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International Mineral Asset Valuation Conference 2025

Navigating Mineral Asset Valuations in an Uncertain Future

Proceedings Book

1-3 October 2025

The Maslow Hotel, Sandton

THE SOUTHERN AFRICAN INSTITUTE OF MINING AND METALLURGY
JOHANNESBURG 2025

International Mineral Asset Valuation Conference 2025

Navigating Mineral Asset Valuations in an Uncertain Future

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FOREWORD

Navigating Mineral Asset Valuations in an Uncertain Future

I am delighted that you have all taken the time to attend this conference. We have brought together international experts, practitioners, academics and decision-makers from both the mining and finance sectors to discuss and debate mineral asset valuation approaches in the context of our increasingly uncertain and rapidly changing world.

Our familiar free market system may well be dying as a result of this period of global transformation, but the mineral resources sector continues to offers enormous opportunity, albeit in the face of huge challenges. We are experiencing separate camps and the emergence of multiple pricing markets because of:

- ongoing technological progress;
- political agendas behind changing economic forces;
- ideological stances instead of transactional engagements; and
- different perceptions around the “rules of the game” with respect to efficiency, safety, environmental stewardship, and social responsibility.

I’ve heard countless times that “value lies in the eye of the beholder”, and we need to accept that mineral asset valuations cannot only be derived through the eyes of the West. Our values are not universal and so our perceptions around the risk / reward trade-off are unlikely to be the same.

Uncertainty results when these “rules of the game’ are unclear. We should all listen with an open ear if we are to test our prevailing mindsets and inform ourselves so that we can level the playing fields “so to speak”.

This may then enable us to deliver more meaningful mineral asset valuations in a truly international context. Global alignment will not happened if we simply forge ahead in isolation. We need open dialogue and a shared commitment to worldwide collaboration.

This conference is designed to do exactly that and I welcome you all and look forward to an engaging couple of days. I trust that we will question the Status Quo and consider new ideas that may contribute to improved alignment across our internationally turbulent waters.

A workshop has been arranged for the day prior to the official commencement of the conference to explore the role of IMVAL. It will be hosted in the morning by Keith Spence, the Chairperson of IMVAL, and then in the afternoon by Tania Marshall of SAMVAL.

Finally, I wish to sincerely thank the organising committee, our keynote speakers, presenters, reviewers, sponsors and everyone else involved in making this conference a success. Thank you for being part of these discussions.

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Contents

Page No

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IMVAL template: A critical analysis of the first 10 years of existence, adoption, success, challenges and its future

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For over a century, most companies in the minerals industry have operated across multiple geographical, regulatory or legislative jurisdictions. This trend has been further intensified by the globalisation of the world economies in recent decades. Such cross-jurisdictional engagement necessitates that information on Mineral Assets or properties be reported in a standardised manner to ensure a consistent understanding regardless of the jurisdiction. The Committee for Mineral Reserves International Reporting Standards (CRIRSCO) established a template to provide a minimum standard for adoption in national/regional reporting codes and standards for the public reporting of Exploration Targets, Exploration Results, Mineral Resources or Mineral Reserves. Once Mineral Resources and Mineral Reserves are reported according to the national reporting codes, which in turn conform to the minimum requirements of the CRIRSCO Template to define the Mineral Asset, it provides a basis for the development of an International Mineral Property Valuation Standards Template (IMVAL Template) for harmonising national valuation codes. The valuation template is a principles-based template which is recognised as a common set of minimum requirements for national codes or standards concerning the valuation of Mineral Assets and ensures common understanding, interpretation and valuation of Mineral Assets or properties (IMVAL, 2021). It can be noted that there are some unintended consequences arising from the CRIRSCO code impacting the IMVAL-aligned code. Understanding an extractive entity's minerals or oil and gas resources and reserves is crucial, as these are typically its single most valuable asset and primary source of future cash flows during extractive activities (IASB, 2010; Njowa and Musingwini, 2018). This paper will explore the brief history on the development of the CRIRSCO Template, critical events in the global mineral industry and how it led to the creation of the IMVAL Template in 2012, after the Brisbane Valuation Conference. The objective of this paper is to examine the regulatory guidelines, sharing insights on why these global templates are important for the mineral industry, its investors and stakeholders. It will also summarise the progression from the first edition to the latest edition (Fourth Edition) (IMVAL, 2021). The paper further critically assesses the level of adoption of this Template by the major mining countries around the world, as a measure of its success, challenges and its prospects for the future. Lastly, the paper will propose potential key focus areas that the IMVAL committee could consider as part of the journey in improving global acceptance of the IMVAL Template.

Keywords: CRIRSCO Template, Mineral Property Valuation Codes, Global Harmonisation, IMVAL Template

INTRODUCTION

Most companies within the minerals industry have operated across multiple geographical jurisdictions for more than a century, a trend which has been further accelerated by recent decades of globalisation. The mining companies comply with the appropriate regulatory and corporate framework, depending on the applicable listing requirements. The expansion of global trade and financial services has increased the exposure of these companies to diverse geological terrains, resulting in mining operations, shareholdings, or consultancy engagements spanning multiple countries. This evolution has necessitated the standardisation of public reporting and the promotion of industry best practices in the reporting of Mineral Assets to ensure a consistent understanding regardless of location, regulatory or legislative differences. The adoption of globalised reporting standards (or codes) promotes uniformity in the interpretation, understanding and communication of information on Mineral Assets throughout the minerals industry.

This cross-jurisdictional exposure underscores the need for the public reporting of information on Mineral Assets to be comparable and consistent across different jurisdictions. Additionally, comparable and consistent reporting has in part been catalysed by the increasing globalisation of investors and access to capital that are further supported by an overriding securities or stock exchange principle of protecting the investors (Njowa *et al.*, 2014). Consequently, reporting practices should be standardised to create common understanding regardless of the applicable jurisdiction. Accordingly, a global committee known as the Committee for Mineral Reserves International Reporting Standards (CRIRSCO) was formed at Sun City in South Africa in 1994 during the 15th Council of Mining and Metallurgical Institutes (CMMI) congress. CRIRSCO's main purpose was to align national minerals reporting codes to create common understanding by harmonising the definitions, classification and the requirements of public reporting of Exploration Results, Mineral Resources and Mineral Reserves. This led to CRIRSCO initially publishing a mineral reporting template in 2006 to improve the alignment of national mineral reporting codes. CRIRSCO later updated the template in May 2013, followed by the most current version of the template recently published in 2019, which is also synonymously referred to as the International Reporting Template or (IRT) (Sides and Allington, 2024; CRIRSCO, 2019; 2024). The CRIRSCO IRT improves alignment of the national reporting codes.

As illustrated in Figure 1, it has taken approximately 30 years (1994 - 2024) to harmonise the reporting of Exploration Results, Mineral Resources and Mineral Reserves through the CRIRSCO Template which has evolved to the current IRT. The evolution process continues so that it becomes easier to compare and evaluate projects across different countries across the world.

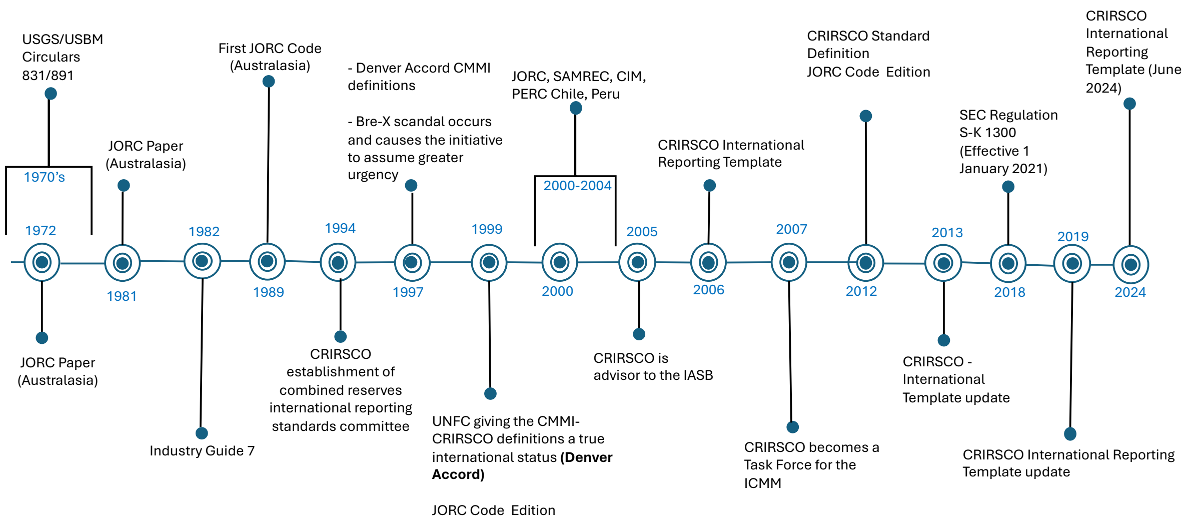

Figure 1. CRIRSCO Template timeline.

The CRIRSCO Template has managed to achieve international recognition through some key collaborations and agreements that include:-

- The Denver Accord was a significant preliminary agreement in 1999 among mining organisations to align their definitions of mineral resources and reserves, which served as a foundation for the CRIRSCO Template;
- CRIRSCO's collaboration with the International Accounting Standards Board (IASB) strengthened the international status of its reporting template and encouraged adoption of financial reporting for extractive industries;
- The CRIRSCO Template is regularly updated, with the latest version released in 2024 above it says 2019, ensuring it remains aligned with industry best practices;
- An agreement between CRIRSCO and the United Nations Economic Commission for Europe (UNECE) in 1999 led to the integration of CRIRSCO's resource and reserve definitions into the United Nations Framework Classification (UNFC), thus advancing global recognition of the CRIRSCO Template; and
- The IASB's preference to utilise existing mineral reporting systems like the CRIRSCO Template and the Petroleum Resources Management System (PRMS) for commodity-specific financial reporting demonstrates the widespread acceptance of CRIRSCO's framework and cemented the international status of the CRIRSCO Template.

The purpose of national mineral reporting codes is to provide a set of minimum standards, recommendations, and guidelines for public reporting of exploration results and mineral deposits and thus to prevent the dissemination of misleading, inaccurate, or fraudulent information on mineral properties to investors through stock exchanges. The development of these codes was initially prompted by the Poseidon Nickel Bubble in Western Australia in 1970 (Camisani-Calzolari, 2004; Rupprecht, 2017; Sides and Allington, 2024), which led to the creation of the JORC Code in 1989. Subsequently, the Busang or Bre-X Scandal in Indonesia in 1997 (Camisani-Calzolari, 2004; Rupprecht, 2017; Sides and Allington, 2024), accelerated the introduction and publication of additional codes. In both cases, reports regarding the grade and tonnage of the respective deposits lacked substantiation and were not founded on scientific principles, resulting in fraudulent disclosures. These frauds artificially increased share prices until the facts were revealed, causing a sharp decline in the values of the shares. This raised the importance of validating Exploration Results, Mineral Resources and Mineral Reserves.

Why harmonise Mineral Asset Valuation codes?

Before the creation of the IMVAL Template, there was no single, internationally recognised template that provided global guidelines for the valuation of petroleum resources or mineral properties or assets. Mineral reporting scandals such as the Poseidon Nickel Bubble of 1970 and Bre-X scandal of 1997 revealed a lack of accountability, obvious incompetence and misleading reports on Mineral Resources and Mineral Reserves reported on international financial markets. Leading mineral-rich countries and their respective stock exchanges together with relevant professional associations developed new reporting standards and codes to guide the public reporting of Exploration Results, Mineral Resources and Mineral Reserves that align with the global CRIRSCO Template. This development provided a suitable basis for the creation of a global harmonised template to provide guidance and minimum requirements for the valuation of petroleum and/or mineral property (IMVAL Template).

The IMVAL Template which is now in its fourth edition (April 2021) is intended to complement the national reporting codes and standards and create a foundation which the accounting fraternity can rely upon to develop a future global accounting standard for the financial reporting of Mineral Assets. Harmonisation will assist the mineral industry in the following issues: -

- **Resolving valuation disputes**: A global template should enable Mineral Asset values to be declared alongside other assets on corporate balance sheets, thus promoting consistency;
- **Valuation methodology**: Current codes allow valuators to choose their valuation approach, which can lead to inconsistencies. It is hoped that the international template will assist in reducing such variations;

- **Investor confidence and capital access**: Reliable, transparent reporting is crucial since events like the Global Financial Crisis and COVID-19 have made fundraising challenging for the extractive industry;
- **Industry feedback**: The Hong Kong Exchange highlighted problems caused by the lack of a unified international Mineral Asset Valuation (MAV) template; and
- Global need for standards: Ellis (2009) estimated that approximately 150 countries require local guidance for MAV reporting.

History Leading to the Creation of the IMVAL Committee
Companies working in the minerals industry sector operate in one of the most internationalised sectors of the global economy. Typically mining companies tend to be listed on stock exchanges in two or more countries and would arrange multinational financing for their mining projects. To conduct such complex international business efficiently, uniform global valuation standards and definitions based on internationally recognised classifications for Mineral Resources and Mineral Reserves are necessary.

This international environment is the reason for the adoption of these comprehensive standards by the USA-based Society for Mining, Metallurgy, and Exploration, Inc. (SME), specifically designed for appraisal of the value of the unique assets of the minerals industry sector, while employing globally accepted valuation principles. It is also the reason for the SME Valuation Standards Committee's continuing participation in the ongoing IMVAL harmonisation project.

The standardisation of minerals reporting codes is a foundation from which subsequent MAV is undertaken. The valuations draw guidance from national MAV reporting codes. Figure 2 illustrates the geographical mapping of existing MAV reporting codes as of 2025.

