and abstracts of the short-listed documents. Following that, the final gathering was examined for accessibility, considering both open access options and the particular access rights offered by the library of the TU Bergakademie Freiberg.

Four mine planning and optimisation software programs have been selected from G2's top mining software list (https://www.g2.com/categories/mining), and five consulting firms have been found using the industrial sector 'Metals and Mining' filter on Frobe (www.forbes.com). Google has been used to conduct searches using the name of the digital technology and the listed consulting firm and software name to gather publicly accessible, readable online content or documents. All of the data is kept in the prepared database as PDF documents.

### Text mining algorithm

In text mining and analysis, knowledge of word combinations' frequency and structure can offer profound insights into the text's concepts and content (Jurafsky and Martin, 2018). A Python algorithm developed using text mining techniques (Figure 1) has been used to extract information from the collected PDF documents.

In Figure 1, trigrams are created after extracting, cleaning, and tokenising the text from the assembled PDF in steps 1.1–1.3. Step 1.4 sorts the trigrams with the most common function (top 300) based on the frequency of each pdf and assembles the trigrams with frequency numbers in an Excel database. Targeted trigrams are then identified by reading all the most common trigrams, and step 1.5 is used to compile sentences as text in the Excel database containing each targeted trigram from each PDF.

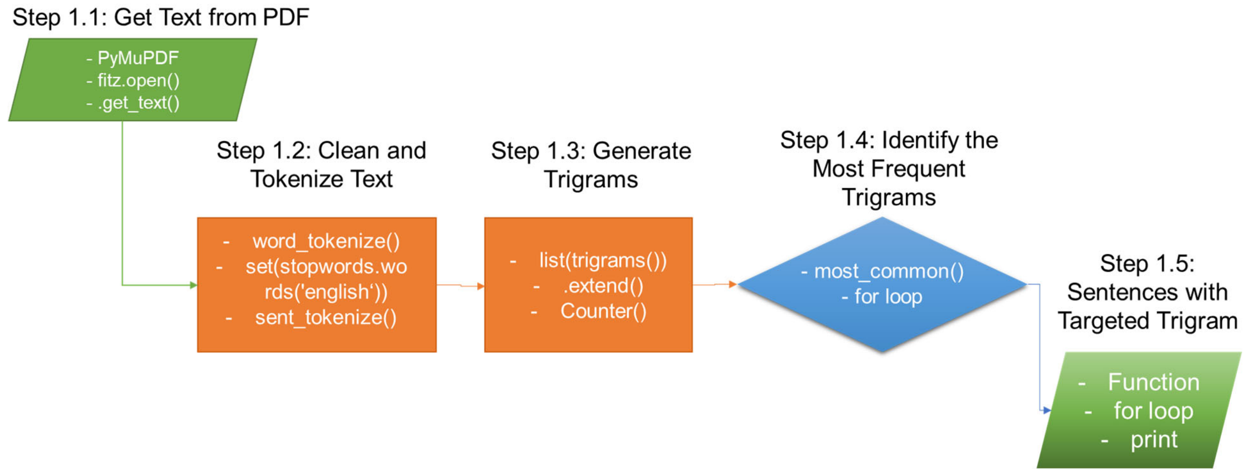


**FIG 1** – Workflow diagram of the Text Mining Algorithm.

## Text processing algorithm

Using a developed machine-learning model (Figure 2), the sentences gathered in the Excel database are categorised into distinct groups at this point in order to identify the digital technology, current application, and possible future application.

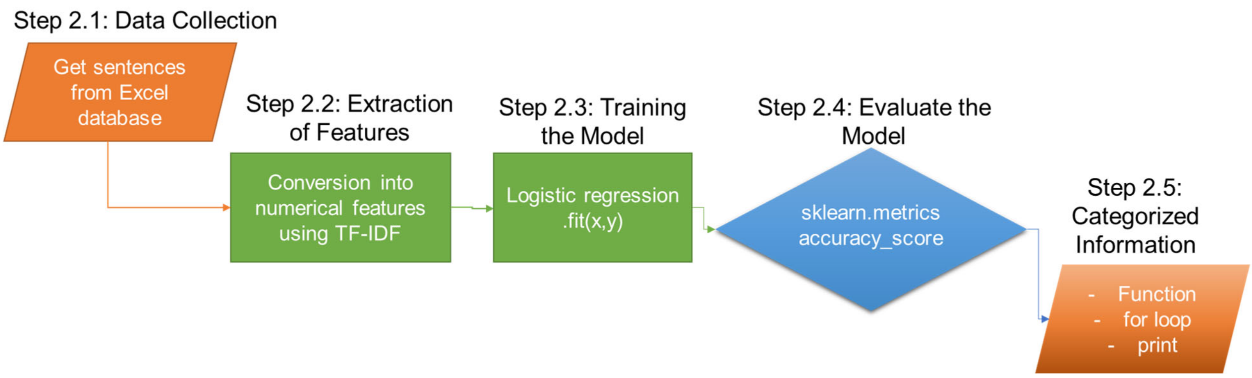


**FIG 2** – Workflow diagram of the Text Processing Algorithm.

In Figure 2, steps 2.1 and 2.2 involve getting the sentences from the Excel database and converting the text data in vectorised form using TfidfVectorizer(), .fit_transform(), and .transform(). Model development with LogisticRegression() and .fit() and predicting and evaluating the model are conducted in steps 2.3 and 2.4. Step 2.5 categorises the information within the expected frame and stores the information in data tables.

# RESULT

## Collected documents

After filtering language and keywords, 52 documents from Scopus are initially identified. However, in the second and third stages, only ten documents are identified as closely related to the study's goal when full text is available and the first reading is conducted. It is worth mentioning that journal and conference articles related to digital applications in various stages of the mining value chain show an average dramatic increase in trends since 2005, shown in Figure 3. Documents collected on newsletters from mine planning and optimisation software and insight reports of the consultancy companies are confined to the number 45 altogether.

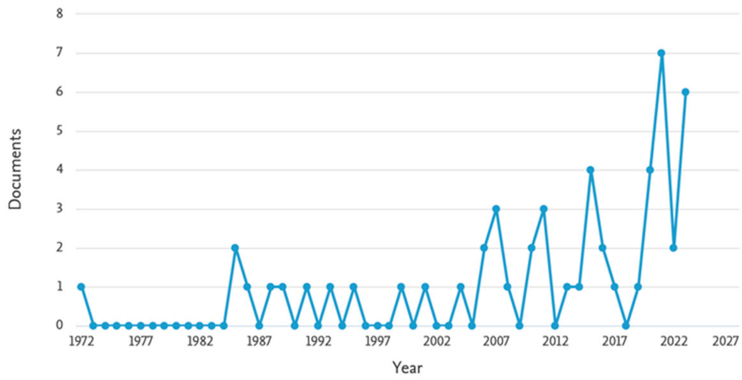


**FIG 3** – Research article numbers on digital technology application in mine planning and operation in Scopus from 1972 to 2024.

## Current application of digital technologies in mine planning and operation

The 45 documents from software and consultancy companies are text-mined with the described text-mining algorithm (Figure 1), and the collected Excel databases are processed with the text-processing algorithm (Figure 2) to identify the digital technology, current application, and potential near-future application of those under improvement. The identified key findings are summarised in Table 1.

**TABLE 1**

Current application of digital technology on mine planning and operation based on the information from software and consultancy companies.

| Technology | Current application | Potential in improvement |
|---|---|---|
| **Artificial intelligence** | Machine vision, speech recognition, and natural language | Increased productivity and more extensive exploration, greater confidence in resource estimates |
| **Artificial neural networks** | Ore reserve estimation | Multiple orebody styles |
| **Deep learning** | Drill hole sample data | A broader spectrum of geological styles improved the accuracy and efficiency of orebody modelling |
| **Data security** | Reconciliation, maintaining site productivity, data security and version control | Increase mining efficiency and productivity across the industry |
| **Machine learning** | Geological domain modelling, model marble reserves, fast and precise grade models | Leveraging machine vision |
| **Data analysis** | In-depth understanding of the nature of the deposit | The Grade Copilot's ability |
| **Cloud computing** | Evolving by incorporation | Efficiency and productivity in mining operations |
| **Automation** | Operational processes | Automation in processes within the mining industry |
| **Robotics** | Optimise the mine value chain | Continuous improvement |
| **Neural net deep learning** | Generating classified orebody models | Reduced time and effort to generate orebody models |
| **Big data** | Large complex orebodies | The efficiency and scalability of generating orebody models |

The technology in Table 1 is briefly discussed below based on the study's findings, emphasising its present uses and possible future applications.

### *Artificial intelligence*

A recent industry event discussed consolidating advanced sensor data and AI to optimise the mine value chain. This highlighted how AI-driven digital transformation may significantly improve efficiency and resource estimation.

### *Artificial neural networks*

Artificial Neural Networks (ANN or NN) are used in Iron Ore Deposits in Western Australia to estimate ore reserves.

### *Deep learning*

With intentions to develop deep learning applications and provide a commercial solution by the end of 2019, this digital revolution demonstrated excellent results, greatly enhancing the precision and productivity of orebody modelling in mining operations.

### *Machine learning*

Mining operations have shown benefits from a machine learning-based geological domain modelling process, especially when dealing with enormous volumes of data. Machine learning in marble reserve modelling produced more consistent quality classifications for extraction guidance at a faster pace.

### *Data analysis*

By quickly pointing out patterns and connections, the Grade Copilot makes Exploratory Data Analysis (EDA) easier and provides a dependable foundation for comprehending deposit features. This skill is expected to improve deposit analysis's efficiency and understanding, benefitting the mining industry's decision-making and resource estimation.

### *Cloud computing*

Solutions change when new technologies like cloud computing and machine learning are integrated. This all-encompassing approach to data management seeks to build repeatable and auditable processes to improve automation, efficiency, and productivity in mining operations.

### *Automation*

Automation and intelligence technology adoption is forcing mining firms worldwide to re-evaluate and modernise their operational procedures.

### *Robotics*

Discussions at a recent event highlighted the industry's focus on utilising robotic systems for increased operational efficiency.

### *Big data*

Large, complex orebodies or big data problems present challenges for conventional mining industry techniques to generate orebody models. This has led to research into future developments using machine learning and artificial intelligence that could improve the efficiency and scalability of model generation.

## Potential of digital technology to handle the techno-economic constraints

The ten research articles sorted through Scopus were subjected to text mining using the algorithm described (Figure 1), and the gathered Excel databases were subjected to text processing (Figure 2) to identify digital technology and its potential applications in addressing current constraints in the mining planning and operation phase. Table 2 summarises the study's key findings on the potential use of digital technology in solving techno-economic uncertainties in the mining value chain.

**TABLE 2**

Potential of digital technology to handle the techno-economic uncertainties during the project evaluation and implementation based on published paper collected from Scopus.

| No | Digital Technology | Constraints | Outcome | Source |
|---|---|---|---|---|
| *i* | *Geoinformation Management System (GMIS), MINEFRAME platform* | Geological/geotechnical, operation timing, safety rules | Automated underground mine production planning | Lapteva and Gurina (2023) |
| *ii* | *Spatial Data Mining (SDM), Geographic Information Systems (GIS)* | Exploration and land planning of high-place-value mineral resources | Valuable insights to support the land use planning decisions | López-Acevedo, Escavy and Herrero (2022) |
| *iii* | *Integer programming* | Resource planning and equipment allocation | Bee colony optimisation algorithm | Li *et al* (2021) |
| *iv* | *Terrestrial Laser Scanning (TLS), UAV photogrammetry, and GNSS positioning* | Acquiring accurate spatial data for creating 3D surface models | Comprehensive 3D surface models for open cut mining operations | Fotheringham and Paudyal (2021) |
| *v* | *Image processing, data analysis, Internet of Things (IoT), and cloud computing* | Equipment leading to safety hazards and production delays | An intelligent monitoring and identification system | Ma and Chen (2021) |
| *vi* | *Data analysis* | Efficiently managing a production system while maximising profitability and sustainability | Allows alternate decisions related to the production system | Chugh and Agarwal (2021) |
| *vii* | *(3D) point cloud data and laser scanning* | Measuring stockpiles in underground metal mines | An algorithm utilising multi-scale directional curvature | Yang, Huang and Zhang (2020) |
| *viii* | *Automation and intelligent decision support* | Scattered operating locations and complex mining processes in underground | Visualising geological resources, optimising design and planning processes, automation | Nailian *et al* (2011) |
| *ix* | *Data warehouse, metadata, and SQL Server* | Uniformity in data, methods, and management | A three-layer model is proposed | Liu *et al* (2008) |

Below is a summary of a thorough discussion of Table 2. Roman numbers in the table's left column (i-ix) have been used to arrange the order of the following paragraph. Nevertheless, due to a lack of information, number vi is not included in the below discussion.

Underground mine production planning constraints are intricate factors that traditional approaches may find difficult to handle, resulting in less-than-ideal operations, such as geological limitations and resource availability. The Geoinformation Management System (GMIS) in the MINEFRAME platform automates underground mine production planning by using a multi-factor optimisation technique to integrate the most recent mining data and geological/geotechnical conditions into engineering calculations.

The underutilisation of spatial data impedes the efficient exploration and land planning of significant mineral resources in high-value areas, making it challenging for governmental entities to regulate land use and for mining firms to effectively investigate suitable sites. Highlighted is the use of spatial data mining (SDM) in geographic information systems (GIS), which uses a variety of approaches to draw conclusions and patterns from sizable spatial databases. This is especially useful when examining national mine inventories to find trends like hot spots, outliers, collocations, and spatial predictions about mineral resources.

Underground mining operations encounter difficulties allocating resources and equipment effectively, exacerbated by suboptimal usage and fluctuating output requirements. Short-term resource plan optimisation models are created by integrating underground mine production requirements with integer programming. These models optimise equipment allocation between stopes to reduce overall equipment wait time while considering the limits inherent in ore hauling and striving to maximise profit.

Open cut mining surveyors confront difficulties in effectively gathering precise spatial data for 3D surface modelling since different data acquisition methods vary, and integrating numerous data sets is necessary. Three essential technologies for effective spatial data collecting are GNSS positioning, UAV photogrammetry, and terrestrial laser scanning (TLS). High-resolution point clouds are produced by TLS and UAV photogrammetry, and accuracy is improved by GNSS positioning, enabling geospatial experts to quickly and effectively produce detailed 3D surface models.