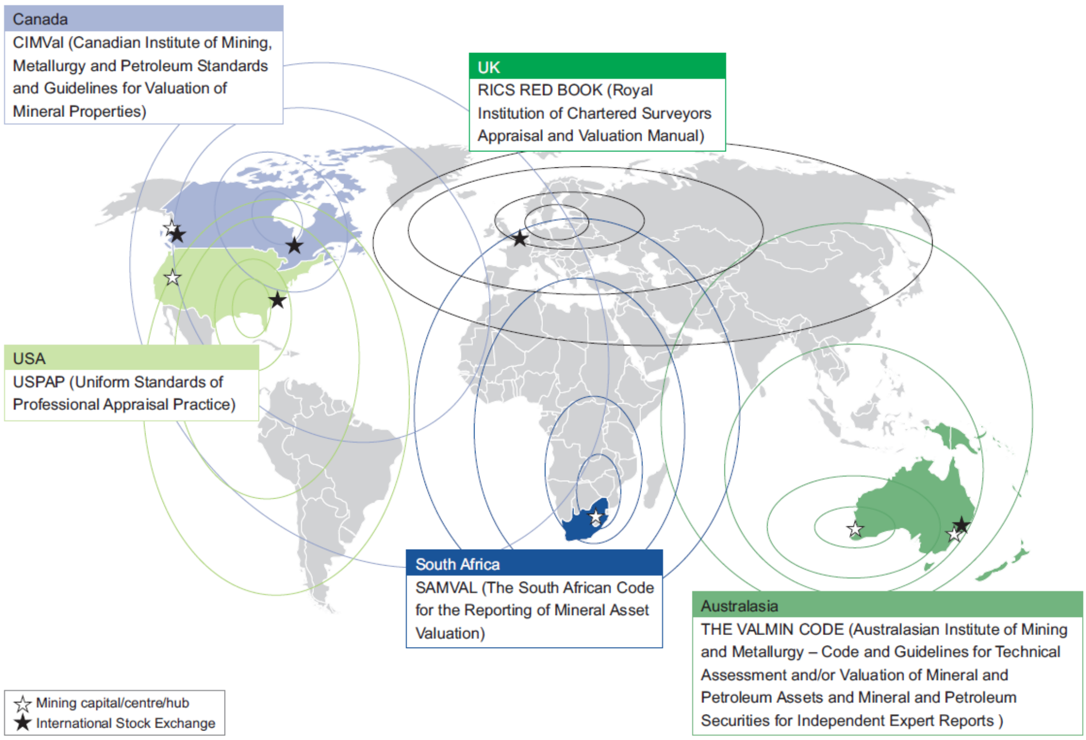

Figure 2. Global mapping of national Mineral Asset Valuation Reporting Codes as of 2025 (Source: Venmyn Deloitte, n.d.)

The MAV reporting codes share high-level commonality on some principles, valuation approaches, competence and application. However, despite various national Mineral Asset valuation codes sharing adequate commonality, differences tend to arise in the areas of definitions, some principles and scope, hence the need for monitoring and updating to foster alignment. Consequently, IMVAL was formed in 2012 in Brisbane in Australia. IMVAL's main purpose was to develop a globally acceptable MAV template to harmonise the MAV reporting codes and the template is called the IMVAL Template. Since the template provides standards for MAVs, it is not prescriptive, therefore there is flexibility for the template to evolve over time to include aspects not initially addressed on inception of the template. IMVAL was formed to fulfil a perceived need for an international template or standard for mineral property valuation which could be adopted by national mineral valuation organisations and used by other interested parties. The first and second editions of the IMVAL Template were released in 2016, the third edition in June 2018 and the fourth edition in 2021. The Terms of Reference for the IMVAL Committee were developed in 2017. The IMVAL Template is therefore the initial harmonisation outcome of MAV standards development. Figure 3 chronicles the high-level roadmap of events leading to the establishment of the IMVAL Template.

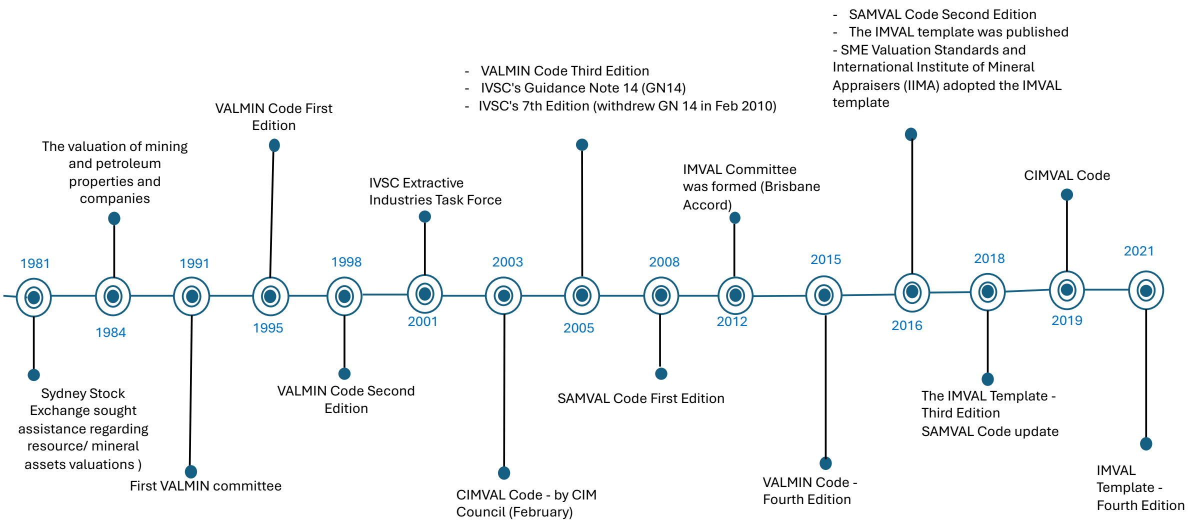

Figure 3. IMVAL Template timeline.

Some key milestones from Figure 3 are that (IIMA, 2015):

1. In February 1995, the Australasian Institute of Mining and Metallurgy (AusIMM) published the VALMIN Code to provide guidance for the technical assessment and valuation of mineral and petroleum assets and securities. As Table 1 indicates, several subsequent revisions have been made to the code with the fourth version of the code as the current version as of 2025;
2. Early in 2001, the International Valuation Standards Committee (IVSC) convened an Extractive Industries Task Force comprising international mining and petroleum industry valuation experts to explore gaps in MAV and financial reporting;
3. In March 2003, the Canadian Institute of Mining, Metallurgy and Petroleum (CIM) adopted the CIMVal Standards and Guidelines for the valuation of mineral properties;
4. In January 2005, the IVSC published in the IVSs Seventh Edition – an 18-page standard called *Guidance Note 14 (GN 14)*, for the Valuation of Properties in the Extractive Industries. The IVSC republished GN14 in 2007 in the IVSs Eighth Edition;
5. The Southern African Institute of Mining and Metallurgy (SAIMM) convened a working group to develop a code to provide guidance for the reporting of Mineral Asset valuations leading to the publication of the first SAMVAL Code in April 2008. Later, an amendment to the SAMVAL Code was issued in July 2009; and
6. In February 2010, the IVSC Standards Board withdrew GN 14 pending the outcome of the Extractive Industries Project. As of 2025, the outcome is still pending.

7. As part of the VALMIN update process, the IMVAL Committee was established with the objective of developing a CRIRSCO-equivalent framework for Mineral Asset valuation. The Committee was established after the VALMIN Seminars Series. These seminars were held in Australia in October 2011 in Perth and in April 2012 in Brisbane (Rozman, 2019). The VALMIN Seminar Series facilitated valuable feedback and consultation on proposed amendments. Throughout 2013, these inputs were incorporated into redrafts and underwent peer review. During the seminar series, discussions in Brisbane in April 2012 led to the initiation of a harmonisation project for existing MAV codes, including the Australasian Code for Public Reporting of Technical Assessments and Valuations of Mineral Assets (The VALMIN Code), the South African Code for the Reporting of Mineral Asset Valuation (The SAMVAL Code), the Canadian Institute of Mining, Metallurgy and Petroleum (CIM) Code for the Valuation of Mineral Properties (CIMVAL), the Uniform Standards of Professional Appraisal Practice (USPAP), the International Valuation Standards (IVSs), and, where applicable, the International Financial Reporting Standards (IFRSs).
8. The VALMIN key stakeholders were consulted in 2014, and a draft received feedback from the Australasian Institute of Mining and Metallurgy (AusIMM), the Australian Institute of Geoscientists (AIG), Minerals Council of Australia (MCA), Australian Securities Exchange Ltd (ASX), and the Australian Securities and Investments Commission (ASIC). The resulting Exposure Draft was released for public comment in April 2015, with public input reviewed and incorporated as appropriate. A final review involving ASX and ASIC took place in late 2015, and the new edition of the VALMIN Code (2015) was approved by AIG and AusIMM in December 2015.
9. The SME published its first edition of the SME Valuation Standards in January 2016. The USA-based International Institute of Mineral Appraisers (IIMA) adopted the Second Edition of the Template in 2015 and subsequently formally adopted the Third Edition.
10. The SME, VALMIN, CIMVAL and SAMVAL codes have since been updated since the creation of the IMVAL Template; this creates the first step for a truely international template in due course. Using the experience from the development of the CRIRSCO Template, it has taken more than 30 years to be recognised globally as the international template.

Table 1 summarises the five MAV codes that are aligned to the IMVAL Template. It shows the years when the original valuation codes were introduced, years when updates where done, and years of latest versions as of 2025. The compliance requirements of each code are also indicated to provide a sense of the effect of each code, because the codes may either have legislative or regulatory authority or merely serve as guideline documents. To provide a sense of bulkiness (hence ease of referencing and application) the lengths of each code are also provided. The websites are included to assist with ease of accessing the codes. The MAV codes reflect alignment with the IMVAL Template but have additional adjustments to accommodate specific national and/or regional requirements. However, all the codes share common principles, requirements, guidelines, and definitions as outlined in the IMVAL Template, to ensure consistency among the different jurisdictions represented on the IMVAL Committee. However, there are other Mineral Asset valuation reporting codes that are not within the framework of the IMVAL Template, hence are not within the purview of this paper. It is important to note that the VALMIN Code is recognised by ASIC but not fully recognised by the ASX.

Table 1. Summary attributes of MAV codes aligned to the IMVAL Template

Country or Region	Language	Status	Code Name	Year of First Version	No. of Updates	Year of Current Version	Compliance Requirement	Applicable Security Exchange or Alternative Recognition	Length (Pages)	Home website
Australia	English	Code	Australasian Code for Public Reporting of technical assessments and valuations of Mineral Assets (VALMIN Code)	1995	4 (1995; 1998; 2001; 2015)	2015	Regulatory	Australian Securities Exchange (ASX); Australian Securities and Investments Commission (ASIC); New Zealand Stock Exchange (NZX)	42	https://www.valmin.org/docs/VALMIN_Code_2015_final.pdf
Canada	English, French	Code	Code for the Valuation of Mineral Properties (CIMVAL Code)	2003	2 (2003; 2019)	2019	Legislative	The Toronto Stock Exchange (TSX) and TSX Venture Exchange (TSX-V) recognise the NI 43-101.	44	https://www.cim.org/ OR https://mrmr.cim.org/
Poland	Polish	Code	The Polish code for the valuation of Mineral Assets (POLVAL Code)	2008	2 (2008; 2021)	2021	Legislative	Unclear	58	https://www.polval.org.pl/wp-content/uploads/2022/06/KODEKS-POLVAL-2021-angielski.pdf
South Africa	English	Code	South African Mineral Asset Valuation Code (SAMVAL Code)	2009	2 (2009; 2016)	2016	Regulatory	Johannesburg Stock Exchange (JSE)	34	https://www.samcode.co.za/
USA	English	Standard	Uniform Standards of Professional Appraisal Practice (USPAP)	1987	26 (1987; 1990; 1992-1999; 2000-2021; 2024)	2024	No direct regulatory or legislative effect on its own but indirectly through . incorporation into regulations and laws	Not specified	62	https://appraisalfoundation.org/pages/uspap
USA	English	Code	SME Standards and Guidelines for Valuation of Mineral Properties (including Petroleum)	2015	2 (2015; 2017)	2017	Guidance	SME Members	21	https://smenet.blob.core.windows.net/smecms/sme/media/smeazurestorage/professional%20development/pdf%20files/sme_valuation_standards_2017.pdf
IMVAL	English	Standard	International Mineral Property Valuation Standards Template (IMVAL Template)	2015	4 (2015; 2018; 2021)	2021	Guidance	Guidance to the National Reporting Codes	17	https://www.valmin.org/docs/imval-template-fourth-edition-final-april-14-2021-a4.pdf

Note: NI 43-101 refers to National Instrument 43-101

The IMVAL Template serves as a globally recognised framework for harmonising mineral property valuation. It provides a common set of minimum requirements for national codes and standards, ensuring consistency and comparability in valuation practices across different jurisdictions. Key aspects of the IMVAL Template and its usage are:-

- It standardises mineral property valuation by harmonising national codes and promoting consistent reporting and valuation practices;
- It is principles-based, focusing on core principles rather than prescribing specific methodologies, allowing flexibility for different contexts;
- It lays out minimum requirements for valuation, including competence, valuation approaches, reporting, and definitions;
- It guides the content and structure of valuation reports to ensure transparency and

completeness;

- National and regional bodies can adopt or adapt the template, encouraging global collaboration and best practices; and
- The template is designed to evolve, incorporate new developments and address emerging issues in mineral property valuation.

SOME CONSIDERATIONS ON THE ADOPTION OF THE IMVAL TEMPLATE SINCE ITS INCEPTION

The IMVAL Committee is an international advisory body without legal authority, relying on its constituent members to ensure regulatory and disciplinary oversight at a national level. It recognises the truly global nature of the minerals industry and the agreed need for international consensus on reporting standards. The IMVAL Template is intended for use by mineral valuators, mining companies, investors, regulators, and other stakeholders involved in mineral property valuation. The ultimate objective for the IMVAL Template in the coming decades should be for any MAV to be mapped against the IMVAL Template in a similar way to any standard developed by national reporting organisations and in particular the Internationally Recognised Reporting Standard (IRRS).

CRIRSCO is also recognised by global organisations such as the IASB, the UNECE and the International Council on Mining and Metals (ICMM). The ICMM is the key international organisation representing the mining industry on issues relating to the classification and reporting of Exploration Results, Mineral Resources and Mineral Reserves. The relationships that have been created by CRIRSCO over the last 30 years have led to the global recognition of the CRIRSCO Template and its applicability for different purposes in the mineral industry, for financial reporting and for public reporting through the stock exchanges as illustrated in Figure 4.

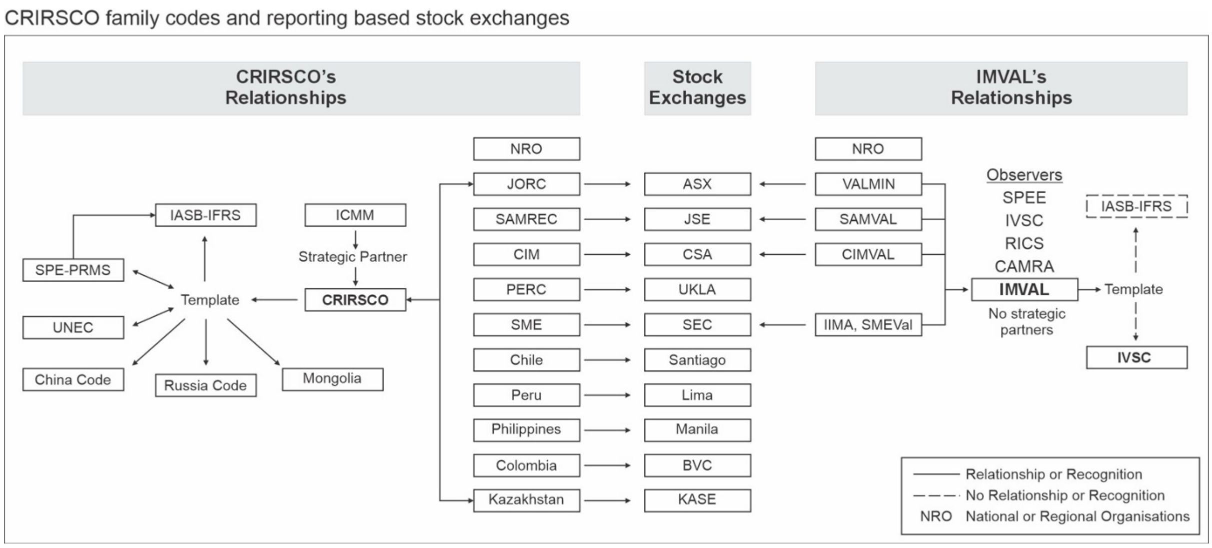

Figure 4. CRIRSCO and IMVAL family codes with their associated stock exchanges and other key international organisations in the minerals industry.