Effective inspection and monitoring of vital machinery, such as water pump rooms and belt conveyors, present difficulties in coalmines. Conventional techniques are laborious and ineffective, resulting in safety risks and production delays. Important digital technologies, such as cloud computing, the Internet of Things (IoT), image processing, and data analysis, make an intelligent monitoring and identification system for coalmines possible. Utilising this technology improves safety and efficiency in coalmine operations by enabling real-time monitoring and analysis of subterranean conditions.

Precisely gauging stockpiles is difficult when overlapping limits and uneven shapes and conventional techniques have trouble finding crest points and distinct boundaries. Laser scanning technology and three-dimensional (3D) point cloud data are critical digital technologies for measuring stockpiles. By capturing intricate spatial morphology, these technologies make calculating variables like volume, floor area, and height possible. This technology improves the efficiency and precision of stockpile measurement, proving to be faster and more accurate than traditional techniques. It is advantageous to the mining and construction sectors.

Underground metal mines face several difficulties because of their dispersed locations and intricate processes. These include issues with real-time device location, production dispatching, and personnel tracking. Deposit size and ore type variations impede design and planning optimisation efforts. The six areas of digitalisation that can be targeted in underground metal mines are intelligent decision support, integrating safety management, automating production, optimising design and planning, visualising geological resources, and assuring interoperability. By utilising these technologies, mines may improve operational efficiency and safety, optimise design and planning, acquire insights into ore resources, coordinate production phases seamlessly, and make well-informed decisions that eventually lead to more secure, cost-effective, and sustainable outcomes.

The construction of a digital coalmine presents obstacles in integrating heterogeneous data sources and subsystems with different forms and formats, which impedes efficient data mining, information fusion, and real-time control and monitoring from a surface dispatching room. The most important digital technologies that enable decision-making for mine users by integrating data into a consistent warehouse for online analytical processing (OLAP) include data warehouse technology, metadata approaches, and SQL Server embedded data warehouse.

## Proposed concepts of a digital tool

An economic evaluation of mining projects must navigate a complicated web of variables, including market dynamics, operational expenses, and geological uncertainty. Given these complex obstacles, a thorough and ongoing evaluation of a critical raw materials project's economic viability is essential.

This study offers a tool concept to address this demand by creating a complex digital tool that can integrate a wide range of assessment approaches. The tool aims to provide decision-makers with a comprehensive picture of a project's economic landscape across various scenarios by integrating conventional and innovative methodologies, such as discounted cash flow analysis, machine learning, and artificial intelligence with sophisticated sensitivity and scenario analysis. By examining extensive data sets and recognising complex patterns, the tool seeks to offer forecasted information that can enhance project economics and anticipate possible hazards for ongoing and future underground mining projects.

This digital tool's development will be supported using contemporary computer programming languages, including Python, and constructing an easy-to-use graphical user interface (GUI). This dual strategy keeps the tool accessible and user-friendly, enabling mining professionals to confidently and easily conduct complex economic studies.

Most importantly, the proposed tool's effectiveness will be directly tested by implementing it in actual mining projects. By fully engaging with the operational realities of current and future projects, the tool will authenticate its usefulness in aiding decision-making procedures, ultimately promoting the long-term viability of underground mining undertakings.

## CONCLUSION

Forty-five documents, including insight reports from five consulting firms and newsletters from four mining planning and optimisation software publishers, were gathered for the study. Furthermore, ten scholarly publications were taken into final consideration from Scopus. In order to analyse all 55 PDF documents and pinpoint current and potential uses for digital technology during the mining sector's mine planning and operation stages, text mining and text processing algorithms have been developed using Python programming language. The identification of constraints that are being addressed or suggested by the use of digital technology is also included in the investigation. In addition, current use and potential future use are listed and discussed in the study. In order to increase the sector's dependability for investors, it has lastly examined the potential of all the recognised digital technologies and put up the idea of a continual economic analysis tool for the critical raw materials project.

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# A changing work environment for managers in a Swedish mining company – observations in the wake of the Covid-19 pandemic?

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## INTRODUCTION

Few persons, if any, would disagree that the Covid-19 pandemic has had a large impact on the ways that many people work. For a substantial portion of workforces, in general, this impact has meant a shift to remote working or working from home. However, it is still an open question as to what changes will become permanent and what aspects of work life will return to that which was considered 'normal' before the pandemic. It is also unclear as to what the effect of these changes are and will be. In this paper, thus, we explore how the pandemic and its associated workplace measures have affected the work and work environments of managers in a large Swedish mining company.

## METHODS

The empirical material for this study comes from a larger research project titled 'Organisational and social work environment for managers' that was conducted at a large Swedish mining company (Larsson *et al*, 2022). In the present study, we revisit – through what we call a secondary analysis – relevant parts of the original empirical material, with the purpose of gaining more insight into the effects of the pandemic on managers' work environments. This research project has ethical approval from the Swedish Ethical Review Authority (Dnr: 2021-01392).

## RESULTS AND CONCLUSIONS

Despite the fact, this is an exploratory study, we have found some interesting consequences and effects of Covid-19 pandemic measures, and we have gathered these consequences and effects into six hypotheses that can be fruitful for further and future studies. Note that some of the hypotheses can be mutually exclusive.

### Hypothesis 1 – The workday is densified due to remote meetings

Pandemic measures lead to a densified workday; this is due to several changes. The number of meetings – while perhaps decreasing in time due to aspects of a social nature disappearing – increased, because the logistics surrounding the meetings were simplified (a physical location does not have to be booked, no travel to the meeting location is required, and there are virtually no turnaround times).

### Hypothesis 2 – 'Double work' during meetings is the rule rather than the exception

If meetings come to claim more time from the manager's agenda while that manager is still left with the same tasks, then 'double work' becomes the rule rather than the exception. By double work we refer to other work tasks being performed while attending a digital meeting. This situation is also increased when calling for or into a meeting becomes easier, as one does not have to impose the same limits on who is called to that meeting. Generally, more people attended meetings and on average those meetings were experienced to be less relevant. Instead of paying attention fully, managers instead used that time to answer emails and other tasks during the digital meetings.

## Hypothesis 3 – Meetings become more focused

Our third hypothesis is a precondition for the first hypothesis but contradicts the second hypothesis. That is, the workday can become densified if less time is spent on social interaction and more time is spent on the task at hand. However, for meetings truly to be more focused requires that everyone pays close attention to the meeting, which is hard to do when doing 'double work'.

## Hypothesis 4 – Meetings become more accessible

If meetings remain less resource-intensive (ie requiring less planning and participation by nature of simply logging in to an online meeting platform), we can understand this as the meetings becoming more accessible. This means, for example, that managers are likely to be invited to meetings that they previously were not invited to. If a manager is invited to the 'right' meetings, this should, in turn, give a better sense or understanding of one's (eg organisational) context. Such a scenario could help a manager in their role as manager. Additionally, by viewing one's contribution to a larger whole, such as through a broader range of meetings attended, one's motivation in one's work might be increased.

On the other hand, an increased 'accessibility', as described here, might also simply only lead to more meetings whereby such meetings are not really needed. This situation may lead to frustration and a workday that is needlessly filled with meetings.

At the same time, this 'accessibility' development also means that one can participate in meetings on one's own terms. For example, with physical meetings it is more difficult to enter and leave when the meeting is still ongoing; this is not the case with digital meetings. This factor means that managers are freer to enter and leave meetings as they are needed. This reality can have positive effects in reducing actual meeting time, but it also risks fragmenting the workday if the manager has to 'jump' between many different meetings in one day.

## Hypothesis 5 – The manager becomes less operational

As an effect of working less at the physical workplace close to operations, the manager might come to realise that they do not need to have full control over or total insight into the workplace and that much of the day-to-day work will function without them. That realisation frees up the manager to focus more on strategic questions or, to larger extent, engage in behaviours associated with relationship- or change-based leadership.

## Hypothesis 6 – A new work culture

With new ways of managing, a new work culture will arise; this new work culture will, in turn, affect both managers and the employees they manage. With management being less physically present, for example, a culture that is more trusting and freer may grow at the workplace. Where remote work is possible, a larger acceptance can grow for doing work remotely. Being able to work from home can also foster a positive work-life balance; this culture will probably also be a condition for the long-term success of new work arrangements.


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# Research study on social and governance risks assessment for the future phosphorite mining in Estonia

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## ABSTRACT

Today, raw materials have become essential in the manufacturing of common goods and technologies we use every day. Readily accessible raw materials are critical to EU industries and the continued growth of the European economy. This growth has resulted in an economy that is heavily reliant on raw materials, many of which need to be more sustainable and need to be sourced from regions outside the EU. The EU has determined that 34 individual raw materials have been deemed critical for Europe. Phosphorite rock is listed on the CRM list. Estonia has significant phosphate rock reserves within the EU, and their extraction and processing in Estonia have been sensitive issues in the past. Last year's research on identifying and understanding the most critical Environmental Social Governance (ESG) risks for any potential phosphorite mining and processing by compiling and analysing the opinions of Estonian mining experts and finding similarities and differences between the perceptions of mining experts and wider society groups.

The results of the research show that assessments of the importance of risks are multifaceted, being different among different interest groups. For example, mining experts assessed governance risks as more essential and social risks as less critical, leaving environmental risks in the middle and earning a profit risk, which got the highest score. Comparison with other stakeholders from the research reveals that governance risks are most important for mining experts, but environmental risks are most important for other stakeholders.

Currently, the Estonian Geological Survey is running a government-funded research program to make a feasibility study in the pre-selected area. The end of this research will give a major understanding of how Estonia can move forward with larger plans for the Estonian phosphorite rock deposit. Important is to understand the ESG risk in future mining projects of phosphorite rock.

# Research trends in mine planning and optimisation techniques identified from a bibliometric mapping and qualitative review of research from selected university-based research entities

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## ABSTRACT

The capital intensiveness of the minerals industry and inherent uncertainty accompanying the extraction of Mineral Resources, require optimal planning to maximise return on investment, while limiting room for errors. To find optimal ways of exploiting Mineral Reserves, university-based mine planning and optimisation research entities undertake research in this regard. The research is undertaken within an evolving research landscape which is characterised by changes such as emerging digital technologies and increasing demands on mineral project development by various stakeholders that further add to project constraints and uncertainty. This paper used the PRISMA technique together with the VOSviewer™ and R-Biblioshiny™ bibliometric software to map scholarly publications published by three selected research entities and indexed on Scopus and Web of Science databases. The three research entities are COSMO, DELPHOS, and MOL. From a total of 1784 papers published between 1974 and 2023, it was found that between 2006 and 2023, a total of 233 papers were published by the three research entities. The period from 2006 to 2023 was the period during which the three research entities were established up until 2023. A bibliometric mapping and qualitative review of the 233 papers revealed that:

1. Relationships exist between each research entity and the predominant mineral commodities and mining methods practised in its country of domicile.
2. Some papers reported value-add from employing optimisation techniques.
3. Uncertainty is now a prominent theme in research on mine planning and optimisation.

This paper is the first of its kind to review research publications per mine planning and optimisation research entity and presents trends identified from these findings to assist current and future research entities to strategically position themselves in an evolving research landscape. In addition, the paper also assists mining engineering schools worldwide with current and future focus areas in mine planning and optimisation education.

## INTRODUCTION

The minerals industry is a complex and challenging industry to operate in. This is due to its capital intensiveness which is often in the hundred million to several billion dollars of capital expenditure and inherent uncertainty associated with the search for, and extraction of the Mineral Resources which are exhaustible resources. The uncertainty includes geological, technical, and economic uncertainties. Consequently, it is important to undertake careful mine planning to maximise return on investment to optimise the value realised from the mineral commodities that are extracted from the Mineral Reserves, while limiting room for errors due to uncertainty. The economic value is normally expressed using the net present value (NPV). Mine planning and optimisation techniques play a key role in value optimisation as they are used to derive optimal ways to extract minerals from the ground. The optimal ways generally entail considerations such as minimising costs, improving safety, maximising recovery, or increasing productivity. To achieve value optimisation, mining companies or software companies utilise research outputs from work undertaken by departments within their organisations, consulting firms or university-based research entities. Research is a core mandate of university-based research entities and is often communicated through publications.

Therefore, it was necessary to undertake a bibliometric mapping combined with a qualitative review of published research from some university-based mine planning and optimisation research entities. This approach would assist in identifying strategies that current and future research entities should be aware of so that they can better serve the minerals industry. The approach would also inform mining engineering schools worldwide on education in current and future focus areas in mine planning and optimisation.

Mine planning and optimisation research entities are sometimes referred to as research groups, research laboratories, or research centres. These are units within university institutional structures that develop and/or implement advanced mathematical optimisation techniques to optimise mining processes from the planning stage to production stage along the mine value chain. Figure 1 illustrates the positioning of mine planning and optimisation within a generic mine value chain and shows that mine planning and optimisation is part of the value optimisation process, through which Mineral Resources are converted to more valuable Mineral Reserves. Since Mineral Resources are exhaustible resources that are replenished through ongoing exploration, mine planning and optimisation processes also occur throughout the Life-of-mine (LOM) as more Mineral Resources are converted to Mineral Reserves to sustain the mining operations. The International Accounting Standards Board (2010) and Njowa and Musingwini (2018) stated that Mineral Resources and Mineral Reserves constitute collectively, the single most significant asset or is among the most significant assets of any company conducting business in the minerals industry because they are the primary source of future cash flows from which economic value is derived. Therefore, it is important to conduct proper mine planning as this will ultimately lead to the attainment of value at the plan execution phase when production is being undertaken (Bester *et al,* 2016).

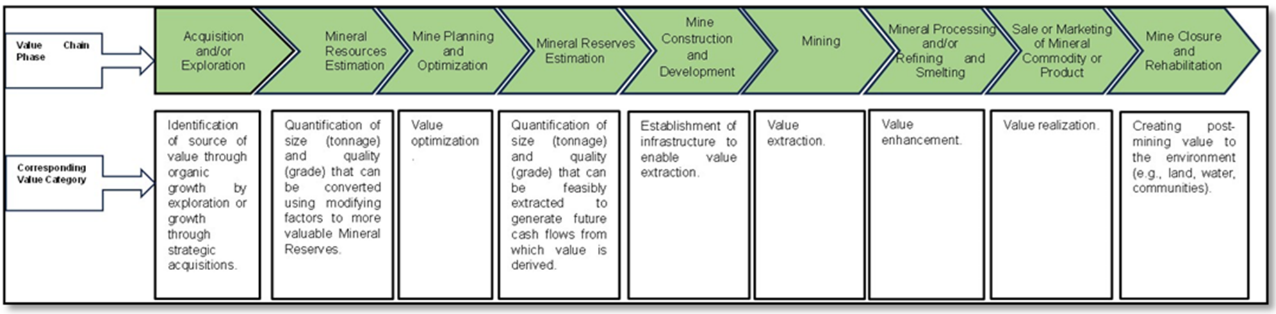


**FIG 1** – Positioning of mine planning and optimisation within a generic mine value chain in green colour and associated value focus categories in white boxes.