Figure 4 shows that the IMVAL Committee still has a lot of work to do if the IMVAL Template is going to achieve the same international status as the CRIRSCO Template, while noting that the IMVAL Template history so far spans just over 10 years. Section 2.5 of the IMVAL Template specifies that Mineral Resource and Mineral Reserve definitions in CRIRSCO should be used as the basis in the valuation of mineral properties, hence an opportunity exists to tap into existing CRIRSCO networks. In this way the link between the CRIRSCO Template and IMVAL Template can be strengthened.

Global Mineral Property Valuation Codes or organisations that fall under the umbrella organisation of IMVAL Committee include:-

- VALMIN Code 2015;
- CIMVAL Code 2019;
- SAMVAL Code 2016;
- SME Valuation Standards 2016;
- POVAL Code 2015;
- Mining & Metallurgical Society of America (MMSA); and
- International Institute of Minerals Appraisers (IIMA).

The following guidelines and standards have not fully recognised or adopted the IMVAL Template:-

- International Financial Reporting Standards (IFRS);
- Generally Accepted Accounting Practice (GAAP);
- International Valuation Standards (IVS);
- National Association of Certified Valuators and Analysts (NACVA) Standards; and
- Royal Institute of Chartered Surveyors (RICS) RED BOOK.

Given the short time that the IMVAL Template has been in existence, the accounting fraternity has not recognised nor adopted the guidance provided by the template. The IASB and IVSC do not formally 'recognise' the IMVAL Template in the same way as specific IFRS standards, Accounting Standards or CRIRSCO family of codes. As a result, requirements, valuation processes, and methodologies for valuing mineral properties can vary across jurisdictions. This situation contributes to the IMVAL Template not being widely adopted within MAV and financial reporting frameworks at the international level.

Prior to the development of the IMVAL Template, there was no common template or standard for mineral property valuation. Instead, three national codes or standards existed, these being the CIMVAL (Canada), SAMVAL (South Africa), and VALMIN (Australasia) codes. Although these codes have many similarities, they also have differences in structure, definitions, scope, and jurisdictional requirements. For example, the SAMVAL Code is fully incorporated into Section 12 of the JSE Listings Rules, while VALMIN is not fully recognised by the ASX. However, according to ASX Guidance Note 31- Reporting on Mining Activities, the ASX listing Rule 5.16.6 requires that the technical assessment report should be prepared in accordance with the VALMIN Code (ASX, 2013). In addition, minerals while in the ground are specified as a part of Real Estate in the International Valuation Standards (IVSs). The IVSs and the USA's USPAP also contain valuation standards of general application without being specific to mineral property valuation.

The IMVAL Committee which developed the IMVAL Template is an international committee comprising representatives from SAMVAL (South Africa), CIMVAL (Canada), VALMIN (Australasia), the SME Valuation Standards Committee (USA), and IIMA (USA). Representatives of the RICS from the United Kingdom (UK), were also involved in the early deliberations of the IMVAL Committee, with additional observer organisations from the UK, USA, and China (Gustavson, 2021).

The IMVAL Template is intended as a principles-based template that recognises three common principles of materiality, competency and transparency (Figure 5). These three fundamental principles were the basis on which the CRIRSCO framework was built on; hence were adopted as the fundamental principles for the valuation of the Mineral Assets. The three common principles were adopted from their respective national companion codes which are the CIM Definition Standards (including the associated NI 43 – 101), SME Guide, JORC and SAMREC codes. These principles are expected to ensure that MAV is undertaken objectively, reasonably and independently. It is to be recognised as a common set of minimum requirements for national codes or standards concerning the valuation of Real and Mineral Properties. The template represents a consensus of current good mineral property valuation practices and is expected to be updated from time to time. The template is not intended to be a standalone reporting code and does not supersede existing MAV codes.

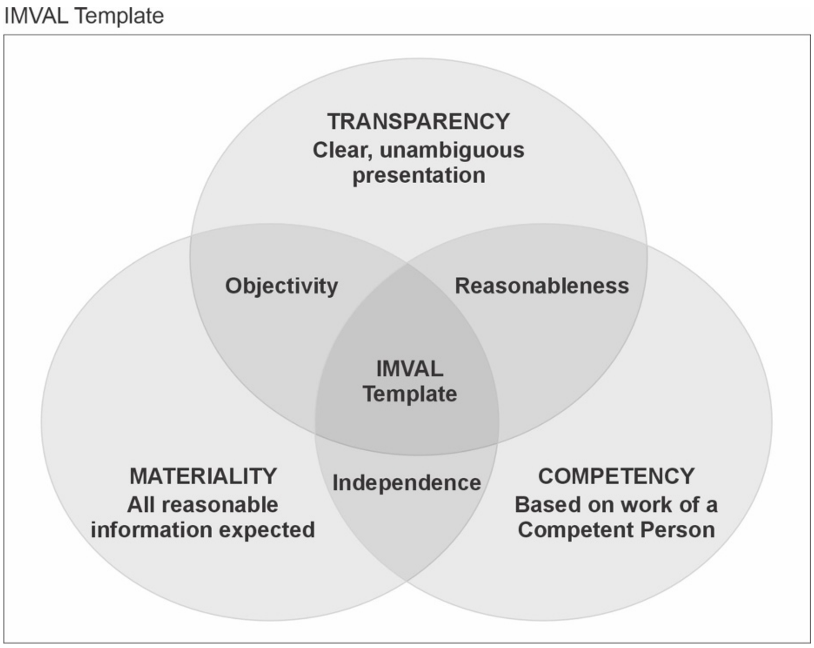

Figure 5. IMVAL core principles.

In addition to the three common fundamental principles, the CIMVAL Code and the POLVAL Code added two more principles namely, independence and reasonableness, SME Valuation Standards added the two principles of independence and objectivity, whereas the VALMIN Code only included independence while the SAMVAL Code added only reasonableness and has referred the additional principles to regulatory bodies such as the JSE (Table 2).

Table 2. Overview of inclusion of principles among the MAV Codes and IMVAL Template (Source: VALMIN, 2015; CIMVAL, 2019; SAMVAL, 2019; SME Val, 2016; IMVAL Template, 2021)

PRINCIPLES	IMVAL Template	VALMIN	CIMVAL	SAMVAL	SME	POLVAL
Materiality	Yes	Yes	Yes	Yes	Yes	Yes
Transparency	Yes	Yes	Yes	Yes	Yes	Yes
Competency	Yes	Yes	Yes	Yes	Yes	Yes
Reasonability	Yes	Yes	Yes	Yes	No	Yes
Independence	Yes	Yes	Yes	No	Yes	Yes
Objectivity	Yes	No	Yes	No	Yes	No
Inc Petroleum	Yes	Yes	No	No	Yes	No

The main focus of these valuation codes is for more transparency, complete and non-misleading disclosure through providing all relevant and material information that investors and their professional advisors would reasonably require and expect to find for the purpose of making a reasoned and balanced judgement regarding the reporting of valuation results. The IMVAL Template was developed as a guideline to support harmonisation of MAV codes while allowing for adjustments to suit local conditions and leading practices. For example, all the national reporting codes that fall under the umbrella of the IMVAL Template had to adopt the three fundamental principles as a minimum and then choose which ones are applicable to their local situation in addition to the three core principles, as outlined in the Table 3.

Table 3. Comparison of principles among the national Mineral Asset valuation codes (Source: VALMIN, 2015; CIMVAL, 2019; SAMVAL, 2019; SME Val, 2016; IMVAL Template, 2021)

SECTION	SUB-SECTION	CIMVAL Code	SAMVAL Code	VALMIN Code	SME Valuation Standards	IMVAL TEMPLATE
Principles	Materiality	*Materiality or Material* refers a Valuation must address all Material information. All Material information must be included or adequately referenced in the Valuation Report. Materiality is the principle that determines whether certain information is relevant to the Valuation.	*Materiality* implies that a Public Report contains all the relevant information that investors and their professional advisors would reasonably require and expect to find, for the purpose of making a reasoned and balanced judgement regarding the Mineral Asset Valuation.	*Material/Materiality* requires that a Public Report contains all the relevant information that investors and their professional advisors would reasonably require, and reasonably expect to find in the report, for the purpose of making a reasoned and balanced judgement regarding the Technical Assessment or Mineral Asset Valuation being reported.	*Materiality* - The determination of what is Material or relevant to the Valuation depends on both qualitative and quantitative factors. A parameter may be Material in the qualitative sense because of its very nature, such as country risk. Valuers should determine that all Material information is considered.	*Materiality* All Material information must be included or adequately referenced in the Valuation Report. Materiality is the principle that determines whether certain information is relevant to the Valuation. Materiality applies to the nature of the items assessed and their influence on the quantum of a Valuation..
	Competence	*Competence or Competent* means having relevant qualifications and relevant experience. A Qualified Valuator must be able to demonstrate to the Commissioning Entity and those entitled to rely on a Valuation Report that the Qualified Valuator is sufficiently Competent to prepare or contribute to the Valuation Report.	*Competence* - A CV is a person who possesses the necessary qualifications, ability, and sufficient relevant experience in valuing minerals assets. A person being called upon to sign as a CV shall be clearly satisfied in their own mind that they are able to pass the scrutiny of their peers and demonstrate competence in the valuation undertaken.	*Competence or Competent* requires that the Public Report is based on work that is the responsibility of a suitably qualified and experienced person who is subject to an enforceable professional Code of Ethics.	*Competence* - The Valuation of Mineral Properties may require Competence in a wide range of disciplines. Depending on the nature of the Mineral Property to be valued, the Basis of Value to be applied, and the availability of currently relevant technical reports for the subject Mineral Property. The 2014 SME Guide requires a minimum of 5 years of experience in subject areas under its coverage.	*Competence* A Valuer must be clearly satisfied that they are able to face their professional peers and demonstrate Competence in the Valuation undertaken. Among other things, Valuers should assess their competence regarding the subject Mineral Property, the market in which the property would trade, and the purpose of the Valuation.
	Transparency	*Transparency and Transparent* means The Valuation process and Valuation Report must be Transparent, such that its Material assumptions and conclusions must be clear and unambiguous and therefore understandable to the reader.	*Transparency* - The reader of a Public Report shall be provided with sufficient and relevant information, the presentation of which is clear and unambiguous, to understand the report and not be misled.	*Transparency or Transparent* requires that the reader of a Public Report is provided with sufficient information, the presentation of which is clear and unambiguous, to understand the report and not be misled by this information or by omission of Material information.	*Transparency* - requires that information should not be presented in a minimal or unclear form, from which the intended user accepting this information at face value could draw incorrect implications or conclusions.	*Transparency* The Valuation process and Valuation Report must be Transparent, such that it must be clear and unambiguous and therefore understandable.
	Independence	*Independence* means that, For certain Valuations, Independence of the Qualified Valuator may be required by law, a national code or standards, or by the circumstances of the Valuation.	Independence is excluded	*Independent or Independence* requires that there is no present or contingent interest in the Mineral Asset(s), nor is there any association with the Commissioning Entity or related parties that is likely to lead to bias. **Independence is not a formal requirement under the VALMIN Code.** However, Practitioners must familiarise themselves and must conform to the relevant statutory and regulatory definitions and requirements of independence in the relevant jurisdictions.	*Independence* - While the **SME Valuation Standards and the IVSs do not specify Independence of the Valuer**, Independence may be specified by national legal or regulatory requirements in various jurisdictions, or by Commissioning Entities or intended users of Valuations.	Independence – for certain valuations, may be required by law, a national code or standards, or by the circumstances of the Valuation. In these cases, Independence means that the Valuer must have no pecuniary or beneficial interest in the Commissioning Entity, the Mineral Property being valued.
	Reasonableness	*Reasonableness* means Any Valuation, assumptions applied, and any method relied upon, should be reasonable within the context of the purpose of the Valuation and the Basis of Value.	*Reasonableness* - means that other appropriately qualified and experienced CVs with access to the same information, as of the same Effective Date, would arrive at a broadly comparable range of value using the same Basis of Value and the same Scope of Work..	*Reasonableness* requires that an assessment that is impartial, rational, realistic and logical in its treatment of the inputs to a Valuation or Technical Assessment has been used, to the extent that another Practitioner with the same information would make a similar Technical Assessment or Valuation..	Reasonableness is excluded	*Reasonableness* - Any Valuation, assumptions applied, and any method relied upon should be reasonable within the context of the purpose of the Valuation and the Basis of Value.
	Objectivity	*Objectivity* - The Qualified Valuator should approach a Valuation with Objectivity. This is promoted by an environment that is supported by data and minimizes the influence of subjective factors, such as the Valuator's personal bias, on the Valuation process.	Objectivity is excluded	Objectivity is excluded	*Objectivity* - The Valuer should approach the Valuation with Objectivity, meaning impartially and without personal bias. While it is necessary to apply the Valuer's professional judgement, the Valuer should be alert to their own bias and mitigate the effect of such bias in preparing a Valuation	*Objectivity*-The Valuer must approach a Valuation with Objectivity. This is promoted by an environment that is supported by data and minimises the influence of subjective factors, such as the Valuer's personal bias, on the Valuation process.

The IMVAL template is envisioned as a set of minimum requirements for national codes, promoting common standards while allowing for jurisdiction-specific adaptations. It aims to foster a shared understanding, thereby reducing the risk of misleading reports and investor uncertainty (Njowa, e*t al.*, 2014). The major goals of the IMVAL Template are:

- The international consensus on terms used in the valuation of mineral properties that include petroleum properties and associated businesses;
- The consistent and high-quality mineral property valuation reports using a principles-based template by setting the common set of minimum requirements for the national codes or standards (IMVAL, 2021);
- The international convergence of the valuation approaches and methodologies via peer review and mapping;
- The international development of the leading and good practice in mineral property valuation; and
- The promotion of best practices in reporting mineral property valuation outputs and clarifies the difference between valuation and evaluation in mineral property.

The Template reflects an international consensus on minimum standards for Public Reporting and is subject to periodic revision. It is not designed to function as a stand-alone reporting standard, nor does it override any existing national reporting frameworks (IMVAL, 2021).