Operations research techniques are mostly used to solve the optimisation problems encountered in mine planning. These techniques include exact methods such as dynamic programming (DP), linear programming (LP), integer programming (IP), or mixed integer programming (MILP), and metaheuristic methods such as particle swarm optimisation (PSO), genetic algorithm (GA) and simulated annealing (SA).

## SELECTED UNIVERSITY-BASED MINE PLANNING AND OPTIMISATION RESEARCH ENTITIES

To identify university-based mine planning and optimisation research entities that focus on mine planning, a scanning of the internet was conducted using web sources such as Scopus, Google Scholar, Scielo, Researchgate and Academia.edu. The scanning process identified the following nine mining planning related research entities (Qwabe, 2023):

- COSMO – Stochastic Mine Planning Laboratory at McGill University in Canada
- DELPHOS – Laboratorio de Planificación Minera Laboratory at Universidad de Chile in Chile
- MOL – Mining Optimisation Laboratory at the University of Alberta in Canada
- Mining Research Laboratories at Queen's University in Canada

- MioT – Mine of Internet of Things Laboratory at the University of New South Wales (UNSW) in Australia
- USP Research Centre for Responsible Small Mining at the University of Sao Paulo in Brazil
- MIRG – Mine Intelligence Research Group at the University of Arizona in the United States of America (USA)
- MSOS – Mine Systems Optimisation and Simulation Laboratory at the University of Nevada, Reno in the USA
- MPVL – Mine Planning and Valuation Laboratory at the Hasanuddin University in Indonesia.

However, not all the research entities focus solely on mine planning and optimisation research, and some of them undertake limited research in mine planning and optimisation or peripheral to that area of research focus. Only the following three research entities had a strong research focus on mine planning and optimisation and were therefore, selected for further analysis (Qwabe, 2023):

- COSMO at McGill University
- DELPHOS at Universidad de Chile
- MOL at the University of Alberta.

These research entities are typically structured such that they are led by a director, often supported by an industry advisory board, academic staff, postdoctoral research fellows and postgraduate research students. This structure seems to work well for the research entities in ensuring that there is a strong link between the entities and the mining industry, and a talent pipeline of postgraduate students is readily available to solve research problems. The link with the mining industry is important in that it enables the resourcing of the entities by industry to ensure the sustainability of the research entities.

## SELECTION OF DATABASES AND BIBLIOMETRIC ANALYSIS SOFTWARE

The Scopus and Web of Science (WoS) databases were chosen as sources of data because these databases are the most extensively used citation indexes in the global research community and are compatible with most bibliometric analysis tools (De Groote and Raszewski, 2012). However, the publication listings from these two databases generally overlap by about 43 per cent to 66 per cent (Tabacaru, 2019). The extent of overlap depends mainly on first, the subject matter being reviewed and secondly, the period being reviewed (Tabacaru, 2019). Therefore, it is always important to merge the publication listings from the two databases to identify and eliminate duplicate entries so that no research paper ends up being double counted (Mutandwa and Musingwini, 2024).

Software is now generally available to use when conducting bibliometric analysis and includes software such as R-Biblioshiny™ developed by Aria and Cuccurullo (2017), VOSviewer™, CiteSpace™, Gephi™, Bib Excel™, and Histcite™ (Ampah *et al,* 2021). For this study the R-Biblioshiny™ and VOSviewer™ software were selected based on the following reasons provided by Mutandwa and Musingwini (2024):

- Both R-Biblioshiny™ and VOSviewer™ are freely available from the public domain for academic research purposes and are simple to use. In addition, they have the capability to present data in clusters. The clustering of data is useful because similar research papers can be grouped easily for further focused analysis.
- Bib Excel™ is generally difficult to use because it requires some user expertise and experience (Ampah *et al,* 2021).
- Fahimnia, Sarkis and Davarzani (2015) noted that Histcite™ cannot interpret Scopus data. Since Scopus is one of the data sources used in this paper, Histcite™ was therefore not an option to be considered.
- No licenses were available to run the CiteSpace™ and Gephi™ full-suite software as the software requires licenses to run detailed bibliometric analyses.

The data obtained from Scopus and WoS was subsequently analysed using the R-Biblioshiny™ and VOSviewer™ software. The next section describes the methodology that was followed in conducting the different analyses.

## METHODOLOGY FOLLOWED IN THE BIBLIOMETRIC MAPPING AND ANALYSIS

This paper contributes to the analysis of mine planning and optimisation research by undertaking a bibliometric mapping which was complemented with a qualitative review to improve the methodological and reporting quality, and transparency required in research reviews. It is also the first time that a review of research, differentiated by research entity is being undertaken in mine planning and optimisation, to inform future research directions. To achieve these two aims, it was important to initially perform a keyword analysis related to mine planning and optimisation to enable the identification of relevant and emerging keywords associated with the research topic for use in subsequent steps of the research study. Advanced search features in Scopus and WoS databases were used to retrieve indexed articles in mine planning and optimisation. The search expressions used in the abstract, keywords, and title sections were 'mine planning and optimisation', 'mine production scheduling and optimisation', and 'mine design and optimisation'. The Boolean operators 'AND' or 'OR' were used to combine the search expressions to limit or broaden the search. In total, 1784 papers that are indexed on Scopus and WoS databases were identified using the keyword search process and these spanned the period from 1974 to 2023. The indexed records were compiled in a*.csv* file format for compatibility with VOSviewer™ and R-Biblioshiny™ software. An analysis of the identified 1784 papers in VOSviewer™ software generated a network map visualisation as shown in Figure 2.

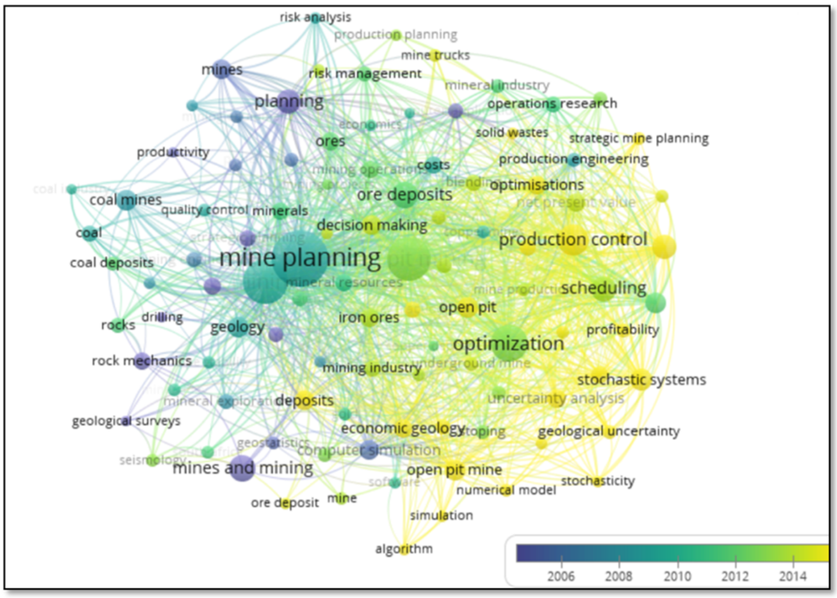


**FIG 2** – VOSviewer™ network visualisation map of keywords on the mine planning and optimisation research topic.

The analysis of keywords revealed four distinct clusters as shown in Figure 2. The first cluster, represented in purple, emerged prior to 2006 and was characterised by keywords such as 'computer simulation' and 'geostatistics'. The second cluster, depicted in green, spanned from 2007 to 2010 and was dominated by keywords related to 'mine planning', 'mining operations', and 'ore deposits'. The third cluster, shown in light green, covered the period from 2010 to 2012 and was marked by keywords like 'open pit mining', 'optimisation', and 'scheduling'. The fourth and final cluster, illustrated in yellow, began around 2012 and was defined by frequently used keywords such as 'stochastic systems' and 'integer programming'. As shown in Figure 2, recent research in mine planning and optimisation has increasingly shifted towards topics that incorporate uncertainty. The changing trend in clusters indicates an evolving research landscape within which the research topic is located. However, mine planning and optimisation research in underground mining seems to be limited and not feature prominently in Figure 2. This is despite some open pit mines planning to or having transitioned to underground mining globally due to them becoming uneconomic from increased depths of mining or declining ore grades (Ghorbani *et al,* 2023; Chung, Topal and Ghosh, 2016; Opoku and Musingwini, 2013).

Articles from the three research entities, COSMO, DELPHOS, and MOL, were identified by further refining the search using identified author names and affiliations. From the initial total of 1784 papers identified in mine planning and optimisation, 233 were published by the three research entities between 2006 and 2023 and indexed on Scopus and WoS. The identified research papers published by the three research entities were subsequently analysed using some elements of the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) technique together with the VOSviewer™ and R-Biblioshiny™ bibliometric software to aid visual interpretation.

The PRISMA technique is an approach for improving transparency in systematic bibliometric reviews (The University of North Carolina at Chapel Hill, 2023). The technique is useful to researchers as it enables them to interrogate several aspects of a manuscript, such as its title, abstract, introduction, methods, results, discussion, and funding. For each research entity, a three-step approach based on the generic PRISMA technique was used to select eligible research papers for further analysis (Figure 3). This three-step approach was developed following that of Harichandan *et al* (2022).

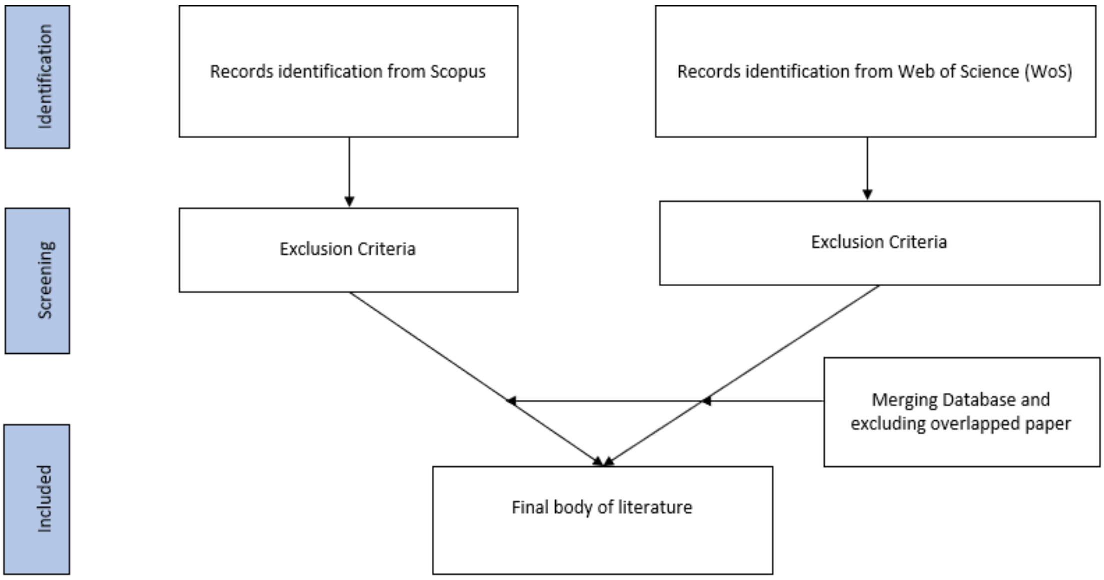


**FIG 3** – Three-step approach used to select papers for each research entity.

The first step entailed a preliminary evaluation to identify qualifying publications from the databases by utilising the refined set of search keywords as an 'inclusion' criterion. To ensure analysis of high-quality publications, it was necessary to include only publications from academic journals (not books, book chapters, conference papers, nor conference proceedings). The next step was to apply 'exclusion' criteria. For example, the search was limited to publications from 2006 to 2023 as an 'exclusion criterion' so that the search covered the period during which the three selected research entities were established up until 2023. Some papers were excluded after reading their titles and abstracts to ensure relevancy, while others were excluded due to unavailability of full-text versions. Lastly, to identify and eliminate duplicates it was necessary to merge the publication listings that were compiled as*.csv* files. The integrated and 'cleaned-up' data set was then subjected to further bibliometric mapping and analysis. This was complemented by undertaking a qualitative analysis of some papers published by each of the research entities to note claims of the value-add of the research conducted, as this was critical to underpin the importance of the research entities and their research publications. The next three sections present findings for each research entity.

## BIBLIOMETRIC ANALYSIS OF RESEARCH BY COSMO

McGill University founded COSMO in September 2006 in partnership with AngloGold Ashanti, Barrick, BHP, De Beers, Newmont, and Vale, and the Canadian and Quebec governments (COSMO, 2023). As can be inferred from its name, COSMO has a strong research focus on stochastic mine planning and optimisation under uncertainty that addresses problems across the entire mine value chain (COSMO, 2023). It achieves this overarching goal by developing, modifying, and/or applying computationally challenging approaches that seek to enhance value while simultaneously reducing risk for large mining complexes.

Using the three-step approach presented earlier in Figure 3, a total of 217 COSMO affiliated research papers were found and these were split as 128 from Scopus and 89 from WoS and considered suitable for further investigation. Of these, 71 papers overlapped across the two databases. Therefore, after merging both data sets and eliminating duplicates, the integrated data set comprised 146 papers, which were then subjected to further bibliometric mapping and analysis.

Figure 4 is an R-Biblioshiny™ word cloud visualisation of the results of keywords identified from the identified COSMO affiliated research papers indexed on the Scopus and WoS database. The size of letters in words as depicted in Figure 4 indicate the frequency of occurrence of keywords in the research papers. Large fonts indicate areas associated with high frequency of occurrence that gradually transition into smaller font areas which are areas of least frequency of occurrence.


**FIG 4** – Visual output of prominent research keywords from identified COSMO affiliated research papers.

Figure 4 emphasises that the prominent research keywords associated with COSMO's research focus include 'stochastic systems', 'optimisation', 'production control', 'open pit mining', 'stochastic models', 'scheduling', 'integer programming', 'uncertainty analysis', and 'computer simulation'. These prominent keywords are mostly in the 2014 to 2023 cluster depicted in Figure 2. This might suggest that the COSMO research laboratory is instrumental in steering the trajectory of mine planning and optimisation. Further analysis was performed to categorise the papers by mineral commodity type, optimisation technique, type of mine planning and optimisation problem and mining method evaluated. Figure 5 illustrates the categorisation of the selected research papers published by COSMO.

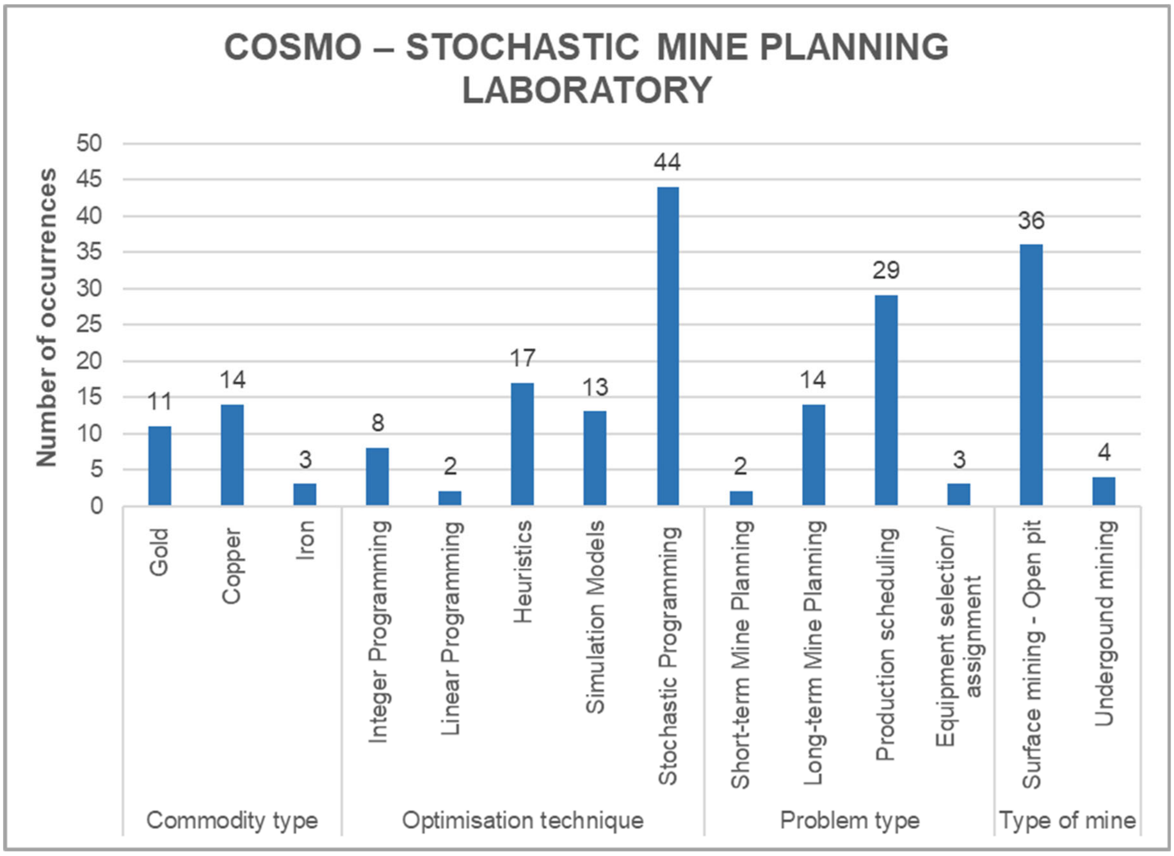


**FIG 5** – Visual output of prominent research keywords from identified COSMO affiliated research papers.

From Figure 5, it appears that the most prevalent occurrences in the published COSMO affiliated research papers are in:

- Gold and copper by mineral commodity types. This indicates that a relationship exists between the COSMO research studies and some of the main metal commodities mined in Canada because the Government of Canada (2022) indicated that gold, copper, and iron are the main metal commodities mined in Canada.
- Stochastic programming and heuristics are the commonly applied optimisation techniques, which align with COSMO's research objective of solving problems that deal with uncertainty such as commodity price uncertainty, geological uncertainty, and grade variability.
- Long-term mine planning and production scheduling are the most prevalent type of problems solved as these tend to be the starting point in mine planning and optimisation in mineral project evaluation.
- Surface mining and/or open pit mine planning are the predominant mining methods evaluated in the research papers. These are the predominant mining methods practised in metal mining in Canada.

Both Figures 4 and 5 indicate that there is limited research in mine planning and optimisation for underground mining. A qualitative review of the papers listed on the COSMO website was undertaken to determine the value-add of the COSMO research. Table 1 illustrates examples of some of the value-add claims made in some of the papers. The demonstration of value-add is important because it aids in attracting more support and underpins the importance of the work and the research entity. For example, in addition to the initial donors the COSMO Laboratory is now funded by a larger combined consortium of major mining companies that collectively represent about 75 per cent of global mining activities, coupled with continued support from the Canadian and Quebec governments (COSMO, 2024). The funding is *circa* one million Canadian dollars per annum, split approximately 60 per cent:40 per cent between government and industry, respectively (COSMO, 2024).

**TABLE 1**

More recent examples of COSMO affiliated research papers indicating value-add generated from applying optimisation or other operations research techniques.

| Authors | Title | Value-add claimed |
|---|---|---|
| Levinson and Dimitrakopoulos (2023) | Connecting planning horizons in mining complexes with reinforcement learning and stochastic programming | Compared to initial forecasts, a new integrated approach decreased deviations of short-term cash flows from long-term cash flows by 21 per cent during the first year of production. |
| MacNeil, Dimitrakopoulos and Peattie (2022) | A stochastic mine planning approach to determine the optimal open pit to underground mining transition depth – case study at the Geita gold mine, Tanzania | Stochastic optimisation produced a 23 per cent increase in NPV compared to deterministic approaches and there was an improvement in milling throughput over the LOM. |
| Kumar and Dimitrakopoulos (2021) | Production scheduling in industrial mining complexes with incoming new information using tree search and deep reinforcement learning | Compared to the initial production schedule, copper concentrate production increased by 7 per cent and cash flows by 12 per cent for a 13-week short-term production schedule. |
| Levinson and Dimitrakopoulos (2020) | Adaptive simultaneous stochastic optimisation of a gold mining complex: A case study | A 6.4 per cent increase in NPV when implementing an autoclave expansion and 27.5 per cent increase in NPV without implementing an autoclave expansion. |
| Chatterjee and Dimitrakopoulos (2020) | Production scheduling under uncertainty of an open pit mine using Lagrangian relaxation and branch-and-cut algorithm | For a copper mine the technique generated an 11 per cent higher NPV compared to a deterministic equivalent of the proposed approach, while it generated a 26 per cent higher NPV compared to a commonly used conventional industry approach over the LOM. |

## BIBLIOMETRIC ANALYSIS OF RESEARCH BY DELPHOS

The DELPHOS Laboratory is a unit within the Advanced Mining Technology Center (AMTC) which is part of the Mining Engineering Department of the Universidad de Chile. The DELPHOS Laboratory was created as a joint initiative between BHP Billiton and Universidad de Chile, with the main objective of facilitating and conducting research in mine planning (DELPHOS, 2023a). However, its exact date of establishment could not be ascertained but could be *circa* mid-2000s because based on DELPHOS (2023b), its listed publications date back to about 2009. In addition, according to Mineria Chilena (2009), the laboratory was two years old in 2009 implying that it should have been established in or around 2007.

Using the three-step approach (Figure 3), a total of 56 DELPHOS affiliated research papers were found, of which 32 were identified from Scopus and 24 from WoS and were suitable for further investigation. Of these, 22 papers overlapped across the two databases. Therefore, after merging both data sets and eliminating duplicates, the integrated data set comprised 34 papers which were then subjected to further bibliometric mapping and analysis.

Figure 6 is an R-Biblioshiny™ word cloud visualisation of the results of prominent keywords identified from the identified DELPHOS affiliated research papers indexed on the Scopus and WoS databases. Figure 6 indicates that the prominent research keywords associated with the research focus of DELPHOS include ‘open pit mining’, ‘mine planning’, ‘integer programming’, ‘production control’, ‘optimisation’, ‘scheduling’, ‘production scheduling’, ‘operations research’ and ‘mathematical programming’. Some of the prominent keywords from the articles are in the 2008 to 2010 cluster of Figure 2. However, many are found in the yellow cluster representing the period 2014 to 2023 in Figure 2.


**FIG 6** – Visual output of prominent research keywords from identified DELPHOS affiliated research papers.

Further analysis was performed to categorise the papers. Figure 7 illustrates the categorisation of the selected research papers published by DELPHOS.

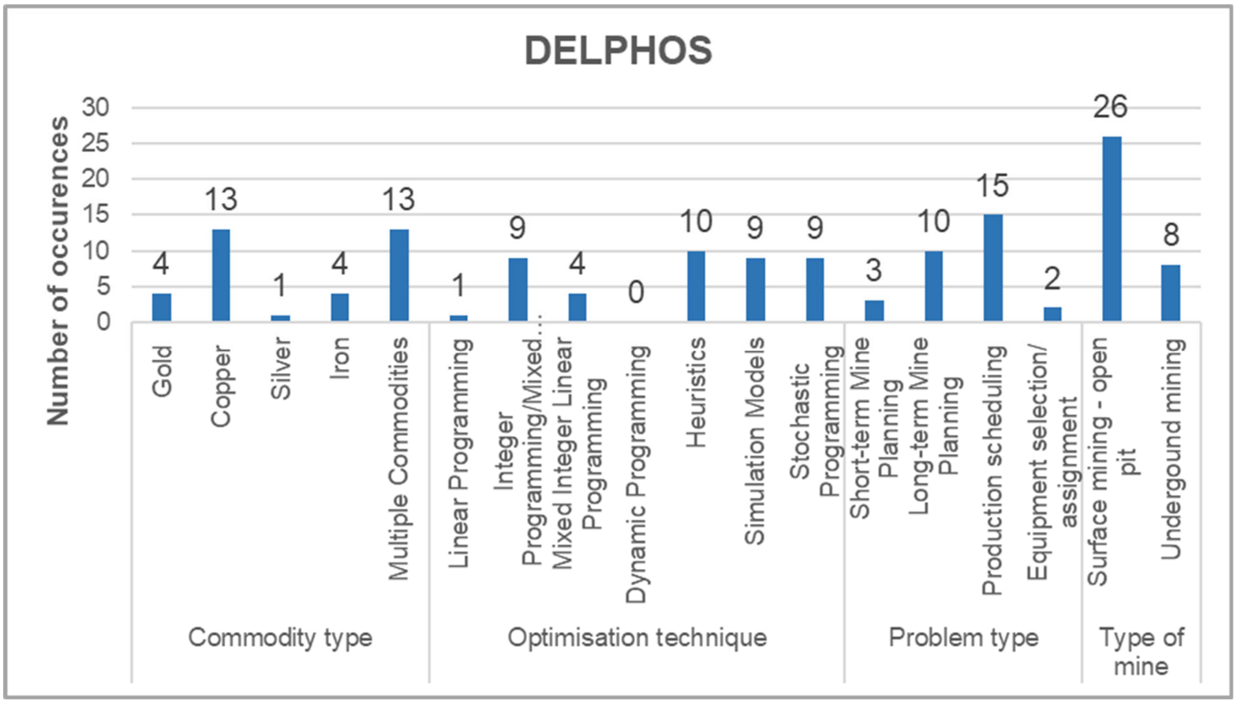


**FIG 7** – Summary categorisation of DELPHOS affiliated research papers.

From Figure 7, it appears that the most prevalent occurrences in the published DELPHOS affiliated research papers are in:

- Copper by mineral commodity types. This indicates that a relationship exists between the DELPHOS research papers and the main metal commodity mined in Chile because according to the International Trade Administration (2022), Chile is the largest producer of copper accounting for 28 per cent of global copper production. It is also estimated that there are about 626 copper mines operating globally and of these about 127 are in Chile (Mining Technology, 2023). Copper mining contributes about 10 per cent to the Chilean Gross Domestic Product

(GDP) (Selman, Marris and Burford, 2023). These factors emphasise the importance of copper mining to Chile; hence it is logical to expect that most of the DELPHOS affiliated research papers are on copper mining.

- A mix of optimisation techniques that does not indicate a particular preference for an optimisation technique and this aligns with the main objective for which Delphos was created so that it could facilitate and conduct research broadly in mining planning.
- Long-term mine planning and production scheduling are the most prevalent type of problems solved as these tend to be the starting point in mine planning and optimisation when conducting mineral project evaluation.
- Surface mining and/or open pit mine planning are the predominant mining methods evaluated in the research papers. These are the predominant mining methods practised in copper mining in Chile.

Both Figures 6 and 7 indicate that there is limited research in mine planning and optimisation for underground mining. A qualitative review of papers listed on the DELPHOS website was undertaken to determine the value-add of the DELPHOS affiliated research, as was done for the COSMO affiliated research papers. Table 2 illustrates examples of some of the value-add claims made in some of the DELPHOS affiliated papers.