SOME ASPECTS RELATING TO FUTURE VERSIONS OF MAV CODES

Some Valuation Challenges Created by CRIRSCO family of Codes – Inclusive and Exclusive

The IMVAL Template's reliance upon the CRIRSCO family of reporting codes (e.g., JORC, SAMREC, NI 43-101) for inputs into Mineral Property Valuation has created challenges for mineral property valuators. If the CRIRSCO or PRMS systems are not used, the Valuation Report must explain why not and should provide, to the extent possible, a reconciliation of the resources and reserves with CRIRSCO or PRMS (IMVAL, 2021). These Codes are primarily designed to provide guidance on the minimum requirements on the reporting of Exploration Results, Mineral Resources and Mineral Reserves and are not necessarily mindful of the valuation implications that flow from such classifications. Reporting Mineral Reserves as either inclusive or exclusive of Mineral Resources can impact mineral asset valuations, influencing transparency, investor confidence, and comparative analysis because of the different modifying factors involved in converting Mineral Resources into Mineral Reserves. Inclusive reporting may result in higher reported mineral resource figures and reduce clarity for analysts attempting to distinguish economically viable reserves from less certain resources, potentially complicating assessments of a company's prospects. Mineral Reserves and Mineral Resources are typically valued using different methodologies, and adding these categories together may lead to inaccurate asset valuations. Exclusive reporting distinguishes Mineral Reserves from Mineral Resources, requiring separate disclosure and valuation methods. Reporting standards, such as the U.S. Securities and Exchange Commission's (SEC) Regulation S-K 1300, require that Mineral Resources be reported exclusively from Mineral Reserves. This distinction demonstrates the importance of clear definitions in public reporting and indicates that additional guidance may be needed for effective valuation practices beyond the CRIRSCO framework.

Guidance on circumstances requiring ranges to be established for MAVs

Due to uncertainty, the valuation of a Mineral Asset must ideally report a range of values together with the estimated value and its justification thereof. However, the accounting fraternity only requires a single-point value for balance sheet purposes, but a range of values would assist in mitigating impairments, provided the carrying value of the asset is within the range of estimated values. In this regard, MAVs can use calculation tools and comparative studies from a wide range of asset classes, using tools and/or software such as @RISK software which utilises Monte Carlo Simulation, Central Limit Theory and Set Theory to enable quantitative ranges to be established which can be factually defended. To do this however, one needs to establish ranges for each parameter and historically this has been largely a 'judgmental' qualitative process which is no longer good enough. The usefulness of ranges and statistics to develop meaningful ranges for valuation is already a practice in Petroleum Resources Management Systems (PRMS) through the gradual elimination of the 'Deterministic' resource classification method to purely 'Probablistic'. This is a consideration that can be taken on board in future revisions of the IMVAL Template.

Different Standard of Value – Market Value, Fair Market Value and Fair Value
For mineral assets, Market Value and Fair Market Value are generally considered to be the same. The International Valuation Standards Committee (IVSC) defines *Market Value as the estimated price at which a property should trade between a willing buyer and a willing seller in an open market, with both parties acting knowledgeably, prudently, and without compulsion.*(IVS, 2025 p25) The Market Value is the 'Price' set in the market normally established through security exchange comparisons of publicly-listed similar equities. Fair Value is a broader, accounting-based standard predominantly employed for financial reporting purposes, particularly in impairment testing. It differs from market-based valuations as defined by the International Valuation Standards (IVS). According to IFRS 13, Fair Value is defined as "the price that would be received to sell an asset or paid to transfer a liability in an orderly transaction between market participants at the measurement date" (IVS, 2025 p29). Fair Value may also incorporate specific advantages or synergies available only to certain market participants. For example, a mining company might determine a higher Fair Value for a resource due to its proximity to existing infrastructure. The future IMVAL Template may consider harmonising these definitions regarding the standard of value. This approach could facilitate engagement with the accounting profession as committee members and promote recognition of the Template for valuing mineral properties.

Valuation of Oil and Gas, Mineral Corporations or Companies
While the IMVAL Template is principally designed to be a principles-based template to be recognised as a common set of minimum requirements for national codes or standards concerning the valuation for the valuation of Mineral Assets, its template demonstrates sufficient flexibility to potentially accommodate the assessment of entire mineral corporations, companies, their securities, and oil and gas assets in the future. Currently, the SAMVAL Code, CIMVAL Code, and VALMIN Code are more commonly employed for mineral property valuation. The IMVAL Template serves as an essential framework for fostering transparency, consistency, and good practices within the global mineral property valuation sector. Although its primary application is for solid mineral and petroleum asset valuations, the template can be adapted to cover additional areas, such as the valuation of mineral corporations.

Incorporation of environmental, social, and governance considerations in MAVs
Environmental, social, and governance (ESG) factors that have been identified and assessed as part of preparing a CRIRSCO-compliant Public Report need to be appropriately addressed in the supporting project economic (valuation) model. The inputs to the model will typically relate to mitigation measures that address the identified ESG factors. Whilst disclosure of material ESG factors is only required in terms of CRIRSCO, the economic model should include all costs or provisions associated with management of ESG factors in line with the level of accuracy of other inputs to the model and this has implications for MAVs.

Differences in the concept of 'best practice' versus 'leading practice' in MAVs
The CIM advocates the concept of 'leading practice' in relation to industry practice while the rest of the IMVAL members still prefer to refer to 'global industry good practice'. Debate should be held to achieve convergence on the best way to approach this concept. However, the current Template was designed as a minimum standard for public reporting aimed to inform the investors and their professional advisors.

POTENTIAL CHALLENGES ALONG THE ADOPTION JOURNEY OF THE IMVAL TEMPLATE

Non-recognition by IFRS/GAAP/IASB/IVSC for financial reporting
Since the IFRS/GAAP/IASB/IVSC do not explicitly 'recognise' the IMVAL Template for financial reporting purposes, this is challenge that the IMVAL Committee should engage in with the relevant

bodies on how they can integrate the Template in the financial reporting frameworks. This is one of the weaknesses of the current IMVAL Template in which it fails to be recognised as a fully international template in the MAV space. There is no specific IFRS standard dedicated solely to MAVs. Therefore, the general principles of IFRS, including IAS 38, are applied with consideration of the unique characteristics of mineral properties, as outlined in the IMVAL Template. Considerations should therefore be given to securing recognition by the IAS and IVSC and through full membership of the existing MAV codes.

The IVSC considers that a mineral occurring within a real property is the subject of appraisal activity and therefore the general provisions for the valuation of such properties do not take into account the specific nature of Mineral Assets. Given the position by the IVSC, they have concluded that they do not need any specific guidance or standards that specifically focus on the valuation of the mineral properties because they hold the view that real property valuators can undertake MAVs. The IMVAL Committee has an opportunity to lobby or canvass the IVSC on how the IMVAL Template can be adopted to prove that Mineral Asset valuators are more suitable to undertake MAVs.

Non-recognition by other valuation-related regulatory instruments such as in the USA and Australia
In the USA, State or Federal regulations, or valuation user expectations, may require that a Mineral Property Valuation comply with the Appraisal Foundation's Uniform Standards of Professional Appraisal Practice (USPAP), within which the Real Property Appraisal Standards closely align with the SME Valuation Standards. In such situations, the SME Standards will provide mineral property valuation instruction supplemental to USPAP. Federal regulations generally require that such a Valuation Report, for use by a Federally regulated financial institution (such as a Federally regulated bank), have a real estate appraiser, licensed as a Certified General Appraiser by the appropriate State, sign as being responsible for the report. Similar requirements apply to some other Federal and State uses of Valuation Reports (SME Val, 2017). Where such misalignments exist, the IMVAL Committee should consider alignment of the IMVAL Template to grow its acceptance.

The full adoption of the VALMIN Code by the ASX is seen as an issue that still requires to be addressed as part of the on-going efforts to get the IMVAL Template being internationally recognised.

Adoption a comprehensive checklist such as the SAMVAL Table 1 into the IMVAL Template
To be improve clarity and foster consistency in structuring a Valuation Report, the IMVAL Committee should consider adopting a comprehensive checklist such as the SAMVAL Table 1 into the IMVAL Template since the table lists items to be covered in a valuation report, while IMVAL, CIMVAL and VALMIN do not have such a checklist.

Easily searchable IMVAL website
The CRIRSCO website (https://crirsco.com/) is easily searchable online by using the search phrase 'CRIRSCO'. This has probably been part of the reasons for the international visibility of the CRIRSCO Template. However, the IMVAL website (https://www.imval.org/) is difficult to find online even with search phrases such as 'IMVAL' or 'imval.org'. The only direct way to access the IMVAL website is by using the complete website link. This limitation potentially curtails the visibility of the IMVAL Template hence its international proliferation. It is recommended that serious consideration be given by the IMVAL Committee for an easily accessible IMVAL website to improve its international visibility as this will help practitioners solve problems or challenges faced daily when conducting mineral property valuations.

CONCLUSIONS

It has long been recognised that most companies in the minerals industry operate across multiple geographical, regulatory or legislative jurisdictions, thus requiring comparable and consistent cross-jurisdictional reporting of mineral property valuations. The IMVAL Template was developed to cover this purpose. Therefore, this paper outlined a brief history leading to the publication of the IMVAL Template. Reasons for the importance of the IMVAL Template were also discussed. Challenges associated with current versions of MAV Codes were presented to highlight issues that warrant further consideration by the IMVAL Committee and member countries. These challenges highlight gaps in the purpose of what the MAV codes and IMVAL Template were originally developed for vs what they are trying to do now. Some unresolved issues were highlighted as well as the misalignment across the codes, since these may have contributed to the limited degree of the IMVAL Template recognition globally. The paper then proposed potential key focus areas that the IMVAL committee should consider as part of the journey for the IMVAL Template to accelerate its global adoption and effectiveness.

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EY

Godknows has considerable experience in the minerals industry, from mine production, mining research, mine planning and optimisation, management accounting, costing analysis and project feasibility studies of various commodities, including PGMs, Au, Ni and Coal. His mining career started in 2000, at Rio Tinto Zimbabwe's gold mines, where he worked in various capacities. This gave Godknows a solid understanding of mining and the evaluation of mining projects. His key areas of expertise lie in a combination of skills, including technical and financial analysis, mining engineering, financial and management accounting, and corporate governance. Mineral asset valuation, compliance and public reporting of mineral assets for the various stock exchange jurisdictions are his core focus areas. Together with experience in both technical and corporate finance, he has consolidated his expertise in the detailed financial valuation of mineral and mining projects and have completed a PhD in mineral asset valuation and financial reporting..

Valuation of early-stage exploration nickel laterite project in central Sulawesi, Indonesia using the artificial neural network and bat algorithm

V. Veriyadi

PT. GRabuma, Indonesia

This paper presents a methodology for valuing property during the early stages of exploration, with a specific focus on a nickel laterite project in Central Sulawesi, Indonesia. The primary variables used to assess this property are geological uncertainty and exploration costs. Geological uncertainty is quantified based on mineral system probabilities, which adjust the geological factors that can influence the property's value. In contrast, exploration costs represent the inherent value, as determined in accordance with International Financial Reporting Standard (IFRS) 6. The inherent value of the property is converted into potential value, which is essential for determining the net present value (NPV). This calculation considers revenues, initial investment, costs, and a risk-adjusted discount rate (RADR). Revenues are derived from monthly nickel prices and the sale of products. The discount rate comprises the risk-free rate, market risk premium (MRP), project risk, and country risk premium (CRP) of Indonesia. Predictions for nickel prices and market risk premium are based on historical monthly data from May 2003 to December 2024, which are simulated using artificial neural networks (ANN) and the bat algorithm (BA) to optimize the net present value (NPV). The results indicate that both ANN and BA outperform the Monte Carlo simulation in terms of performance.

Keywords: project valuation; early-stage of exploration; artificial neural network; bat algorithm

INTRODUCTION

The valuation of mineral deposits reflects their worth based on the revenue generated from the quantity and quality of the deposits, as well as specific timeframes, market conditions, property levels, and the expertise of the valuator (CIMVAL, 2019). Several valuation methods currently exist for valuing the mineral and mining industry, which have facilitated investigations based on the level of confidence in the mineral resources and reserves (Lilford & Minnit, 2005). However, one of the greatest challenges in the valuation of mineral deposits is the uncertainty present during the early stages of exploration. This phase often reveals insufficient data—such as geological uncertainty and exploration costs—that hinder the accurate valuation of mineral deposits. As a result of these issues, the quality of information available for reporting is often inadequate, leading to a low level of confidence in the valuations.

Previous research has suggested that the valuation of mineral deposits during early-stage exploration should utilize probabilistic conceptual models (Thompson, 2002). These models were introduced by (Mackenzie, 1987) in the mineral industry, having been adapted from the petroleum industry. These models were developed to assess exploration projects based on the probability of resource existence by defining the "expected value" (EV) (Lord, et al., 2001); (Kruezer, et al., 2008). In the most recent research, the probability of existence has been modified to account for exploration risk and geological uncertainty (Faúndez, et al., 2020).

The exploration risk reflects the geological predictions made during a specific stage of the active exploration program. These predictions are calculated using probabilities that assign weights to each variable significantly impacting the exploration results. The outcome of this prediction helps identify the exploration prospects, serving as a guide for the subsequent exploration phase, which can enhance confidence in both the size and continuity of the deposits. The weight assigned to each variable ranges from 0 to 1 and should be adjusted by a qualified exploration team based on the actual conditions at that stage (Faúndez, et al., 2020); (Guj, 2008).

The geological risk is associated with the probability of discovering economic deposits, which includes both geometry and grade. The likelihood of discovering an economic deposit involves five main parameters: the source of metals, channels, the volume of fluids, trapping, and preservation. (McCuaig, et al., 2010). Similar to exploration risk, the value of geological risk probability ranges from 0 to 1 for each parameter that is subjectively determined by the competent exploration team. However, previous studies by (Kruezer, et al., 2008); (Lord, et al., 2001); (Kruezer, et al., 2008); and (Faúndez, et al., 2020), ocused solely on a probabilistic approach to address technical uncertainties, such as geological variability and exploration risks, in order to forecast potential value. While (Faúndez, et al., 2020) developed a model that calculates the expected value by multiplying the probability of exploration risk and geological uncertainty with the potential value, and then subtracting the exploration costs. These processes involved decision tree analysis (DTA) and Monte Carlo simulation (MCS), which were used to predict the expected value. However, like other stochastic models, DTA and MCS did not identify the optimal solution for maximizing the expected value.

The aim of this study was to optimize the value of early-stage exploration. The optimization was conducted using a hybrid model that combines artificial intelligence with metaheuristic techniques. These results can assist junior mining companies in predicting their valuations for early-stage exploration projects.

The remaining paper is structured as Section 2 describes the literature review, Section 3 states methodology, Section 4 discusses empirical results, and Section 5 displays conclusions.

LITERATURE REVIEW

The valuation for early-stage exploration was initiated to assess the weights of exploration risk parameters. Exploration risk encompasses both technical and geopolitical factors. The technical factors pertain to geological understanding and historical data, while the geological factors are categorized into tenement ownership status, environmental and community risks, political risks, and infrastructure considerations. This assessment was carried out by a competent exploration team with extensive knowledge of the characteristics of the deposits (Faúndez, et al., 2020).

Table I: Factors Contributing to Exploration Risks

Theme	Sub-theme
Technical Factors	- Geological understanding of exploration expert
	- Historical Information
Geopolitical Factors	- Tenement Ownership
	- Environment and community issues
	- Political risks
	- Infrastructure

Geological uncertainty was assessed using the probabilistic mineral system model template introduced by Kruezer et al (2008). This template has been modified by Faúndez et al (2020) that added the preservation parameter into account. This parameter was identified by Kreuzer & Etheridge (2010) to ensure that the deposits were protected from earthquakes, erosion, and other natural disasters.

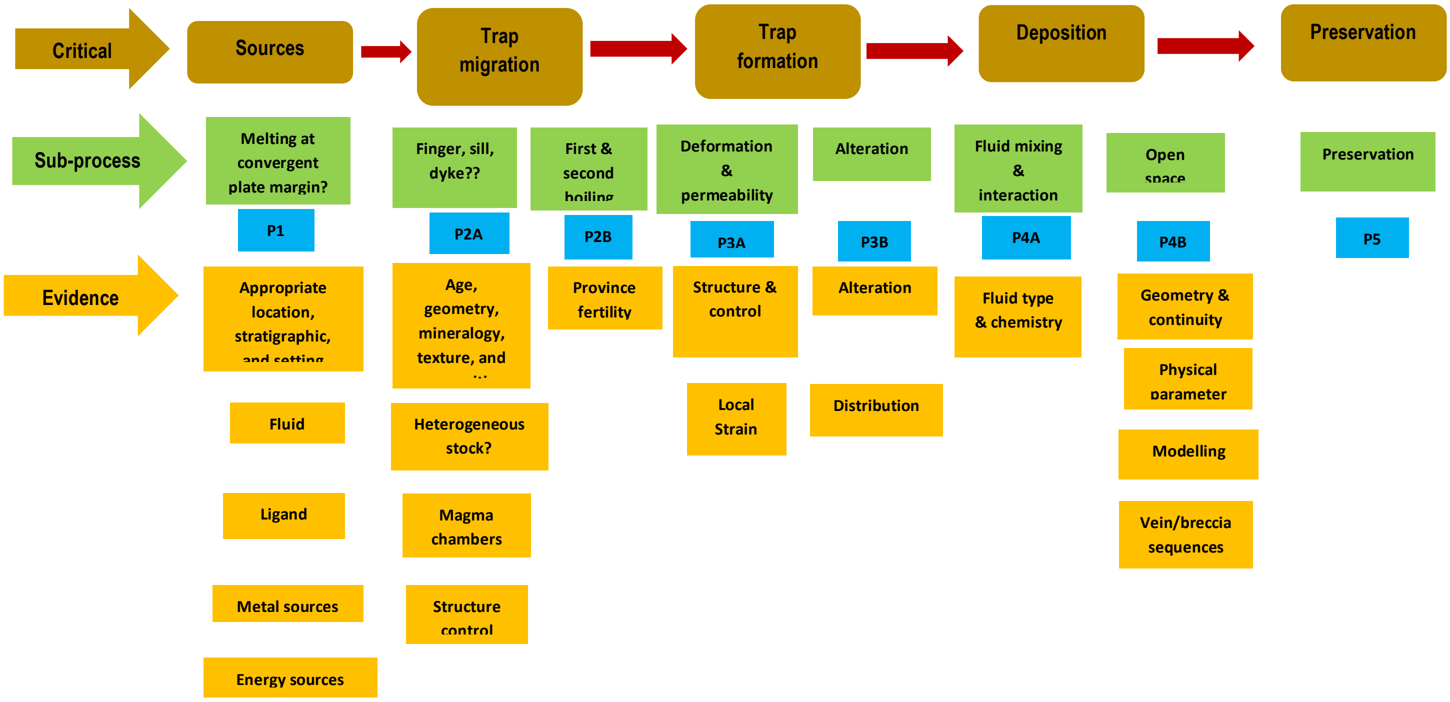

Figure 1. The mineral probabilistic graph template has been adopted from (Kruezer, et al., 2008) (Kreuzer & Etheridge, 2010) (McCuaig, et al., 2010)

The value of property derived from early-stage exploration takes into account exploration risk and geological uncertainty. Consequently, this value is represented as the expected value (EV), as expressed below (Faúndez, et al., 2020):

$$EV = (P_e \cdot P_g \cdot V) - C \quad [1]$$

P_e is exploration risks, P_g is geological uncertainty, V is potential value (using market or income approaches) and C is all exploration costs are accounted for according to IFRS 6. However, one of the greatest challenges in valuing mineral properties during the early stages of exploration is the reliance on inadequate initial data, which can lead to significant errors. Therefore, it is recommended to utilize probabilistic conceptual models to assess the value of mineral properties (Thompson, 2002).

The initial value of the mineral property was derived from exploration costs, which were then projected using a probabilistic conceptual model, specifically the exploration DTA. The method, which uses the expenditures for exploration to value the property, is known as the cost approach (IMVAL, 2018). These processes projected the likelihood of possible NPV (Kruezer, et al., 2008). The exploration DTA is a graph that shows the potential value using the probability of future exploration costs based on the move up and move down factors. The Exploration DTA is a graph that illustrates the potential value by utilizing the probability of future exploration costs, based on the upward and downward movement factors. The Exploration DTA graph was created by integrating nodes and branches. Each node represents the possible NPV at a specific point in time. The higher node branches (P_{0u}) indicate the upward movement factor from the original NPV (P_0) at time zero, while the lower node branches (P_{0d})

represent the downward movement factor. The move-up factor (u) and move-down factor (d) for future exploration costs were computed using the equation below (Brandão, et al., 2005):

$$u = e^{\sigma\sqrt{\delta t}} \quad [2]$$

and

$$d = e^{-\sigma\sqrt{\delta t}} = \frac{1}{u} \quad [3]$$

where σ is a volatility and δt is stepping time.

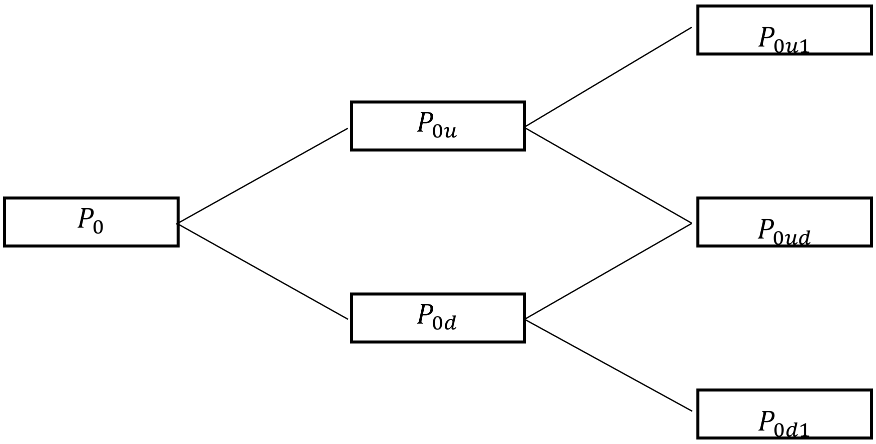

Figure 2. Two-stepping time exploration DTA

Then, all input data from exploration DTA were recalculated using the MCS method. This approach developed a model that revealed the most possible outcomes from random variables. The random values incorporated statistical and stochastic processes that were employed to assess uncertainty, and these results can be used to forecast future probabilities (Brandimarte, 2014). MCS provided numerous potential solutions derived from the minimum and maximum values of each input variable (Samis & Davis, 2014). MCS performed well than exploration DTA that it can identify the fluctuations of multi-variables at any stage in one model of the project (Kamel, et al., 2023). Using the MCS capability, the expected NPV can be determined based on all possible values derived from the exploration targets and associated costs (Kruezer, et al., 2008).

Different methods have been proposed to value early-stage exploration using the income approach. This method suggests that the NPV is derived from the exploration results, which are represented by discounting the future project cash flows (Topal, 2008) (Said, 2006). This formula is expressed below:

$$NPV = \sum_{i=1}^{N} \frac{I_i - C_i}{(1+r)^i} - I_0 \quad [4]$$

where I_i is the incomes, C_i is costs. r is the discount rate. I_0 is the initial investment.

Income is calculated by multiplying the number of products sold by the nickel price at the time of the transaction. Several methods currently exist to simulate nickel prices; however, no single method consistently delivers high forecasting performance. Consequently, the combination of various forecasting methods has emerged as a strategy to enhance overall forecasting accuracy (Mehdi & Bijadi, 2011) (Kristjanpoller & Minutolo, 2015) (Kristjanpoller & Hernández, 2017) (Alameer, et al., 2019).

The combination of various Bayesian scenarios using dynamic model averaging was introduced by (Drachal, 2019) to forecast the spot prices of lead, zinc, and nickel. (Shao, et al., 2019) introduced a combination of an improved particle swarm optimization (PSO) algorithm with long short-term memory (LSTM) networks to forecast nickel prices. To forecast medium- to long-term nickel prices, (Ozdemir, et al., 2022) proposed combining Long Short-Term Memory (LSTM) networks with Gated Recurrent Units (GRU).

Another major parameter of NPV is the discount rate, which incorporates all risks into a single factor (Dou, et al., 2020). For the purpose of practice in the mineral industry, the weighted average cost of capital (WACC) is commonly used to discount future cash flows in order to determine their present value (Lilford & Minnit, 2002). However, WACC has not adequately addressed all the risks associated with the project (Lilford, et al., 2018). Several attempts have been made to improve the WACC. A study conducted by (Lilford, 2023) enhanced the WACC by incorporating quantified risk and uncertainty, referred to as the risk-adjusted discount rate (RADR). However, previous studies on NPV did not address an accurate RADR. The solution involved considering risk-free market risks, including technical and techno-economic parameters, to improve the RADR. The solution involved assessing risk-free market factors, including technical and techno-economic parameters, to enhance the RADR (Dou, et al., 2020) (Lilford, 2023). The RADR can be expressed as the risk-free interest rate plus the MRP, project risk, and the country risk premium (CRP). (Smith, 2016).

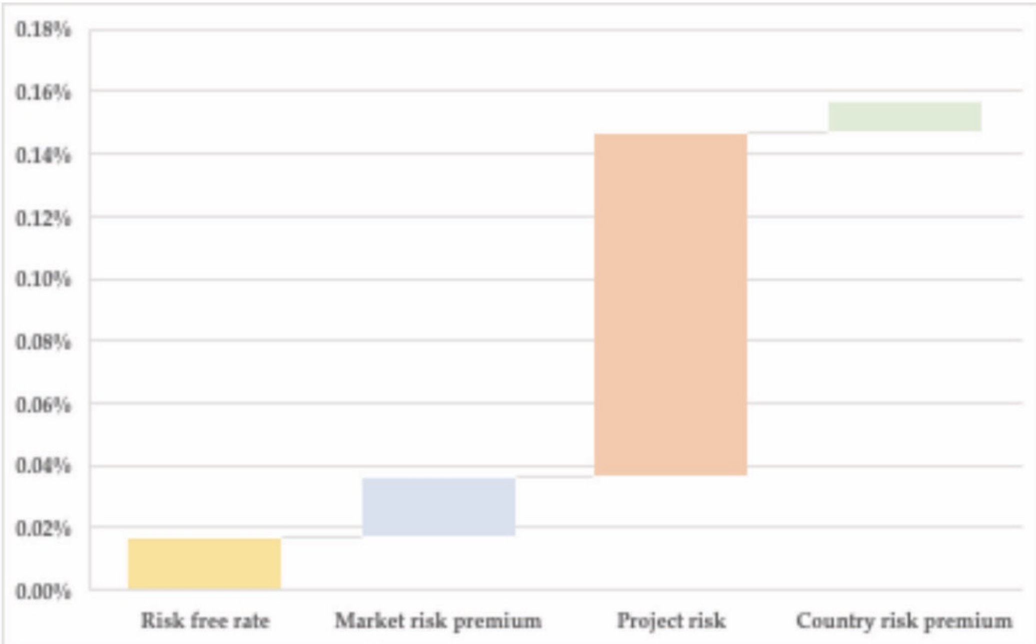

Figure 3. Risk-adjusted discount rate build-up

METHODOLOGY

The value of early-stage exploration is determined by discounting future project cash flows (Said, 2006) (Topal, 2008). In this study, we focus on income and the RADR. Income is dependent on commodity prices, which in this case is represented by the price of nickel. Meanwhile, the RADR is influenced by the risk-free interest rate, MRP, project risk, and CRP. The prices of nickel and the RADR are forecasted using hybrid models that combine Artificial Neural Networks (ANN) and Bat Algorithm (BA).

Artificial Neural Network

The architecture of an artificial neural network (ANN) consists of neurons organized into an input layer, one or more hidden layers, and an output layer. The data from the input layer is transferred to the hidden layers for processing. Each neuron in the input layer has a constant bias value. The processed data is then passed to the output layer, where the output of each neuron is calculated as the total value of the input weights, adjusted by activation functions (Ketkar, 2017).

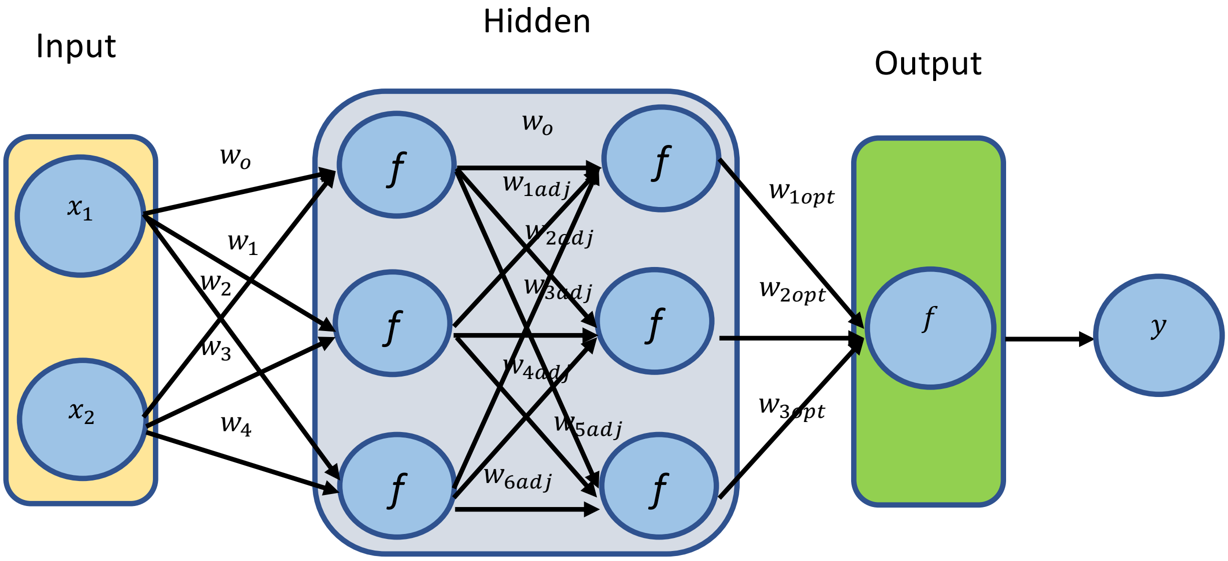

Figure 4. Architecture of artificial neural network (ANN)

The Artificial Neural Network (ANN) model is capable of handling non-linear data and can effectively model the complex relationships between input and output data. However, traditional ANNs often fall short in achieving true optimization, as they adjust weights solely based on a learning coefficient. To address this limitation, it is essential to incorporate biologically inspired algorithms, such as the BA, to enhance optimization processes (Hannan, et al., 2020).