**TABLE 2**

More recent examples of DELPHOS affiliated research papers indicating value-add generated from applying optimisation or other operations research techniques.

| Authors | Title | Value-add claimed |
|---|---|---|
| Morales, Nancel-Penard and Espejo (2023) | Development and analysis of a methodology to generate operational open-pit mine ramp designs automatically | Compared to manual reference pushback designs, the methodology developed automatically generated in shorter time frames, designs that were within 2 per cent and 6 per cent deviations for economic value and tonnage, respectively, from the reference designs. |
| Jélvez, Morales and Ortiz (2022) | Stochastic final pit limits: An efficient frontier analysis under geological uncertainty in the open pit mining industry | Compared to four other different approaches, up to 32 per cent improvement was obtained in minimising the distance to the ideal point (DIP). The DIP is a point at which maximum expected profit and minimum risk along an efficient frontier are found. |
| Nancel-Penard and Morales (2022) | Optimising pushback design considering minimum mining width for open pit strategic planning | An approach incorporating preprocessing applied to pushback design generated comparable practical designs on three different block instances and reduced the computation time by about 14 times for one of the instances. |
| Manríquez, González and Morales (2023) | Short-term open-pit production scheduling optimising multiple objectives accounting for shovel allocation in stockpiles | A MILP optimisation model for shovel assignment and movement in an open pit short-term mine schedule generated improved waste extraction compliance from 20 per cent to 29 per cent (when priority is production) and production compliance from 72 per cent to 73 per cent (when the priority is waste extraction). |
| Morales *et al* (2019) | Incorporation of geometallurgical attributes and geological uncertainty into long-term open pit mine planning | The applied methodology which combined stochastic direct block scheduling (DBS) with metallurgical parameters generated an NPV which was 9.4 per cent higher than that obtained in the deterministic case. |

## BIBLIOMETRIC ANALYSIS OF RESEARCH BY MOL

The School of Mining and Petroleum Engineering at the University of Alberta launched the MOL as an industrial affiliates program in January 2009 (Askari-Nasab, 2009). It was established with the support of two founding sponsors namely, Newmont USA Limited and Suncor Energy Inc. (Askari-Nasab, 2009). It was created with the aim of undertaking research in two main areas, namely risk-based mine planning and design, and optimisation of mining systems using simulation analysis.

Using the three-step approach (Figure 3), a total of 67 MOL affiliated research papers were identified of which 31 were from Scopus and 36 from WoS databases and were suitable for further investigation. Of these papers, 14 papers overlapped across the two databases. Therefore, after merging both data sets and excluding duplicates, the integrated data set comprised 53 papers which were then subjected to further bibliometric mapping and analysis.

Figure 8 is an R-Biblioshiny™ word cloud visualisation of the results of keywords identified from the identified MOL affiliated research papers indexed on the Scopus and WoS databases. Figure 8 indicates that the prominent research keywords associated with the research focus of MOL include ‘production control’, ‘integer programming’, ‘optimisation’, ‘mining’, ‘open pit mining’, ‘linear programming’, ‘production scheduling’, ‘mixed integer linear programming’, ‘oil sands’, ‘mine trucks’, ‘fleet operations’, ‘fleet management system’, ‘truck dispatching’, and ‘simulation’. It is evident that most of the frequently used keywords used in the articles published by MOL are found in the 2014 to 2023 cluster of Figure 2.


**FIG 8** – Visual output of research keywords from identified MOL affiliated research papers.

Further analysis was performed to categorise the MOL affiliated research papers. Figure 9 summarises the categorisation of the selected research papers published by MOL.

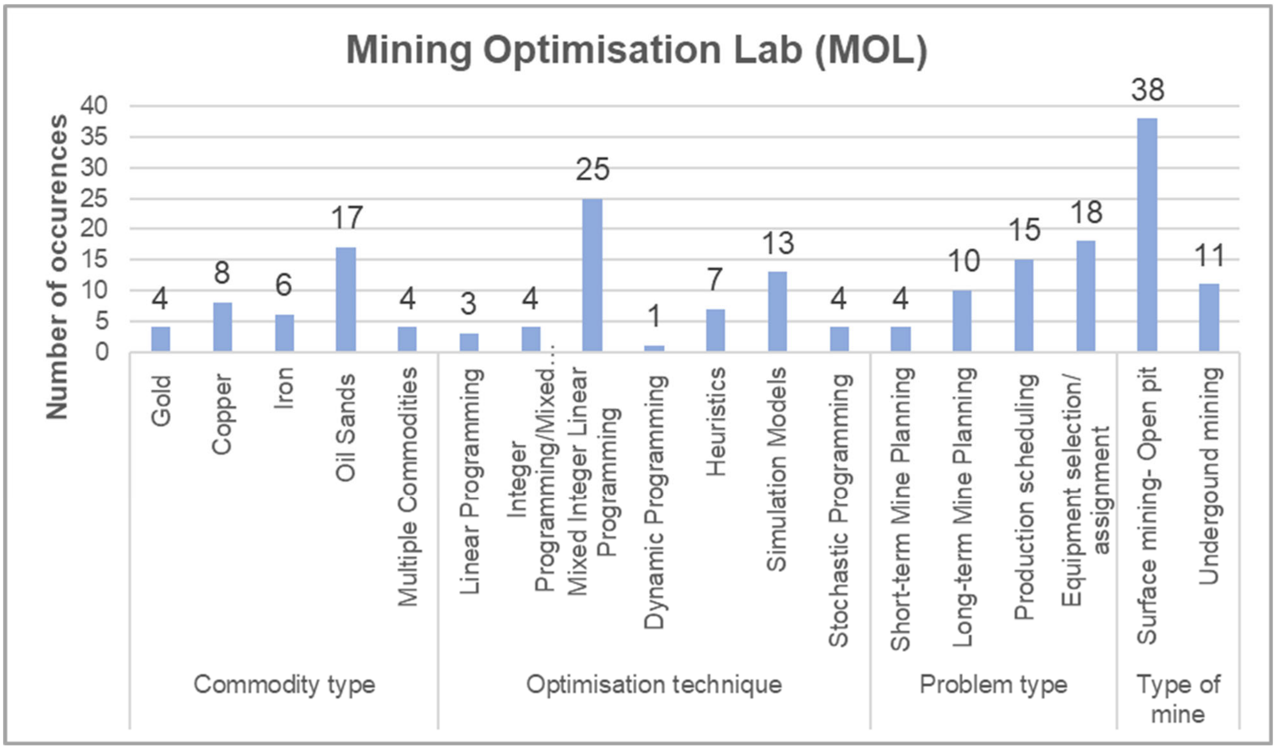


**FIG 9** – Summary categorisation of MOL affiliated research papers.

From Figure 9, it appears that the most prevalent occurrences in the published MOL affiliated research papers are in:

- Iron, oil sands and copper by mineral commodity types. This indicates that a relationship exists between the MOL research studies and some of the main mineral commodities mined in Canada because the Government of Canada (2022) indicated that gold, copper, and iron are the main metal commodities mined in Canada. In addition, CAPP (2023) indicated that oil sands operations in Canada are in three regions within Alberta and Saskatchewan namely, the Athabasca, Cold Lake, and Peace River regions. The oil sands operations extract oil sands from shallow depths of about 70m deep, are well developed and utilise some of the best oil sands production technologies (CAPP, 2023). The MOL places a stronger focus on oil sands mining than does the COSMO Laboratory, while COSMO places more focus on gold mining than MOL does, and both equally contribute to research in iron ore mining. The differences could be attributed to each research entity strategically selecting a niche area that does not create competition with the other and that MOL is geographically the closest research entity to Canada's oil sands fields compared to COMSO.
- Mixed integer linear programming, integer programming and simulation are the commonly applied optimisation techniques, which align with MOL's research objective of solving problems that deal with risk-based mine planning and design, and optimisation of mining systems especially using simulation analysis in fleet management systems.
- Equipment optimisation in fleet management systems, production scheduling, and long-term mine planning are the most prevalent type of problems solved in MOL affiliated research papers in line with its research objectives.
- Surface mining and/or open pit mine planning are the predominant mining methods evaluated in the research papers. These are the predominant mining methods practised in Both Figures 8 and 9 indicate that there is limited research in mine planning and optimisation for underground mining. A qualitative review of papers listed on the MOL website was undertaken to determine the value-add of the MOL affiliated research papers. Table 3 illustrates examples of some of the value-add claims made in some of the papers.

**TABLE 3**

More recent examples of MOL research papers indicating value-add generated from applying optimisation or other operations research techniques.

| Authors | Title | Value-add claimed |
|---|---|---|
| Gong, Afrapoli and Askari-Nasab (2023) | Integrated simulation and optimisation framework for quantitative analysis of near-face stockpile mining | A short-term production scheduling optimisation model based on MILP was applied to an oil sands mine and simulation results revealed that compared to the traditional mining method, overall production increased by 5.06 per cent, truck transportation distance decreased by 17.87 per cent, and utilisation of the shovels and crusher increased by 4.96 per cent and 4.85 per cent. |
| Kamrani, Pourrahimian and Askari-Nasab (2022) | Long-term mine planning optimisation for IPCC-based open pit mining operations | A MILP model solved a long-term mine planning, production scheduling and equipment allocation problem by using an in-pit crushing and conveyance (IPCC) system for an iron ore mine resulting in a decrease in the amount of haul trucks required from 10 to 3, while still maintaining production targets. This meant less fuel and by extension a lower carbon footprint, reduced truck fuel costs and increased profitability. |
| Tabesh, Afrapoli and Askari-Nasab (2022) | A two-stage simultaneous optimisation of NPV and throughput in production planning of open pit mines by introducing multi range stockpiles | A two-stage clustering-MILP algorithm for long-term production planning was applied to an open pit mine and minimised head-grade deviation to 5.1 per cent, while increasing reclaimed material by 10.7 per cent of the total ore delivered to the plant. |
| Afrapoli, Tabesh and Hooman Askari-Nasab (2018) | A transportation problem based stochastic integer programming model to dispatch surface mining trucks under uncertainty | A stochastic model reduced the average number of trucks queuing at the shovel by 36 per cent compared to the benchmark model resulting in shorter queuing time. |
| Cervantes, Upadhyay and Askari-Nasab (2018) | Improvements to production planning in oil sands mining through analysis and simulation of truck cycle times | A new 'effective loaded flat haul' (ELFH) framework to estimate productivity showed that the existing 'loaded flat haul' (LFH) was over estimating productivity by 4 per cent and underestimating productivity 10 per cent. |

## STRATEGIES IDENTIFIED FROM THE QUALITATIVE REVIEW AND BIBLIOMETRIC ANALYSES OF THE THREE RESEARCH ENTITIES

Some strategies can be identified from the qualitative review and bibliometric mapping and analyses done on the three selected mine planning and optimisation university-based research entities. These strategies which have implications for current and future research entities and mining engineering schools worldwide, are:

- A research entity should typically be structured such that it is led by a director, often supported by an industry advisory board that serves as a link between the research entity and the mining industry. Other faculty members and/or researchers including postdoctoral fellows must also be part of the structure of the entity to oversee and link different research projects.
- To be sustainable, a research entity must continually attract many postgraduate students who can research individually or collaboratively on different aspects of mine planning and optimisation research projects. This is because postgraduate students make up the talent pipeline required to solve research problems under the guidance of more experienced and knowledgeable research faculty staff.

- To be locally relevant but globally competitive, a research entity must prioritise solving research problems faced by the mining industry in its country of domicile as this will ensure its continued relevance and have easy access to test sites.
- It is important for a research entity to differentiate itself through a unique research focus but incorporate uncertainty into problem formulation since it is inherent in mine planning and optimisation.
- It is important for a research entity to demonstrate and quantify the value-add of its solutions through such metrics as higher project NPVs, improved operational efficiencies, minimised costs, or shorter solution times.
- For a research entity to be sustainable, it must be able to solve research problems in mine planning and optimisation across the entire mine value chain because some of the problems may be long-term while others are short-term problems. Where a research entity may need to solve a problem outside of its niche area, it may be necessary for it seek collaboration with other research groups working in that focus area. In this way, mining operations are likely to develop more confidence in fostering collaboration with the research entity.
- From the research papers it appears that there was limited to no collaboration among the research entities. There could be merit in research groups to collaborate with each other to avoid duplication of efforts for the benefit of the global mining industry.
- From the research papers it appears that research in underground mine planning and optimisation is still limited, hence there are prospects to conduct more research in this area and for mining engineering schools to place more emphasis in this area in their education programmes.
- To keep abreast with current and future focus areas in mine planning and optimisation education, mining engineering schools should consider including more content on the application of metaheuristic techniques and optimisation in underground mine planning.

## CONCLUSIONS

This paper discussed the importance of university-based mine planning and optimisation research entities because they generate value-add from their research efforts for the benefit of the mining industry. A qualitative review and bibliometric mapping and analyses indicated that:

- A relationship exists between the research that a research entity undertakes, and the mineral commodity commonly found in its the country of domicile.
- There is a relationship between a research entity's research focus and the pre-dominant mining method practised in its country of domicile.
- Some of the research studies attempt to quantify the value-add of solutions generated by using metrics such as higher project NPVs, improved operational efficiencies or minimised costs.

To strategically position themselves and remain relevant within an evolving research landscape, current and future university-based research entities can do two things. Firstly, they must focus research efforts on predominant mineral commodities and mining methods in their country of domicile, while incorporating uncertainty and quantifying the value-add of applied optimisation techniques. Secondly, the research entities can direct more research efforts into underground mine planning and optimisation, given that some open pit mines are planning to transition or have already transitioned to underground mining. Mining engineering schools worldwide can also keep abreast with current and future focus areas in mine planning and optimisation education, by including the application of metaheuristic techniques and optimisation in underground mine planning.


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# The role of education in achieving the sustainable development goals (SDGS) in artisanal and small-scale mining (ASM)

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## ABSTRACT

The mining industry as a source of raw materials is essential to society, yet it lacks a good reputation due to the type of management that has historically been applied to many of its social and environmental impacts. It is argued that this situation has prevented many mining projects around the world from obtaining a social license to operate. The latter considerations are very common in Latin American countries. As a result, the mining sector has realised that long-term business viability is associated with more profits for shareholders, but also with activities that improve the livelihoods of local communities, increase the capacity of local governments and preserve the ecosystems surrounding the projects. However, recent studies have shown that most of the current progress in incorporating sustainability concepts in mining has focused mainly on monitoring and preventing the environmental and social impacts of extractive activities. Thus, contributing to the development of the territories around mining projects is a key aspect of business competitiveness by reducing the costs and risks of project stoppages, innovating new ways of relating to stakeholders and improving the industry's reputation and market position. However, this contribution requires formal strategies and models that allow companies and communities to understand the different resources of the territories where their mining activities are developed and these resource transformations, in order to establish the best way to articulate the project with the territory, seeking an effective contribution to its development, truly sustainable in time even after mine closure.

All these aspects must be considered in the training of new professionals, who must receive adequate education in sustainability issues so that they can support the communities involved in this practice.

## INTRODUCTION

Mining is an activity of great importance worldwide because it is the industry that provides the minerals humans need in daily life. Mining is usually classified into three types depending on the volume of mineral extraction: large-scale, medium-scale, and small-scale mining. In the small-scale category, there are several subdivisions such as formal, legal, and artisanal. It is estimated that more than 40 million people worldwide depend on the Artisanal and Small-Scale Mining (ASM) sector (Havel, 2018).