Bat Algorithm

Bat Algorithm (BA) is a biologically inspired algorithm that was developed by (Yang, 2010). BA was inspired by the behavior of microbats using echolocation to catch their prey. It also provides simplicity in application and flexibility in addressing optimization challenges.

In order to achieve optimal results, the parameters of the Bat Algorithm (BA) must be carefully determined to identify the best fitness. The first parameter is the population size, which represents the maximum quality of food in an unknown area. This area, within the context of the bat population size, is initially computed as a random value, expressed as:

$$x_{ij} = x_{min} + \varphi(x_{max} - x_{min}) \quad [5]$$

where i = 1,2,3….N; j = 1,2,3….d, x_{max} and x_{min} are upped and lower boundaries for j. φ is random value ranges from 0 to 1. While the bat flies at a certain velocity, it can detect its prey and obstacles within its search area using sound waves of varying frequencies, wavelengths, and loudness. The frequency, loudness, velocity, position, and pulse rate are all random variables.

$$f_i = f_{min} + \beta(f_{max} - f_{min}) \quad [6]$$

$$v_i^t = v_i^{t-1} + (x_i^t - x_*)f_i \quad [7]$$

$$x_i^t = x_i^{t-1} + v_i^t \quad [8]$$

f_i indicates minimum (f_{min}) and maximum (f_{max}) frequency for each iteration bat. β is random value. x_* is the global location based on the all bat. v_i^t is velocity of bat for each iteration.

The next step is aimed to select the best solution, therefore the new solution is solved using random walk for each bat.

$$x_{new} = x_{old} + \varepsilon A^t \quad [9]$$

where ε is random value ranging from -1 to 1. A^t is average loudness value for each iteration of all bats. Loudness decreases when a bat is closer to the prey while the pulse rate increases.

$$A_i^{t+1} = \alpha A_i^t \quad [10]$$

$$r_i^{t+1} = r_i^0(1 - e^{-\gamma t}) \quad [11]$$

where α and γ represent constraints, r_i^0 is the pulse rate of each iteration.

Table II: Bat Algorithm Parameters ((Dehghani & Bogdanovic, 2018)

No	Parameter	Value	Remarks
1	Population Size	- Ranging from 10 to 40	Large population size increases the running of the process
2	Loudness & Pulse Rate	- Ranging from 0 to 1	Updated each iteration Processes
3	Frequency & Velocity	- Velocity ranges from 0 to 1	- Frequency represents the best location - Flying with velocity - Affected by random frequency

ANN-BA proposed model

The primary model proposed in this study is a hybrid model that combines Artificial Neural Networks (ANN) and Bat Algorithm (BA) to optimize the adjusted weights of the ANN using the BA. The steps of the hybrid ANN-BA model are outlined as follows:

- Provide the ANN-BA model parameters
  The maximum number of iterations, bat population, minimum loudness, pulse rate, maximum and minimum frequency, and velocity, along with other Bat Algorithm (BA) parameters, are established. Subsequently, the adjusted Artificial Neural Network (ANN) weights should be optimized using the BA parameters to achieve the best results.
- Determine the new solution
  The new solution can be derived from the iterations that identify the optimal position for searching for their prey.
- Obtain the optimal solution
  All iterations are conducted until the maximum number of iterations is reached in order to obtain the optimal solution. The best solution is determined based on the fitness value from each iteration.
- Compute the best performance
  The best performance of each iteration can be evaluated by the minimum values of adaptability functions, such as the root mean squared error (RMSE) and mean absolute error (MAE) (Zheng, et al., 2021).

Forecasting performance measures
The effectiveness and accuracy of the proposed forecasting model are validated by comparing it with other forecasting models and actual data. The most commonly used formulas to evaluate the performance of the proposed model are the RMSE and MAE (Zheng, et al., 2021).

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N}(y_i - \hat{y_i})^2}{N}} \quad [12]$$

$$MAE = \frac{1}{N}\sum_{i=1}^{N} |y_i - \hat{y_i}| \quad [13]$$

where y_i is predicted value , $\hat{y_i}$ is actual value and N is number of observations.

RESULTS AND DISCUSSIONS

This study investigates the uncertainty of nickel prices and the Market Reference Price (MRP) with the aim of optimizing the Net Present Value (NPV). Historical data on nickel prices and MRP indicate that their trends and averages do not adequately account for unpredictable and volatile fluctuations (Lilford, et al., 2018).

Sources of data
The primary data for this study were obtained from project acquisition expenditures and exploration activities. The initial exploration program focused on confirming the presence of saprolite layers at shallow depths, which have been identified as nickel-enriched zones. Exploration costs were collected based on actual activities to determine the exploration targets for the Morowali nickel project in Central Sulawesi, Indonesia. The exploration activities conducted on this property included surface mapping and manual hand auger drilling.

The historical data on nickel prices and RADR (risk-free rate, MRP, and CRP) includes 260 monthly observations from May 2003 to December 2024. This dataset encompasses four significant global events. The year 2008 marks the global financial crisis. The period from 2010 to 2014 reflects the European debt crisis. The oil price crash occurred between 2014 and 2015. Finally, 2021 signifies the impact of the COVID-19 pandemic (Ozdemir, et al., 2022).

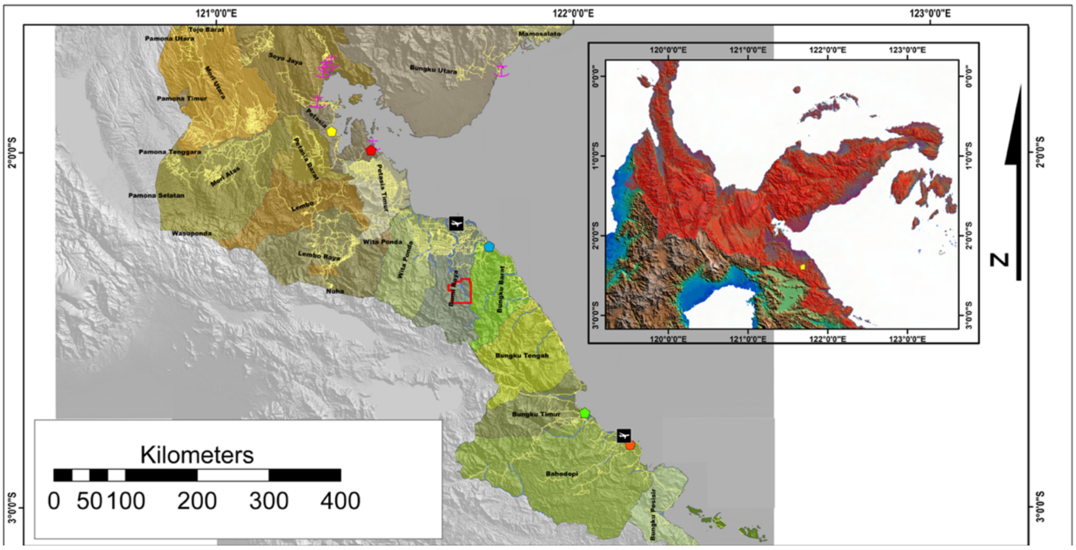

Figure 5. Morowali nickel project location

In forecasting the nickel price, the accuracy of the model can be influenced by the chosen input variables (Alameer, et al., 2019). The recent study on nickel price forecasting has taken several metals into account, namely aluminum, copper, gold, iron, lead, silver, and zinc (Ozdemir, et al., 2022). This study proposes the addition of a Geopolitical Risk (GPR) index, which has been shown to influence the occurrence of price bubbles in nickel (Wang, et al., 2023).

Table III: Source of Secondary Data for this study

Variables	Period	Unit	Source
Nickel price	monthly	US$/ton	World Bank https://www.worldbank.org/en/research/commodity-markets
Aluminum price	monthly	US$/ton	World Bank https://www.worldbank.org/en/research/commodity-markets
Copper price	monthly	US$/ton	World Bank https://www.worldbank.org/en/research/commodity-markets
Gold price	monthly	US$/oz	World Bank https://www.worldbank.org/en/research/commodity-markets
Iron price	monthly	US$/ton	World Bank https://www.worldbank.org/en/research/commodity-markets
Lead price	monthly	US$/ton	World Bank https://www.worldbank.org/en/research/commodity-markets
Silver price	monthly	US$/oz	World Bank https://www.worldbank.org/en/research/commodity-markets
Zinc price	monthly	US$/ton	World Bank https://www.worldbank.org/en/research/commodity-markets
Geopolitical risk index	monthly	-	GPR Index https://www.matteoiacoviello.com/gpr.htm
Risk-free rate	monthly	%	Market Risk Premia http://www.market-risk-premia.com/id.html
Market risk premium	monthly	%	Market Risk Premia http://www.market-risk-premia.com/id.html
Country risk premium	monthly	%	Market Risk Premia http://www.market-risk-premia.com/id.html

The RADR is calculated as the sum of the risk-free rate, specific risk, and the CRP. The risk-free rate reflects the economic conditions and monetary policy of a country, represented by the level of interest rate changes (Saluga, et al., 2021). The MRP is the difference between the domestic currency return and the domestic risk-free rate, which reflects the required, historical, and expected returns (Kaserer, 2022). The CRP is included in the discount rate because it is associated with resource nationalism (e.g., increased taxes, windfall taxes, withholding taxes, and asset seizures). In this context, the RADR is calculated as the sum of the risk-free rate, the MRP, project risk, and CRP (Smith, 2016).

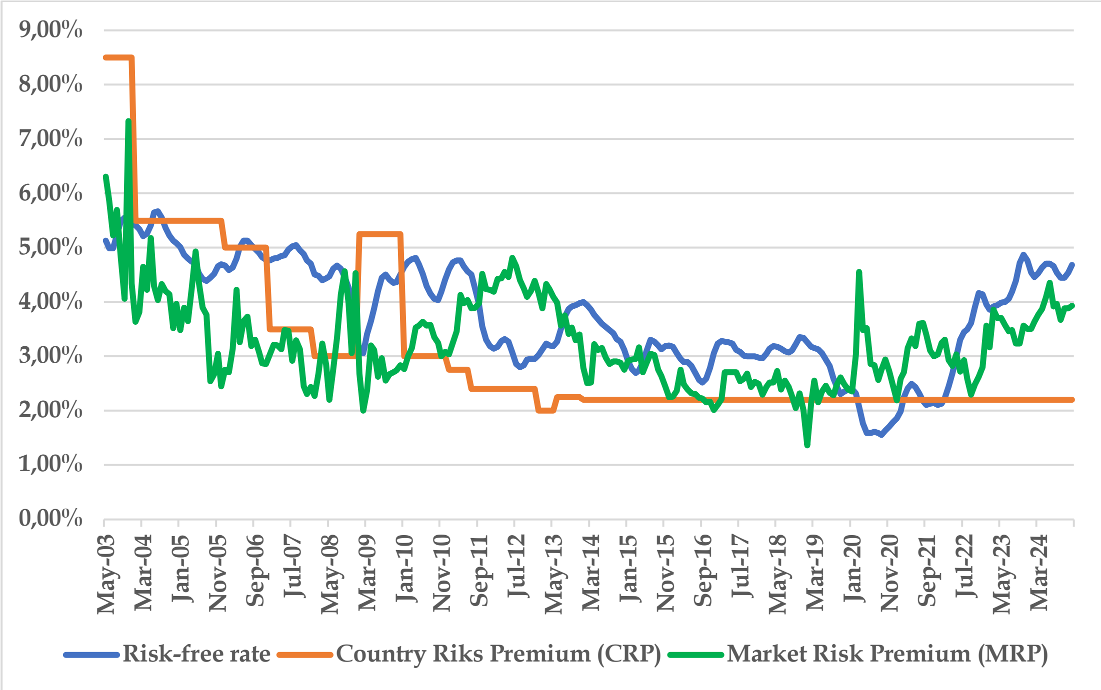

Figure 6. Risk-free rate, MRP and CRP for Indonesia from May 2003 to December 2024

The selected input variables for forecasting the nickel price exhibit various scales and heterogeneous data. To avoid bias, these data are converted to a homogeneous format using the min-max normalization formula, as expressed below:

$$X_{norm} = \frac{X_i - X_{min}}{X_{max} - X_{min}}, i = 1, 2, 3, \dots \dots, 360 \qquad [12]$$

where X_{min} and X_{max} denote the minimum and maximum values of the dataset, respectively.

Descriptive statistics

The descriptive statistics of the selected input variables are displayed in Table IV. Nickel, aluminum, gold, iron, silver, zinc, and GPR exhibit a positively skewed distribution. In contrast, copper and lead demonstrate a negatively skewed distribution. The kurtosis indicates a leptokurtic distribution for nickel and GPR, while the remaining variables are platykurtic. The normal distribution is assessed using the Jarque-Bera (JB) test, which shows that nickel, aluminum, and GPR do not follow a normal distribution. The stationarity of the data is evaluated using the Augmented Dickey-Fuller (ADF) test, which identifies copper, gold, silver, and zinc as non-stationary.

Table IV: The Descriptive statistics of variables to forecast the nickel price

Statistics	Nickel	Aluminum	Copper	Gold	Iron Ore	Lead	Silver	Zinc	GPR
Mean	17,640	2,079	6,613	1,265	101	1,908	19	2,307	101
Min	8,299	1,330	1,648	351	32	464	5	776	58
Max	52,179	3,498	10,231	2,690	214	3,720	43	4,405	319
St Dev	7,162	419	2,015	525	43	547	8	742	29
Skewness	1.72	0.58	-0.50	0.08	0.48	-0.57	0.45	0.15	2.49
Kurtosis	4.34	-0.11	-0.30	-0.39	-0.52	0.77	0.02	-0.13	12.97
Jarque-Bera	129*	17*	14	3	13	15	11	3	293*
ADF	-3.30	-3.23	-2.89**	0.17**	-3.19	-3.38	-2.08**	-2.75**	-6.03
Count	260	260	260	260	260	260	260	260	260

* non-normal
** non-stationary

The descriptive statistics of the RADR variables are presented in Table V. The CRP and MRP exhibit a positively skewed distribution, while the risk-free rate demonstrates a negatively skewed distribution. All variables display platykurtic kurtosis. Additionally, the CRP and MRP are non-normally distributed, and the risk-free rate is non-stationary.