ASM is developed in rural and remote areas where the state is almost never present, and therefore, there is no control over the mineral exploitation carried out. It is primarily focused on gold extraction but can also be found in coal, industrial minerals, platinum, among others. It is characterised by being a low-technology activity with a high proportion of unskilled labour, causing significant environmental, social, and economic impacts on the surrounding community. Consequently, the way the activity has been conducted, often with little technical knowledge, has generally resulted in mining having a poor reputation. Therefore, it is crucial to understand how the community functions where this type of mining is practiced to comprehend the factors influencing decision-making regarding how the activity is conducted, how people perceive mining, and thus, through joint efforts, establish a strategy to make ASM a sustainable activity. This can be achieved by using the recognition of the activity and education as a tool for transforming ASM towards sustainability.

## SUSTAINABLE DEVELOPMENT GOALS (SDGS) AND ARTISANAL AND SMALL-SCALE MINING (ASM)

Artisanal and small-scale mining (ASM) plays a significant role in the global economy, especially in developing countries. Despite its economic contribution, ASM faces numerous challenges including environmental impacts, hazardous working conditions, and health and safety issues. Education is a crucial element in addressing these challenges and advancing towards the achievement of the Sustainable Development Goals (SDGs) in the ASM sector (EITI, nd).

Since the publication of the Sustainable Development Goals by the United Nations (UN), there has been a clear path to achieve sustainability, aiming to protect the planet, preserve resources for future generations, and improve people's lives and prospects. Some SDGs are directly related to ASM in a positive way, such as No Poverty (SDG 1), Zero Hunger (SDG 2), Decent Work and Economic Growth (SDG 8). On the other hand, there is a tendency to perceive mining as having negative impacts on the following SDGs: Good Health and Well-being (SDG 3), Quality Education (SDG 4), Clean Water and Sanitation (SDG 6), and Responsible Consumption and Production (SDG 12), among others. The perception of how the Sustainable Development Goals and ASM are related depends on the conditions of the community where mining is developed and whether it is formal or informal.

ASM has a significant global influence in mining and, as a sector, has been historically stigmatised due to how it is practiced and the consequences it entails. Areas where it develops, regardless of the type of mineral extracted, are characterised by major socio-economic and environmental problems, such as poverty, lack of access to education or health, child labour, discrimination, pollution, armed conflict, among others. These are considered challenges that need to be addressed in the best possible way to help the communities that rely on this activity achieve sustainability.

The various challenges mentioned above must be resolved to align with the SDGs, including social, technical, economic, environmental, and legal components. However, to face these challenges, people must have the knowledge and awareness about the activity they perform. The lack of education in technical mining issues results in people constantly exposing themselves to dangers, risking their lives, and causing negative impacts on the ecosystem surrounding the mining site. It is also important to mention that miners need to be recognised for their activity, regulated, and accepted, allowing them to operate under a legal framework that guarantees decent work and a better quality of life. This is why joint efforts with the government are required to achieve formalisation that benefits both parties. The design of regulations should not aim to attack the impacts of the activity but to prevent them, including greater participation from the people to adequately address the sector's needs.

Understanding the foundation of the SDGs and sustainability as a transversal and integral concept that includes the environment, society, and territorial economy, there is a push for economic activities that have faced rejection regarding formalisation to be included under a regulatory framework providing guarantees of formal and safe work (Villas-Bôas and Beinhoff, 2022).

On one hand, education—not only academic but also financial and technical in the context of ASM—plays a crucial and significant role. It has been identified that there is insufficient technical knowledge among those involved in extraction and commercialisation tasks. The lack of this type of education can lead miners to overestimate their skills and underestimate the risks and consequences, fostering irresponsible behaviour. Specifically, in the case of gold, it has been widely reported that people with a high level of education are more likely to work in safer environments than their untrained counterparts. This means that as people acquire more knowledge and tools for their work, they become more aware of the risks of the activity and are less likely to expose their lives to danger.

In this sense, considering the aforementioned points, it is vital to understand the community before intervening through education. Understanding the problems, they face through a needs analysis, working hand in hand with them and sustainability experts, would allow mining communities to start building a trust relationship between them and the government. This would help find a diagnosis with a holistic vision of the realities of a mining community.

As a result, with education recognised as a necessity and knowledge of the area to be intervened, technical, environmental, and financial training programs can be developed. These should be accessible to miners and enable them to acquire skills and develop capacities that help reduce risks associated with mining and occupational health, and also diversify their livelihoods based on sustainability. Access to education for mining communities would provide opportunities to reduce child labour, increase women's participation in the sector, empower vulnerable communities with knowledge, and raise employment rates in these areas. Combined with a sustainability approach, this would undoubtedly reduce pollution, gender inequality, and poverty, and increase the use of technology, among other aspects contemplated by the SDGs. This would contribute to improving living conditions and socio-economic and environmental indicators in the community.

## IMPORTANCE OF EDUCATION IN ASM

- **Environmental Sustainability Improvement:**
  - **Training in Sustainable Practices:** Education can provide artisanal and small-scale miners with the necessary knowledge about sustainable mining practices that minimise environmental impact. This includes land reclamation techniques, proper waste management, and efficient water use.
  - **Biodiversity Conservation:** Through educational programs, miners can learn about the importance of protecting local ecosystems and endangered species, promoting responsible mining.
- **Health and Safety Improvements:**
  - **Workplace Safety Education:** Training in safety practices can significantly reduce accidents and occupational diseases in the ASM sector. This includes the proper use of personal protective equipment and the implementation of workplace safety measures.
  - **Community Health:** Education on health and disease prevention can help mining communities better manage the risks associated with exposure to toxic substances, such as mercury, and improve overall well-being (Veiga and Fadina, 2020).
- **Economic Capacity Building:**
  - **Management and Entrepreneurship:** Training in business and management skills can empower miners to improve their operations, increase productivity, and access more profitable markets. This includes knowledge about business administration, financing access, and marketing techniques.
  - **Economic Diversification:** Education can open opportunities for economic diversification, allowing miners to explore other income sources and reduce their sole dependence on mining.

## CONTRIBUTION OF EDUCATION TO THE SDGS

- **SDG 1: No Poverty**
  - Education can provide artisanal and small-scale miners with the tools needed to increase their incomes and improve their living conditions, contributing to poverty eradication.
- **SDG 3: Good Health and Well-being**
  - Training in health and safety practices can significantly improve the quality of life for miners and their communities, reducing the incidence of diseases and accidents.
- **SDG 8: Decent Work and Economic Growth**
  - By improving miners' skills and knowledge, education can foster sustainable economic growth and the creation of decent jobs in the ASM sector.
- **SDG 12: Responsible Consumption and Production**
  - Training in sustainable practices and efficient resource use can promote more responsible production in artisanal and small-scale mining.
- **SDG 15: Life on Land**
  - Education in environmental conservation and land reclamation can help protect and restore ecosystems affected by mining, promoting long-term sustainability.

## STRATEGIES FOR IMPLEMENTING EDUCATIONAL PROGRAMS IN ASM

- **Development of Tailored Curricula:**
  - Create specific educational programs that address the particular needs of the ASM sector, including modules on sustainable practices, workplace safety, and business management.
- **Collaboration with Local and International Organisations:**
  - Work with NGOs, educational institutions, and international organisations to develop and implement effective and accessible training programs for artisanal and small-scale miners.
- **Use of Information and Communication Technologies (ICT):**
  - Implement e-learning platforms and other digital tools to reach remote mining communities and offer continuous and accessible training.
- **Community Participation:**
  - Involve local communities in the design and implementation of educational programs, ensuring that they are culturally relevant and acceptable.

## CONCLUSION

Education is a fundamental component for the sustainable development of artisanal and small-scale mining. By providing miners with the necessary knowledge and skills, significant progress can be made towards achieving the Sustainable Development Goals. Well-designed and executed educational strategies will not only improve environmental sustainability and workplace safety but also empower miners to enhance their economic conditions and livelihoods, contributing to a more equitable and sustainable development.

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# Computational simulation of fluid dynamics of thermal conditions at ramp down during the mucking process with diesel load haul dump equipment

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## ABSTRACT

The operation of Load Haul Dump (LHD) vehicles in underground mines generates heat, affecting temperature and humidity levels. Effective ventilation is crucial for maintaining regulated temperatures. This study employs Computational Fluid Dynamics (CFD) to analyse how LHD activities in the ramp down area of an underground gold mine impact temperature and humidity. Validation of the auxiliary ventilation system's numerical model references previous studies by Gani (2017), while heat source conditions are based on Yulianti (2020). Three analysis models were developed: Model 1 for initial validation with criteria for air velocity in the air duct is 19.05 m/s (with diameter of 0,9 m air duct), relative humidity inlet 79.1 per cent and intake air temperature 30.5°C; Model 2 simulating heat sources from a 102 kW LHD, two 37 kW exhaust fans, and two workers; and Model 3, similar to Model 2 but considering the influence of a cooling system with adjusted intake air temperature. Model 1 error compared to actual conditions is relatively small (0.01 per cent to 2.38 per cent), allowing for further simulation. Model 2 shows the increase of dry bulb temperature by about 1°C, so the final effective temperature was 29.0°C above the standard, while Model 3 addresses this by achieving a final effective temperature of 25.9°C within recommended standards for both temperature and humidity. In addition, this optimisation can increase work efficiency by 10 per cent so that in terms of mine scheduling, 10 per cent of time can be prevented from being lost every day in the process of making ramp down tunnels.

## INTRODUCTION

Ventilation systems have an important role in supporting underground mining operations. The safety and comfort of the work environment are the main requirements for increasing work productivity in the mine (McPherson, 1993). The hope is that the ventilation system can control heat hazards in underground mines so that workers can work safely and comfortably (Hartman, Mutmansky and Wang, 1982). Common problems in underground mines are the focus of attention in various countries. In England, mineral extraction is currently carried out at depths of more than 1000 m, with rock temperatures reaching 41.9°C (Lowndes *et al,* 2004). In South Africa, at a depth of 3300 m, temperatures in the mine can reach 50°C. Meanwhile, in the Fengyu Zinc-Pb mine in Japan, at a depth of 500 m, the temperature in the underground mine can reach 80°C. Several mines in China show working temperatures in the underground mine exceeding 30°C (Xiaojie *et al,* 2011).

In Indonesia, challenges arise for underground mining when extracting minerals using underground mining methods at increasingly deeper depths, especially in Indonesia's tropical climate which has humidity above 85 per cent. Ventilation standards in underground mines are strictly regulated by Directorate General Decree No 185.K/37.04/DJB/2019 (Ministry of Energy and Mineral Resources, 2019). This rule stipulates that the air temperature in the mine must be maintained in a comfortable condition for working, namely between 18–27°C with a maximum relative humidity of 85 per cent. Therefore, a ventilation system is required to achieve the established standard ventilation conditions (Chang *et al,* 2020; Duan *et al,* 2021; Nie *et al,* 2022; Wang *et al,* 2019; Xu *et al,* 2018; Zhang *et al,* 2023).

This research will focus on one of the activities of the underground mining cycle, namely mucking activities. The process of mucking with a Load Haul Dump (LHD) in an underground mine is one activity that produces heat which changes the temperature-humidity in the working area. A proper ventilation system is needed to achieve effective temperature and humidity values in the range of regulated values. If the recommended work climate conditions cannot be achieved, this can affect work efficiency. The highest work efficiency is created at an effective temperature of 19°C which shows a work efficiency of 100 per cent, then at an effective temperature of 27°C shows a work efficiency of 90 per cent. Significant changes occur when the effective temperature exceeds 27°C, at an effective temperature of 30°C it can cause a decrease in work efficiency to 80 per cent (Wyndham, 1961; Carrier, 1950).

This research uses computational numerical method simulation based on fluid dynamics called Computational Fluid Dynamics (CFD) using ANSYS Fluent software to analyse the effect of LHD activity that works in the ramp down area of cut-and-fill underground gold mine. The numerical model of the auxiliary ventilation system was validated based on Gani (2017) and the condition of heat sources was referred to Yulianti (2020). The analysis model made were as follows: Model 1 for initial validation with criteria for air velocity in the air duct is 19.05 m/s (with a cross-sectional diameter of 0.9 m air duct), relative humidity inlet 79.1 per cent and intake air temperature 30.5°C; Model 2 that simulate a heat source from a 102 kW LHD engine and operator, two 37 kW exhaust fans, and a foreman; and Model 3 that similar to Model 2, however the intake air temperature has been changed to 20°C that simulated influence of cooling system installed. The research that has been carried out regarding thermal conditions at ramp down is expected to complement the analysis that has been carried out previously on the influence on work efficiency by considering its influence on mine planning and mining economics.

## METHODOLOGY

### Heat sources

There are nine potential heat sources in underground mines. The first four are the most influential, namely auto compression, geothermal gradient, underground water, and engines. The rest is metabolism, oxidation, blasting, rock movement, and pipelines (Hartman, Mutmansky and Wang, 1997). This research focuses on heat sources in the form of machines and the metabolism of workers.

#### *Engine*

In underground mines, there are tools that are run by both electric and diesel engines. The diesel engine in this research is a 102 kW LHD. The heat value of a diesel engine can be obtained from the engine efficiency which can be seen in Table 1.

**TABLE 1**

Heat loss of diesel engines (Navaro, 2011).

| Tool type | Power (kW) | Efficiency (%) | Heat loss (kW) |
|---|---|---|---|
| Wheel Loader | 66 | 34 | 44 |
| LHD | 102 | 34 | 67 |
| Light Vehicle | 51 | 34 | 34 |

As for the electrical machine in the form of two forcing fans of 37 kW each which functioned to push out dirty air through the air pipe, when operating it will produce heat loss as in Table 2.

**TABLE 2**

Heat loss of an electric motor (Engineering ToolBox, 2005).

| Power (kW) | Efficiency (%) | Heat loss (kW) |
|---|---|---|
| 0–2 | 75 | 250 |
| 3–15 | 85 | 150 |
| 15–150 | 90 | 100 |

### *Worker*

The heat from the body is continuously removed through heat transfer processes. The result is a small to moderate increase in the sensible heat and latent heat content of the mine air. The heat loss experienced by the body is described in Table 3.

**TABLE 3**

Heat loss of workers by work level (McPherson, 1993).

| Work level | Heat loss (kW) |
|---|---|
| Light | 268 |
| Medium | 448 |
| Heavy | 662 |

## Computational fluid dynamics (CFD)

Computational fluid dynamics (CFD) is the science in which the calculation of solutions to the basic equations of fluid mechanics is achieved using computers (Aref and Balachandar, 2017). The CFD calculations are based on the Navier-Stokes equations that are solved numerically. These Navier-Stokes equations mathematically show the relationship between the conservation of momentum, mass, and energy in fluids.

$$\frac{\partial \rho}{\partial t} + \nabla(\rho \mathbf{U}) = 0 \tag{1}$$

$$\frac{\partial u}{\partial t}(\rho \mathbf{U}) + \nabla \cdot (\rho \mathbf{U}\mathbf{U}) = -\nabla \mathrm{P} + \nabla \cdot [(\mu_f + \mu_{t,f})(\nabla \mathbf{U} + (\nabla \mathbf{U})^T] + \rho \mathbf{g} \tag{2}$$

$$\frac{\partial}{\partial_t}(\rho C_p \mathrm{T}) + \nabla \cdot (\rho C_p \mathbf{U}\mathrm{T}) = \nabla \cdot (k \nabla T) \tag{3}$$

Equations 1 to 3 are the equations of mass conservation, momentum conservation, and energy conservation, respectively, where ρ is air density (kg/$m^3$), U is air velocity vector ($m^3$/s), P is pressure (Pa), μ is dynamic viscosity (Ns/$m^2$), g is gravity (m/$s^2$), Cp is specific heat (J/(kg·K)), k is heat conductivity (W/(m·K)), T is temperature, the letters f for air and t for turbulent (Currie, 1993).

## Effective temperature

Proposed by ASHRAE in laboratory studies in 1923, effective temperature is defined as the temperature of a calm saturated atmosphere, which in the absence of radiation would produce the same effect as the atmosphere in question. It shows the combined effects of relative humidity, air velocity, air temperature, and clothing (ASHRAE, 1993). In determining the effective temperature value, a nomogram for people in working clothes is used (Koenigsberger *et al,* 1974).

## Standard for working face thermal conditions

Regulations regarding mine ventilation are generally regulated in the Decree Directorate General of Mineral and Coal No. 185.K/37.04/DJB/2019. In this regulation, the quantity control of mine ventilation is the volume of clean air that must be flowed in the ventilation system shown in Table 4.

**TABLE 4**
Air requirements.

| Unit | Air requirements | |
|---|---|---|
| Diesel engine | 3 | $m^3$/min/HP |
| Worker | 2 | $m^3$/min/worker |

In the Decree of the Minister of Energy and Mineral Resources No. 1827 K/30/MEM/2018 which states that to overcome air leakage and safety considerations, the air demand to the underground mining area is added by 15 per cent. In the Decree Directorate General of Mineral and Coal No. 185.K/37.04/DJB/2019 also regulates the standard thermal conditions of a mining worksite from the mine ventilation system as shown in Table 5.

**TABLE 5**
Thermal condition standards.

| Parameter | Threshold value |
|---|---|
| Effective temperature | 18–27°C |
| Relative humidity | 85% |
| Minimum Velocity | 0.12 m/s |

# MODELLING SET-UP

## Research location and field measurement data

Data was collected at an underground gold mine using the cut-and-fill method in the manufacture of Ramp Down at elevation 510. This location has an overlap system and is supported by two fans with a power of 37 kW. The research location has high temperature and relative humidity. At this location, there are two small branches, the first is in the north as a muck bay and the second is at point C which is the raise location.

In Figure 1, point A is the blasting location. Location C is an overhanging raise and many of the blasted rocks are still buried there. Gas detectors were installed at two points, namely: (1) point B and (2) after point C with the results in Table 6.

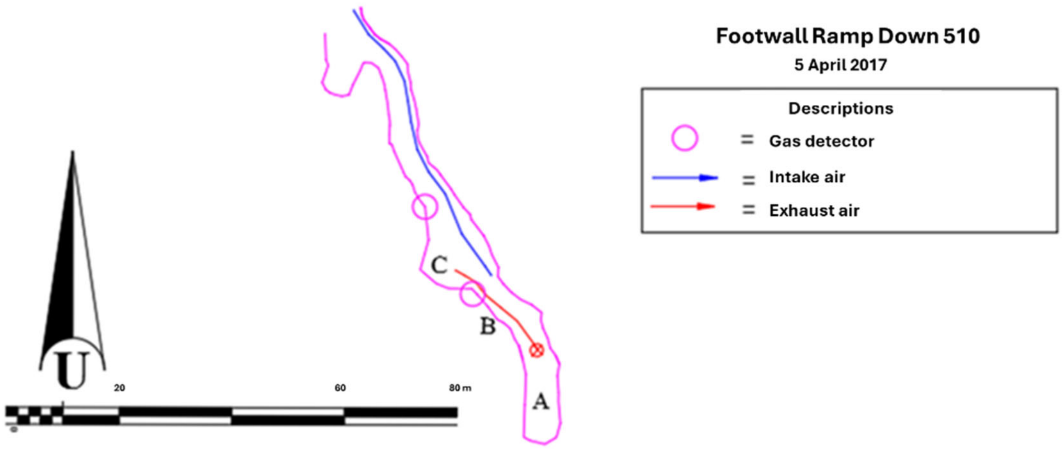



**FIG 1** – Research layout of Footwall Ramp Down (Modified from Gani, 2017).

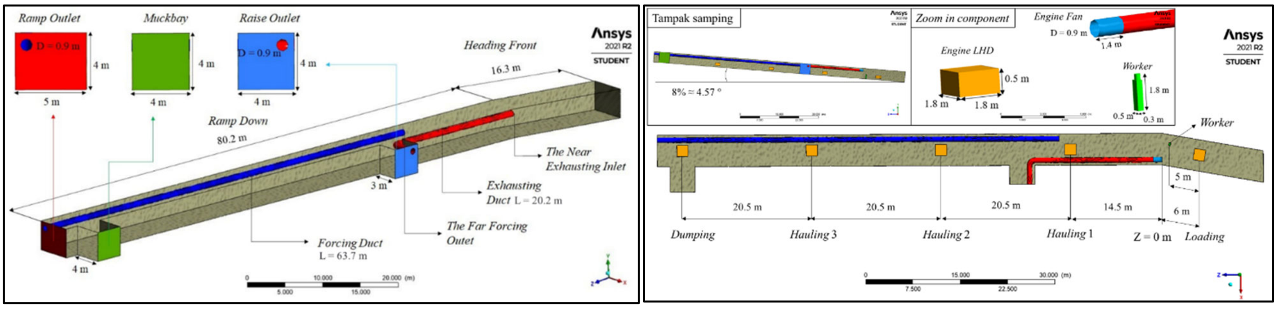
**TABLE 6**
Field measurement data in research location.

| Date | Location | v (m/s) | A ($m^2$) | Q ($m^3$/s) | Td (°C) | Tw (°C) | RH (%) | Notes |
|---|---|---|---|---|---|---|---|---|

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 3-Apr-17 | A | 1.56 | 15.99 | 25.05 | 30.5 | 27.4 | 79.1 | Overlap ventilation |
| | B | 0.49 | 15.99 | 7.95 | 30.5 | 27.4 | 79.1 | |
| 5-Apr-17 | A | 1.57 | 15.99 | 25.22 | 31.8 | 27.7 | 74.3 | Overlap Ventilation |
| | B | 0.38 | 15.99 | 6.21 | 31.8 | 27.7 | 74.3 | |

## Numerical modelling condition

Numerical modelling begins with the creation of the geometry of the research site model in the form of a ramp down. The geometry created for Model 1 as validation while for Models 2 and 3 is shown in Figure 2 which shows the presence of heat sources in the form of workers and LHD machines.




(a) (b)

**FIG 2** – Geometry model for numeric simulation: (a) Model 1; (b) Model 2 and 3.

The difference in parameters for the three models is in the inlet dry bulb temperature and relative humidity, for Models 1 and 2 with inputs of 30.5°C and 79.1 per cent while Model 3 with inputs of 20°C and 79.1 per cent.

## Air requirements

The air requirements needed at the research location with the presence of workers, equipment, and fans, the following air requirements are obtained (Table 7).

**TABLE 7**

Air requirements for local ventilation.

| Parameter | Unit | Air requirement/unit | | Total HP | Air requirements | |
|---|---|---|---|---|---|---|
| *LHD* 102 kW | 1 | 3 | m$^3$/min/*HP* | 136 | 408 | m$^3$/min |
| *Fan Exhaust* 37 kW | 2 | 3 | m$^3$/min/*HP* | 99 | 297 | m$^3$/min |
| Worker | 2 | 2 | m$^3$/min/orang | | 4 | m$^3$/min |
| Total Air Requirement | | | | | 709 | m$^3$/min |
| Total Final Air Requirement (115% of total requirement) | | | | | 815.35 | m$^3$/min |
| | | | | | 13.59 | m$^3$/s |
| Duct cross-sectional area 0.71 m$^2$ and air density at 510 m elevation 1.17 kg/m$^3$ | | | | | | |
| Inlet air velocity at the air duct | | | | | 19.05 | m/s |

## Heat source data input

The values for each heat source contained in each model condition created based on its type are shown in Table 8.

**TABLE 8**

Heat source input for numerical modelling.

| Heat source | Description | Value |
|---|---|---|
| Wall temperature | Back analysis using ANYS Fluent R2 2021 | 31°C |
| *LHD* | A 102 kW Diesel LHD with 34% efficiency | 67 320 W |
| *Fan Exhaust* | Two electric fans of 37 kW each with 90% efficiency | 7400 W |
| Operator *LHD* | Medium level activity | 448 W |
| *Foreman* | Light level activity | 268W |

## Cycle time LHD

In this study, an LHD is operating in the process of loading and transporting material from the working front to the muck bay with 82 m. The type of LHD used has a bucket capacity of 3 m, and a bucket fill factor of 0.85 for well-blasted rock material. The tunnel progress per shift is 1.8 m, with a tunnel width and height of 4 m and 5 m, and a swell factor of 1.6 for well-exploded rock material so that the volume of material to be moved is 57.6 LCM. The volume of material to be moved is divided by the LHD bucket capacity which has been multiplied by the bucket fill factor, the total LHD cycle is 23 times (Table 9).

**TABLE 9**

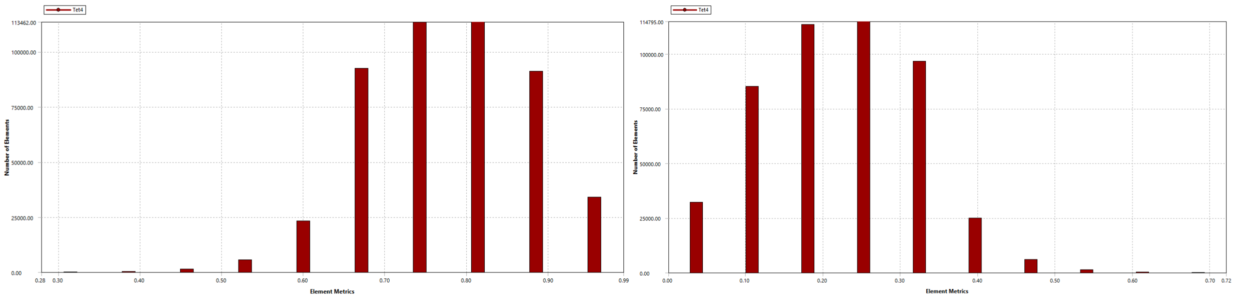
LHD cycle time in ramp down.

| Activity | Duration (s) |
|---|---|
| Loading time/cycle | 13 |
| Hauling time to muck bay/cycle | 42 |
| Dumping time/cycle | 7 |
| Hauling time to front/cycle | 30 |
| Parking time/cycle | 60 |
| **Total time/cycle** | **152** |
| Warm up time | 180 |
| Coordinating time | 480 |
| **Total time for 23 cycles** | **4200** |

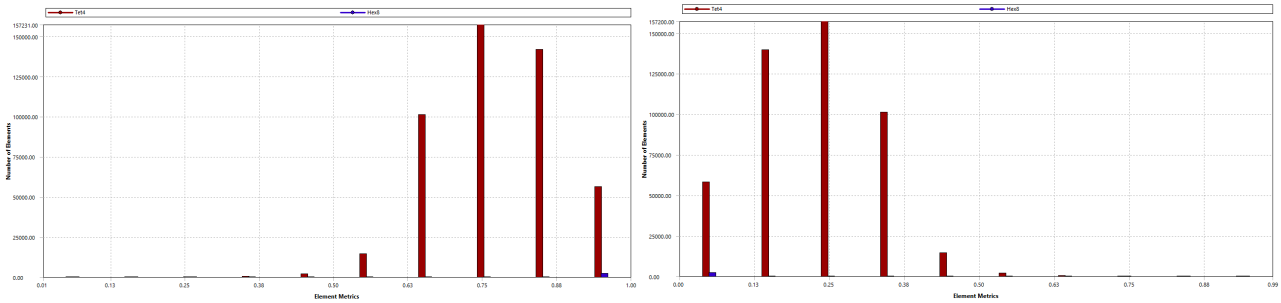
# RESULT AND ANALYSIS

## Validation of the initial model (Model 1)

The results of the skewness mesh value based on Figure 3 are on average below 0.5, namely 0.23. This value tends to be close to the value of 0 so that the quality of the mesh is already in the range of good to excellent. The orthogonal quality value is also based on Figure 3, the average value is above 0.5, namely 0.78. This value tends to approach the value of 1 so that the mesh quality can be categorised into the range of good to excellent (ANSYS, 2013).



(a)



(b)

**FIG 3** – Metric Graph Results of Orthogonal Quality (left) and Skewness (right)*:* (a) Model 1; (b) Model 2 and Model 3*.*

The results of numerical modelling of Model 1 are compared with the results of field measurements on the ramp down at points A and B with the position of the points as in Figure 1 both can be compared to obtain the accuracy of the numerical modelling that has been made by looking at the error value of each parameter under review. The results of the comparison of the two values can be seen in Table 10.

**TABLE 10**

Validation model 1 compared to field data measurement.

| Validation result | Velocity (m/s) | | Relative humidity (%) | | Dry bulb temperature (°C) | |
|---|---|---|---|---|---|---|
| | A | B | A | B | A | B |
| Field data | 1.56 | 0.49 | 79.10 | 79.10 | 30.50 | 30.50 |
| Numerical data | 1.56 | 0.49 | 80.85 | 80.98 | 30.75 | 30.83 |
| % Error | 0.01% | 0.10% | 2.21% | 2.38% | 0.82% | 1.11% |

The error rate of the numerical simulation results of Model 1 against the field measurement data is very small, in the range of 0.01 per cent to 2.38 per cent. Therefore. Model 1 can be validated as a basic framework model for further modelling.