Table V: The Descriptive statistics of RADR variables

Statistics	Risk-free rate	Country Risk Premium (CRP)	Market Risk Premium (MRP)
Mean	0.04	0.03	0.03
Min	0.02	0.02	0.01
Max	0.06	0.09	0.07
St Dev	0.01	0.02	0.01
Skewness	-0.17	1.80	1.05
Kurtosis	-0.91	2.81	2.28
Jarque-Bera	5.14	140.78*	47.49*
ADF	-2.67**	-3.69	-4.63
Count	260	260	260

* non-normal
** non-stationary

Correlation analysis

Prior to the forecasting process, the relationship between the selected input variables and the nickel price should be considered (Alameer, et al., 2019). The relationship analysis can determine whether the selected input variables have a significant correlation with the forecasted variable (Haque, et al., 2015). The simple model can describe the linear relationship between two variables, which is indicated by a positive or negative correlation, known as the Pearson correlation coefficient (PCC) (Molugaram & Rao, 2017).

Table VI: Pearson's correlation coefficient between the predicted variable and the selected input variables

	Nickel	*Aluminum*	*Copper*	*Gold*	*Iron ore*	*Lead*	*Silver*	*Zinc*
Nickel	1							
Aluminum	0.757	1						
Copper	0.517	0.732	1					
Gold	0.010	0.241	0.733	1				
Iron ore	0.469	0.561	0.772	0.480	1			
Lead	0.372	0.479	0.765	0.550	0.663	1		
Silver	0.196	0.353	0.801	0.828	0.683	0.626	1	
Zinc	0.553	0.705	0.696	0.432	0.307	0.598	0.334	1

Table VI presents the PCC between the predicted variables and the selected input variables. The correlation results indicate a significant positive correlation with p-values at 5%, except for nickel and gold, which show no correlation.

Table VII displays the PCC between the RADR variables. This correlation indicates a significant positive relationship, with p-values at the 5% level.

Table VII: Pearson's correlation coefficient of RADR variables

	Risk-free rate	*Country Risk Premium (CRP)*	*Market Risk Premium (MRP)*
Risk-free rate	1		
Country Risk Premium (CRP)	0.643	1	
Market Risk Premium (MRP)	0.411	0.434	1

Output data

The nickel price and MRP are forecasted using precise methods designed to optimize the NPV. Therefore, this study employs MC simulation, ANN, and ANN-based approaches to predict the nickel price and MRP.

Monte Carlo forecasting method

The uncertainty and random fluctuations in nickel prices are predicted using MC simulation. Numerous simulations have been conducted, and the best forecasting performance has been selected. In this case, the MC model generated 50 simulations, with Simulation 3 yielding the best results due to its minimal error.

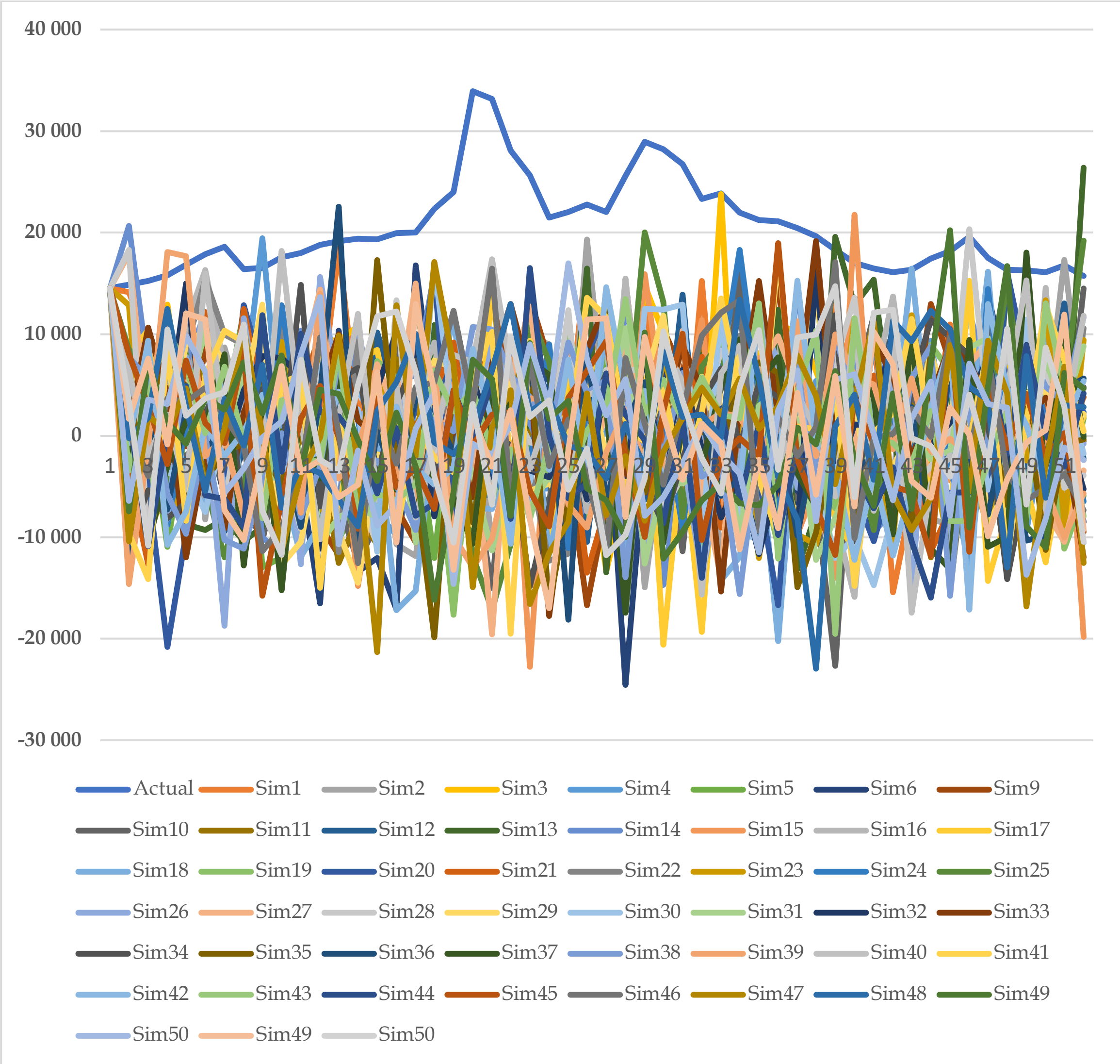

Figure 7. Monte Carlo simulation forecasting results for nickel prices

The MRP is also forecasted using the MC simulation. The most accurate forecast among the 50 simulations was achieved by simulation 49, as it exhibited the least amount of error.

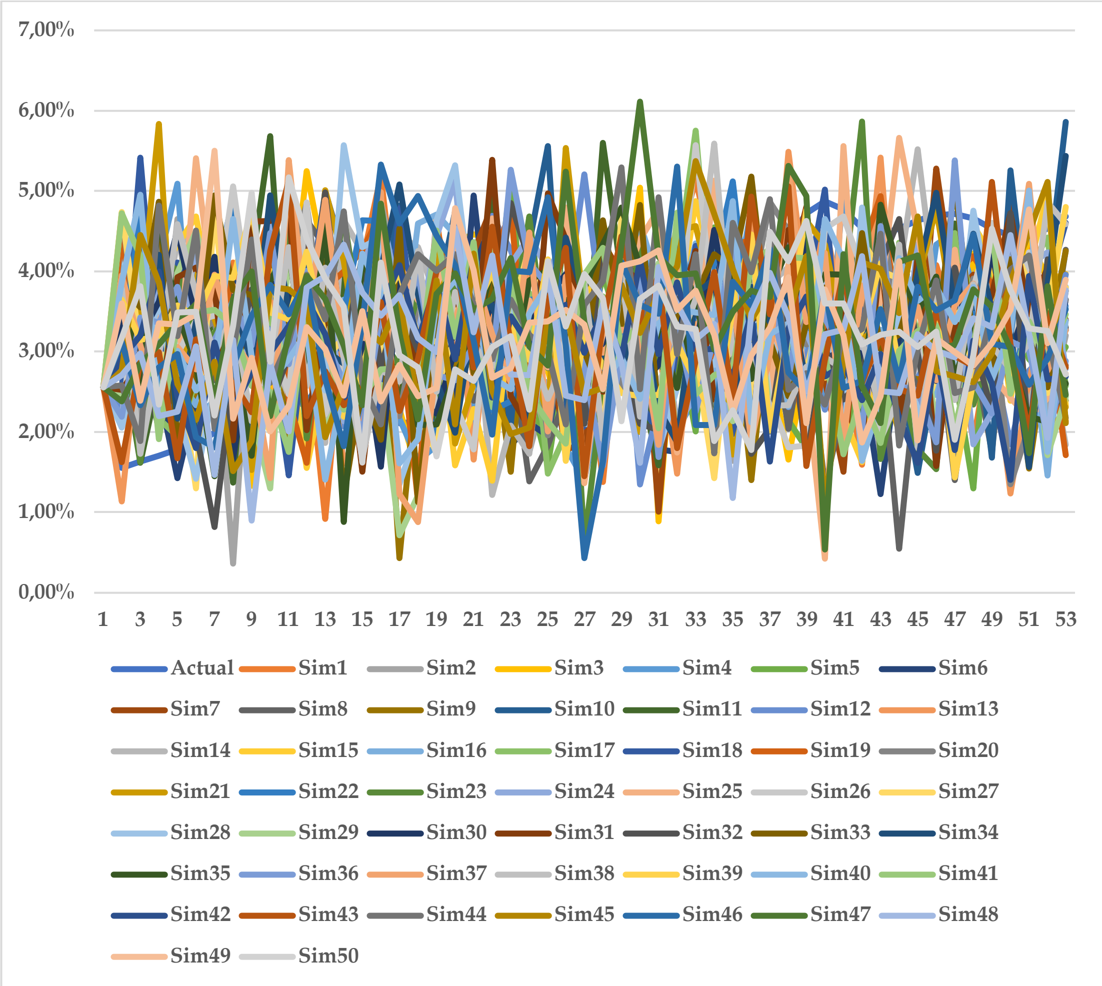

Figure 8. Monte Carlo simulation forecasting results for the MRP

Here, the MC simulation is designed to address the risks and uncertainties associated with nickel prices and the MRP, aiming to achieve optimal outcomes from the random variables. The random variables in the MC simulation are derived from the minimum and maximum values of each variable (Kamel, et al., 2023). Therefore, this model can generate forecasting results within the range of the original data, but it does not account for shock prices or data that fall outside this range. As illustrated in Figure 7, the MC simulations overlook future shock prices for nickel, as the prediction results are based on numerous simulations derived from historical data. This limitation can lead to errors in forecasting, which may prevent accurate optimization of the NPV.

ANN forecasting method

The strength of the ANN model lies in its ability to identify potential future shocks that cannot be detected by MC simulations, as demonstrated in the previous section. The selected input variables—aluminum, copper, gold, iron, lead, silver, zinc, and the GPR—are utilized to forecast nickel prices. The potential for future shocks is determined by adjusting the learning coefficient to 0.6, which produces the optimal solution for forecasting nickel prices. Consequently, the forecasting results for nickel prices are more accurate, as the minimum error is very close to the actual nickel price.

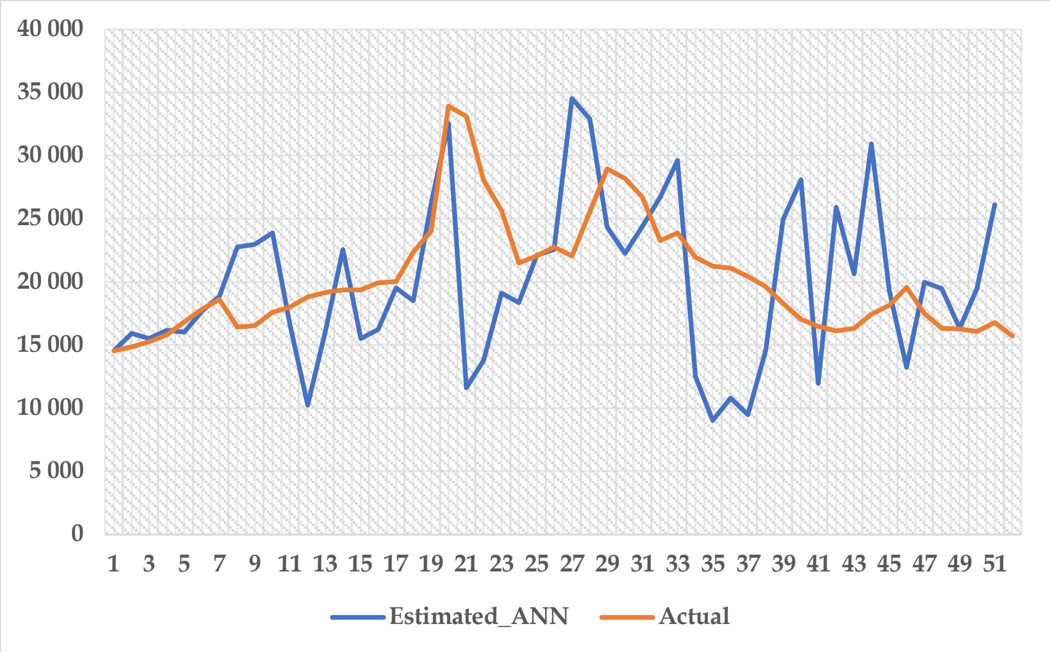

Figure 9. ANN forecasting results for nickel prices

The forecasted MRP using the ANN model incorporates the risk-free rate and CRP as selected input variables. The forecasting results of the MRP using the ANN method are illustrated in Figure 10 below. An optimal solution can be achieved, as the learning coefficient is set at 10.

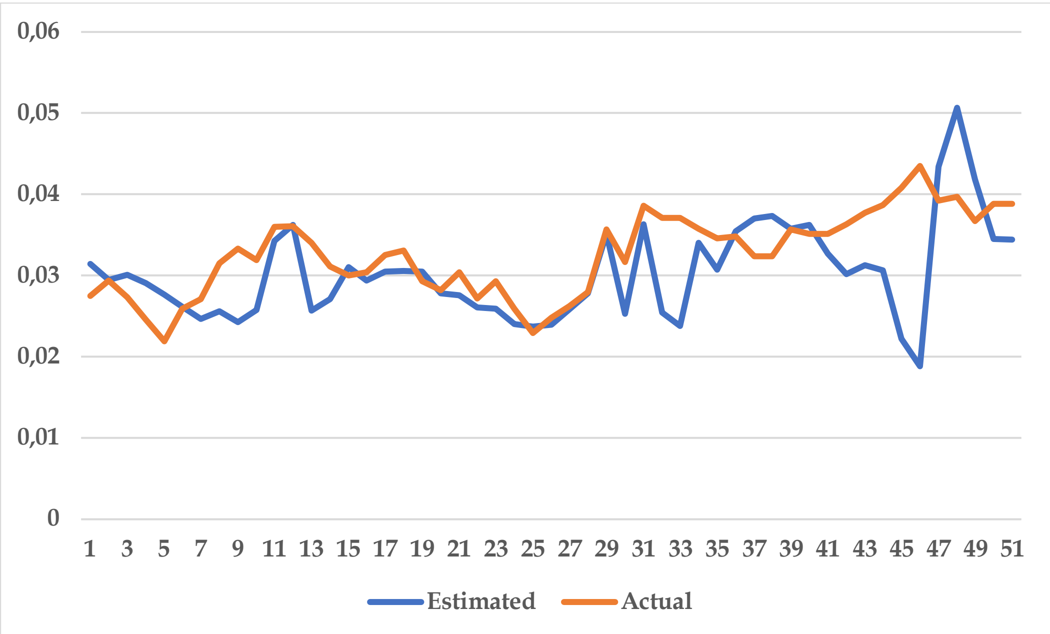

Figure 10. ANN forecasting results for the MRP

ANN-BA forecasting model

The ANN forecasting model for nickel prices is optimized using the bat algorithm (ANN-BA) to produce accurate results. This process involves 40 iterations, with a bat population of 40. The best forecasting results are achieved with a bat population of 34. The optimal loudness for obtaining the best forecasting result is 0.43, while the best forecasting result for nickel prices is achieved with a pulse rate of 0.87. Finally, the most effective iterations are indicated by 29 and 27.