## The influence of the heat source on the thermal conditions of the ramp down (Models 2 and 3)

Based on the numerical simulation results, the average values for the velocity, relative humidity, and dry bulb temperature conditions are obtained as follows (Table 11).

**TABLE 11**

Numerical Simulation Results of Models 2 and 3 against Initial Conditions (Model 1).

| Model | Velocity (m/s) | Relative humidity (%) | Dry bulb temperature (°C) |
|---|---|---|---|
| 1 | 0.42 | 80.97 | 30.85 |
| 2 | 0.43 | 78.39 | 30.86 |
| 3 | 0.54 | 79.71 | 27.71 |

Model 2 when compared to Model 1 even though it has the same initial conditions but has a difference in the results of the average value of the three reference parameters in the tunnel, namely air temperature increased by 0.005°C, relative humidity decreased by 2.584 per cent, and air velocity increased by 0.004 m/s. The difference occurs due to the presence of a new heat source in Model 2, namely 237 kW exhaust fans that turn on at time 0 sec. The change in temperature value is not too significant because the additional heat source only has a heat loss of 7.4 kW and small dimensions of 1.4 m and 0.9 m in diameter. The change in relative humidity is quite large because there are other differences in the form of the LHD geometry in five predetermined positions and the geometry of workers who have a relative humidity value of 0 per cent on the walls of each geometry.

Then, Model 3 which is a recommendation model has significantly different results from Model 1. Changes in each parameter are temperature down by 3.14°C, relative humidity down by 1.26 per cent, and air velocity up by 0.12 m/s. The change in value occurs due to the main factor is the change in incoming air temperature from 30.5°C to 20°C so that the change in temperature value changes down significantly. The average temperature of Model 3 is smaller than Model 2 so it slightly increases the relative humidity value due to the relationship between the temperature value which is inversely proportional to the relative humidity.

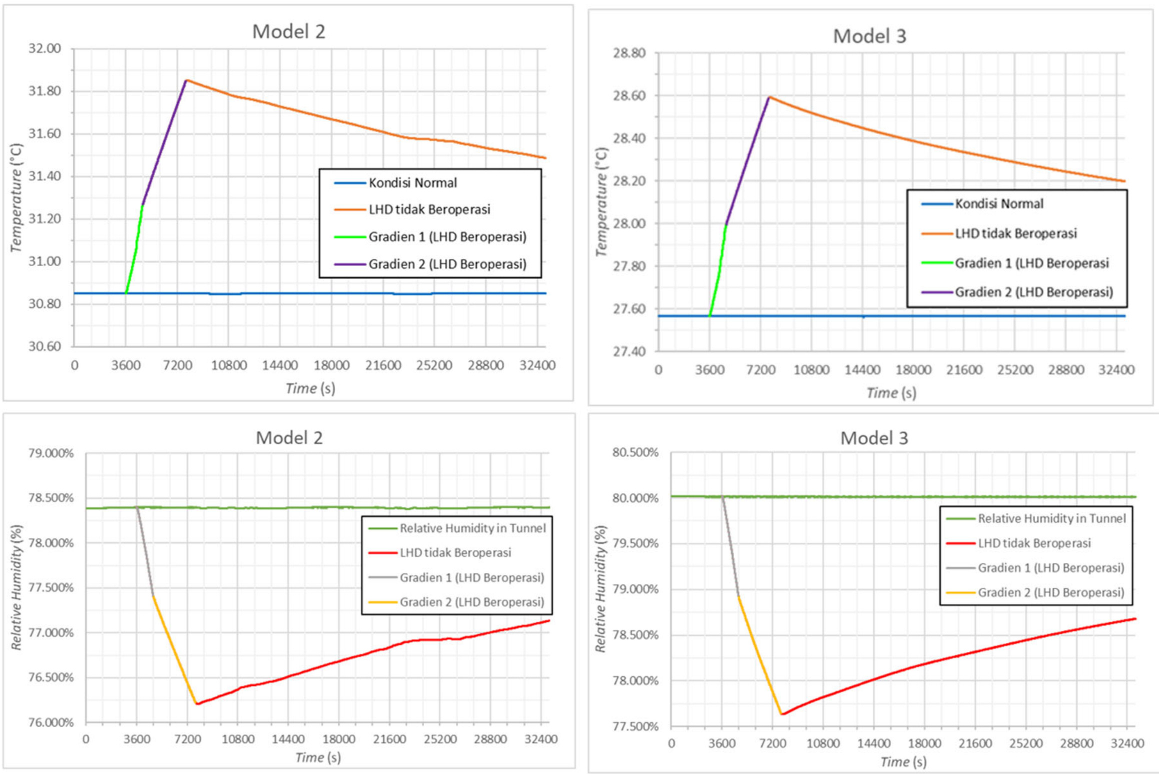



**FIG 4** – Graph of dry bulb temperature and average air relative humidity at ramp down.

When the LHD operates at the heading front. Gradient 1 has a value of more than 1.0°C/h (steeper) due to the influence of other heat sources. Meanwhile, Gradient 2 has a value of less than 1.0°C/h (steeper) when the engine operates in multiple positions because the heat is spread more evenly and is not always concentrated in the loading position which is the position of the initial interacting air intake with the air in the ramp down. In addition, Gradient 3 is a decrease in temperature to less than 0.1°C/hr because there is heat remaining in each LHD engine geometry at a predetermined position and cannot automatically dissipate on the surface of the LHD engine geometry.

**TABLE 12**

Gradient of air temperature and air relative humidity over time.

| Model | Dry bulb temperature (°C/hr) | | | Relative humidity (%/hr) | | |
|---|---|---|---|---|---|---|
| | Gradient 1 | Gradient 2 | Gradient 3 | Gradient 1 | Gradient 2 | Gradient 3 |
| 2 | 1.26 | 0.70 | -0.05 | -3.00 | -1.17 | 0.11 |
| 3 | 1.29 | 0.71 | -0.05 | -3.31 | -1.52 | 0.13 |

## Analysis of compliance with thermal condition standards for Models 2 and 3

Based on the results of the parameter simulation, the parameter values needed to determine the effective temperature values in Model 2 and Model 3 are obtained. There are three effective temperature values for each model, namely the normal temperature condition (N) value obtained from the average value throughout the observation time when the LHD engine is not operating, the peak condition (P) obtained at time 7800 sec, and the residual condition value (R) obtained at time 33 000 sec. Then, the dry-bulb temperature value is obtained from the temperature value obtained from the simulation while the wet-bulb temperature value is obtained from the plot on the psychometric graph. The following are the values for each parameter.

From the values in Table 13, both models fulfil the rules regarding the maximum relative humidity which must be less than 85 per cent and the minimum air velocity of 7 m/min (0.12 m/s). To validate the effective temperature values of the two models, the values in Table 13 were plotted on the effective temperature nomogram. The following are the results of the plot on the nomogram.

**TABLE 13**

Numerical simulation results of each temperature condition in Model 2 and Model 3.

| Parameter | Model 2 | | | Model 3 | | |
|---|---|---|---|---|---|---|
| | Normal | Peak | Residual | Normal | Peak | Residual |
| Air velocity (m/s) | 0.42 | 0.42 | 0.45 | 0.54 | 0.54 | 0.53 |
| Relative humidity (%) | 78.39 | 76.21 | 77.13 | 80.02 | 77.63 | 78.68 |
| *Dry-bulb temperature* (°C) | 30.85 | 31.85 | 31.49 | 27.57 | 28.59 | 28.20 |
| *Wet-bulb temperature* (°C) | 27.91 | 28.36 | 28.17 | 24.89 | 25.51 | 25.29 |

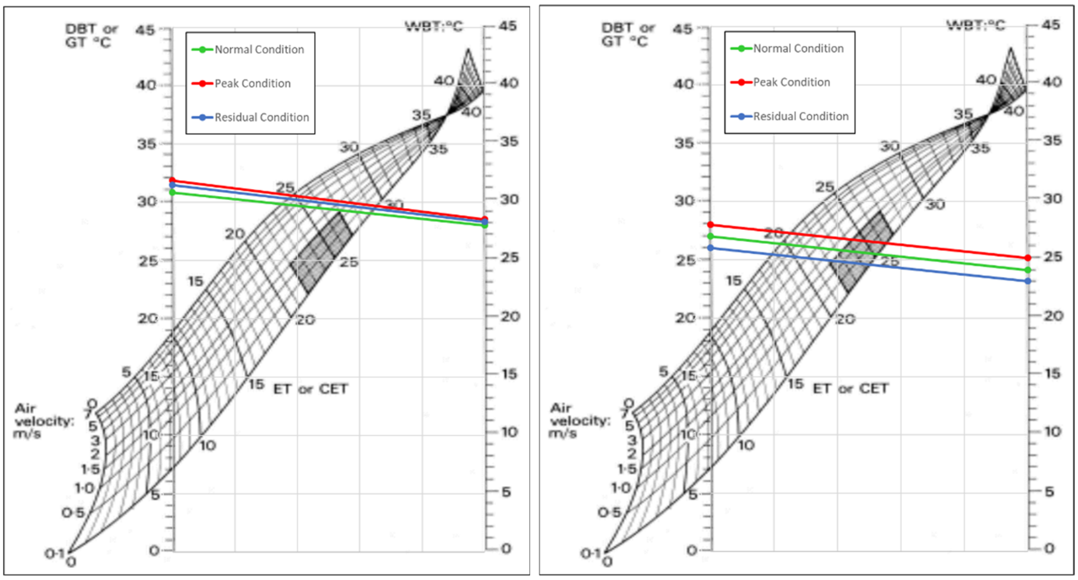



**FIG 5** – Effective temperature nomograms of Model 2 (left) and Model 3 (right).

From the plot results on the nomogram, the effective temperature value for normal temperature conditions is the smallest because there is no LHD engine operating, then residual temperature conditions due to the process after the LHD engine operates, and finally peak temperature conditions because the LHD engine operates to produce the highest heat. The following is the effective temperature value for Model 2 and Model 3 in each of these conditions (Table 14).

**TABLE 14**

Effective temperature of Model 2 and Model 3.

| Model | Effective temperature (°C) | | |
|---|---|---|---|
| | **T Normal** | **T Peak** | **T Residual** |
| 2 (Existing condition) | 28.2 | 29.0 | 28.8 |
| 3 (Proposed condition) | 25.1 | 25.9 | 25.7 |

Model 2 has an effective temperature value for each working condition of more than 27°C while Model 3 has an effective temperature value for each working condition of less than 27°C and more than 18°C. Thus, Model 3 is the recommended model to create thermal conditions that meet the eligibility standards in the regulations on ventilation systems in Indonesia.

## Analysing the effect of thermal conditions on underground mining activities in ramp downs

According to Wyndham (1961) and Carrier (1950), there is an effect of effective temperature conditions on work efficiency. The highest work efficiency is created at an effective temperature of 19°C which shows a work efficiency of 100 per cent, then at an effective temperature of 27°C shows a work efficiency of 90 per cent. A significant change occurs when the effective temperature exceeds 27°C, at an effective temperature of 30°C it can cause a decrease in working efficiency of up to 80 per cent. Determination of the level of work efficiency based on effective temperature can use the graph in Figure 6.

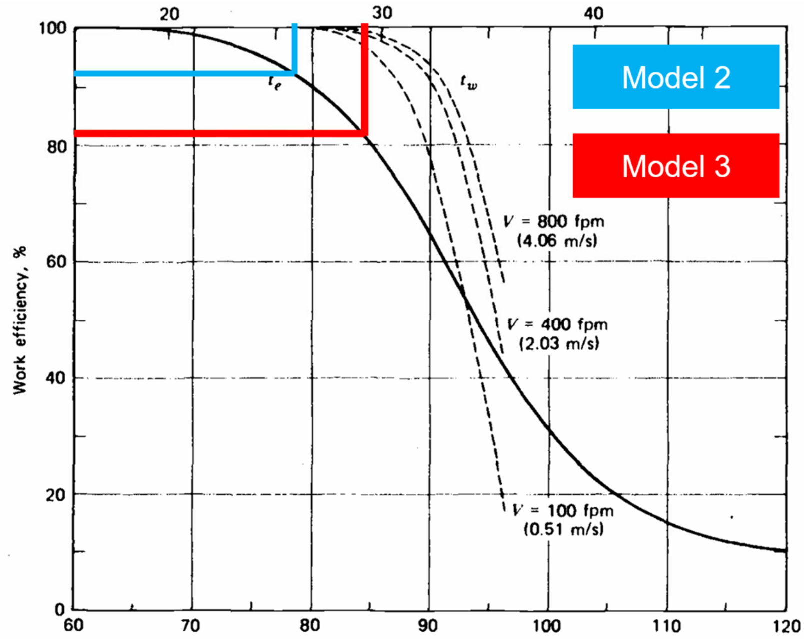



**FIG 6** – Effect of wet-bulb and effective temperatures on work efficiency. Results for /„ at three air velocities are based on acclimatised mine workers. Results for /, are based on industrial workers (after Wyndham, 1961; Carrier, 1950).

Based on the results of the plot of effective temperature at peak conditions in the graph in Figure 6. It is obtained that the given optimisation model can increase work efficiency by 10 per cent, from 82 per cent (Model 3) to 92 per cent (Model 2). This change will have a domino effect on mine scheduling. With the proposed local ventilation model for development ramp down activities, it can prevent 10 per cent of production time that will be wasted every day.

## CONCLUSIONS

Based on the results of the numerical modelling that has been carried out, the numerical model is validated with field measurements with a maximum error rate of 2.38 per cent. Modelling related to the effect of LHD operations on ramp down shows that the existing design causes the effective temperature in the work area to be 29°C which certainly does not meet the standards. Then, an optimisation model was proposed using a cooling system to change the inlet dry air temperature from 30.5°C to 20°C. This model gives an effective temperature when the hottest condition is 25.9°C which means it meets the required threshold value. In addition, this optimisation can increase work efficiency by 10 per cent so that in terms of mine scheduling, 10 per cent of the time can be prevented from being lost every day in the process of making ramp down tunnels.

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