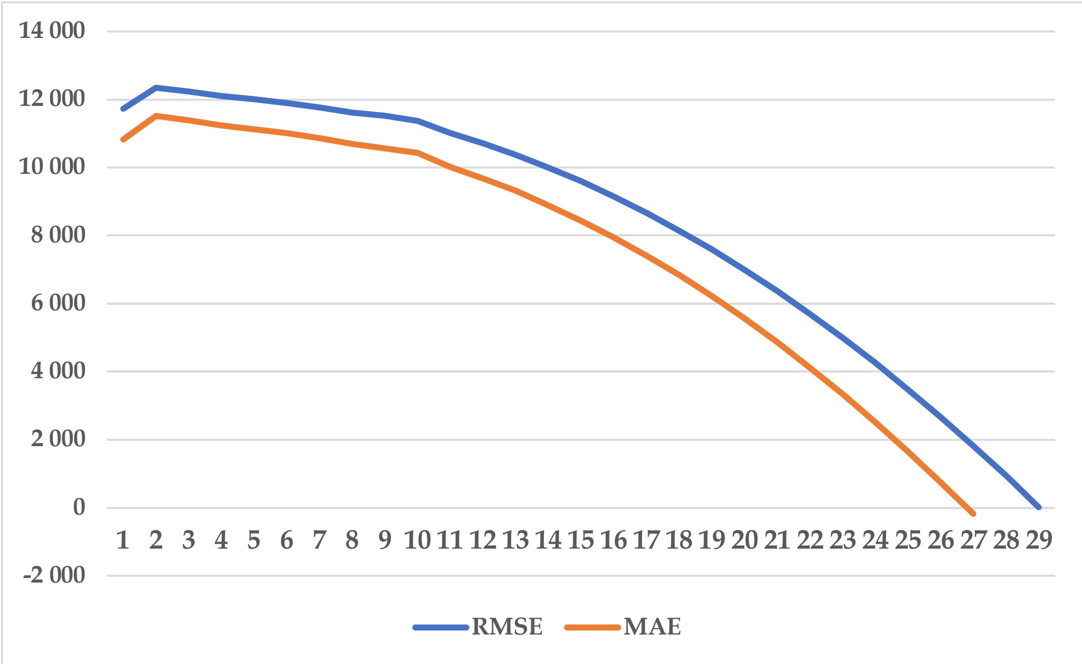

Figure 11. The best iterations from the entire forecasting process for nickel prices

For forecasting the MRP, the optimal bat population size to achieve the best results is 10. The ideal loudness level is 0.09, while the most effective forecasting result occurs at a pulse rate of 0.05. The best iterations are represented by 10 and 11.

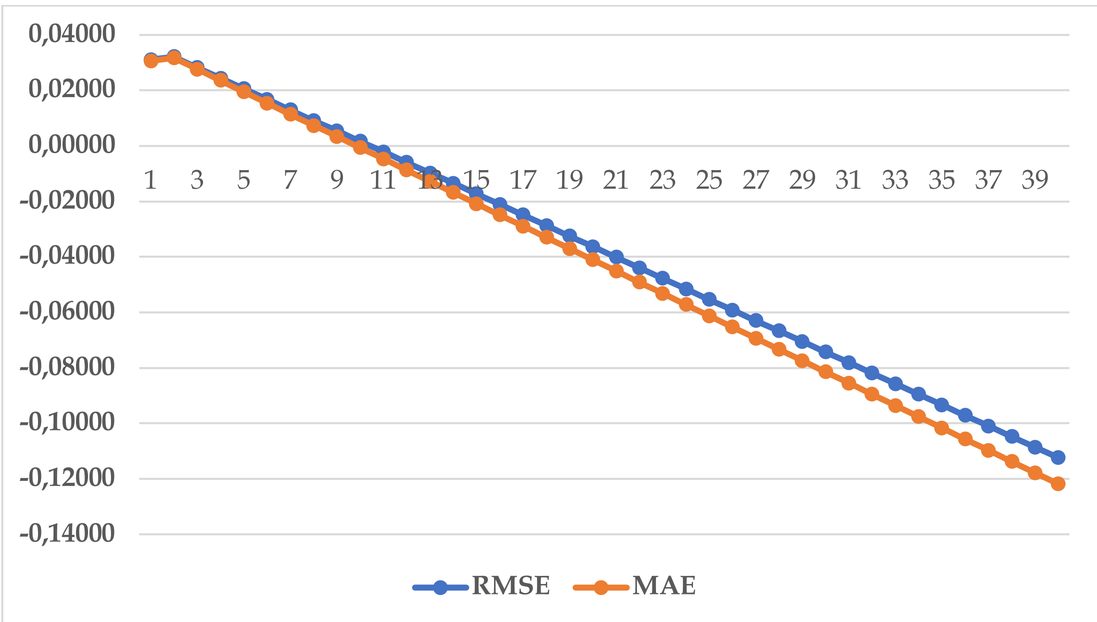

Figure 12. The best iterations from the entire forecasting process for the MRP

Forecasting performance measures

For the forecasting performance measures, the historical data were divided into training and test datasets with ratios of 70:30%, 80:20%, and 90:10% (Alameer, et al., 2019). In this study, a training-to-test ratio of 80:20% was employed. This ratio was selected because it represents a midpoint between the 70:30% and 90:10% ratios. The training dataset contains 208 observations, spanning from May 2003 to August 2020, while the test dataset consists of 59 observations, covering the period from September 2020 to December 2024. The results of the forecasting performance measures for nickel prices are displayed in Table VII. Using MC simulation, the RMSE was 20,311, and the MAE was 18,307. The RMSE and MAE for the ANN model were 8,109 and 5,789, respectively. The RMSE and MAE for the ANN with ANN-BA were 15 and 13, respectively. Therefore, these results suggest that the ANN-BA model is the most effective forecasting technique for predicting nickel prices.

Table VIII: Test data forecasting performance results for nickel prices using MC, ANN and ANN-BA

	Monte Carlo (MC) Simulation	Artificial Neural Network (ANN)	Artificial Neural Network - Bat Algorithm (ANN-BA)
RMSE	20,311	8,109	15
MAE	18,307	5,789	13

The results of forecasting performance measures for MRP using MC simulation yielded a RMSE of 0.012 and a MAE of 0.010. The ANN model demonstrated improved performance, with an RMSE of 0.007 and an MAE of 0.005. The ANN-BA method exhibited even better results, achieving an RMSE of 0.002 and an MAE of 0.001. Similar to nickel price forecasting, the ANN-BA model was identified as the best forecasting model for predicting MRP, as it provided the lowest error rates.

Table IX: Test data forecasting performance results for MRP using MC, ANN and ANN-BA

	Monte Carlo Simulation (MC)	Artificial Neural Network (ANN)	Artificial Neural Network - Bat Algorithm
RMSE	0.012	0.007	0.002
MAE	0.010	0.005	0.001

Figure 13 and Figure 14 display the historical and forecasted nickel prices and MRP to evaluate the performance of the MC simulation, ANN, and ANN-BA models. The historical nickel prices and MRP serve as the training data, while the forecasted results represent the test data. The MC simulation reveals that the forecasted results exhibit dynamic fluctuations, reflecting the random movements inherent in the data. The similar upward and downward trends of the forecasted nickel prices generated by the ANN model closely resemble those of the MC simulation. However, the ANN model demonstrates smoother fluctuations compared to the MC simulation, as it employs true optimization techniques. To achieve even more accurate results, a biological-based algorithm using the BA has been incorporated to optimize the ANN model. This outcome indicates that the ANN-BA model provides smoother forecasts than the conventional ANN model.

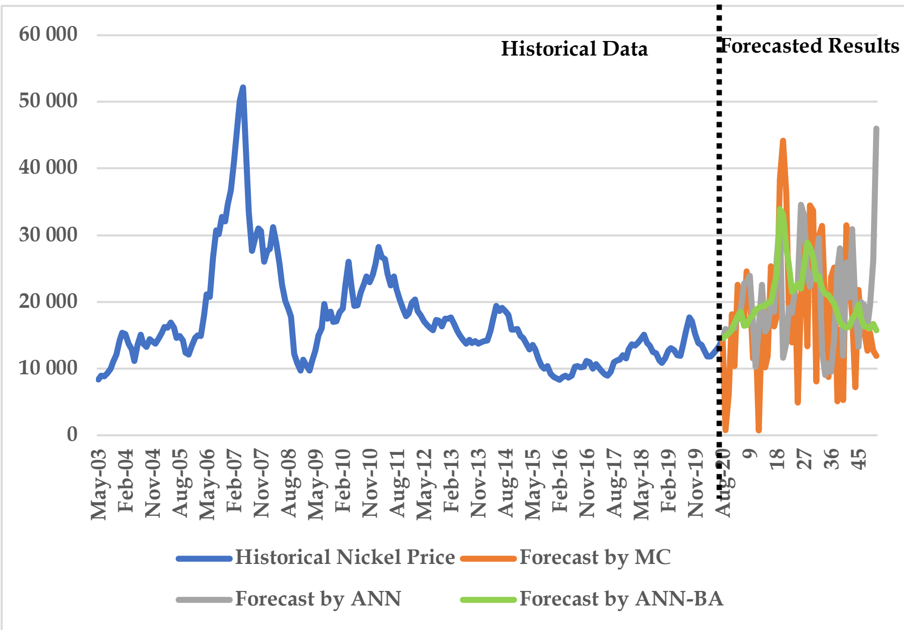

Figure 13. Historical and forecasted nickel prices

The forecasted MC simulation of the MRP demonstrates dynamic movements similar to those of nickel prices, as it incorporates a random mechanism. The ANN model is recommended to enhance the MC simulation for MRP forecasting, as it optimizes prediction accuracy. While the ANN model exhibits a similar trend, it also highlights the optimal upward and downward movements in the forecasting results. The ANN-BA has been recognized as the most accurate model, as it minimizes forecasting errors. This model improves both the MC simulation and the ANN by optimizing the forecasting process.

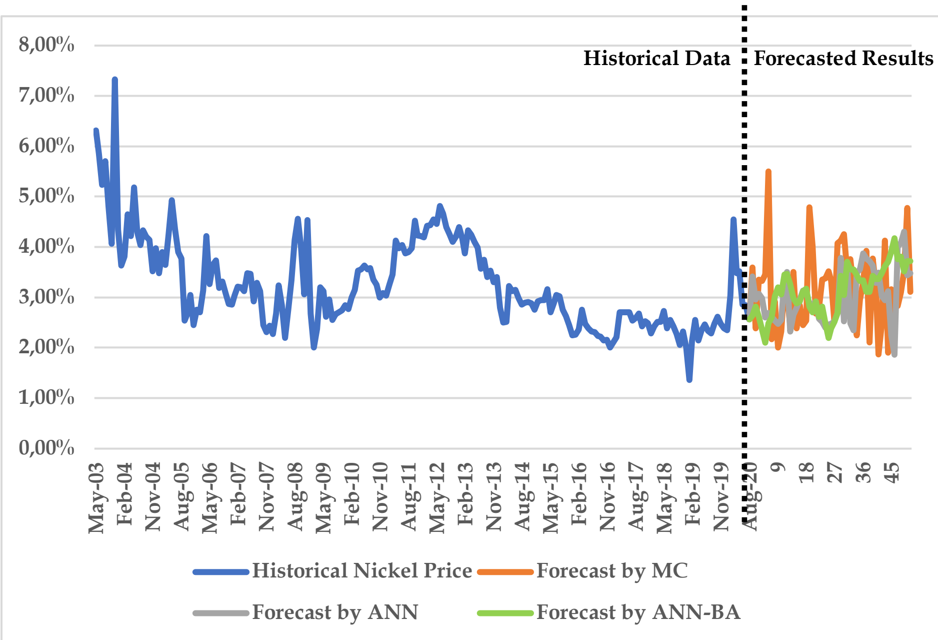

Figure 14. Historical and forecasted the MRP

Project Valuation
The value of the property is determined by calculating the ratio of gross profit, which is derived from the difference between income and operating costs, to the discount rate. This value is then adjusted by subtracting the initial investments. Income is calculated based on the forecasted nickel price multiplied by the quantity of products sold. In this study, incomes were computed using MC simulation, ANN, and ANN-BA. The annual sales of saprolite ore from a similar property in Central Sulawesi amounted to 985,944 tons. Operating costs represent the cash costs to extract the saprolite ore. The cash costs for nickel projects in Central Sulawesi to extract saprolite ore were projected to be US$ 23 per ton in 2024.

Table X: Input parameters to compute the NPV

Description	MC	ANN	ANN-BA
Life of Mine (yr)	3	3	3
Sold Product (t/yr)	985,944	985,944	985,944
Nickel Price (US$/t)	15,952	22,422	16,881
Ore Price (US$/t)	37	52	40
Cash Cost (US$/t)	23	23	23
Risk-free rate (%)	4.57	4.57	4.57
CRP (%)	2.2	2.2	2.2
Project risk (%)	6.0	6.0	6.0
RADR (%)	15.87	16.05	16.77

The ore price was calculated in accordance with the Regulation on Mineral Sales Benchmark issued by the Ministry of Energy and Mineral Resources of the Republic of Indonesia, No. 630.K/32/DJB/205. This formulation is expressed as: $ore\ nickel\ price = Nickel\ grade * CF * LME$. CF is 13% for 1.80% nickel grade.

The RADR calculation is the sum of the risk-free rate, MRP, CRP and project risk. In this study, accurate forecasting of the MRP was proposed to optimize the RADR. The MRP variable was chosen because it reflects the varying returns of global portfolios expressed in Indonesian currency (Kaserer, 2022) that can affect the RADR. While, the project risk is assessed based on the current stage of the project (Smith, 2016). The Morowali nickel project has recently commenced its initial exploration program, which includes surface mapping and hand auger drilling in a somewhat remote area. Consequently, this phase can be classified as a scoping study stage, with a project risk of 5.5% for base metals. Additionally, the risk associated with remoteness is estimated at 0.5%.

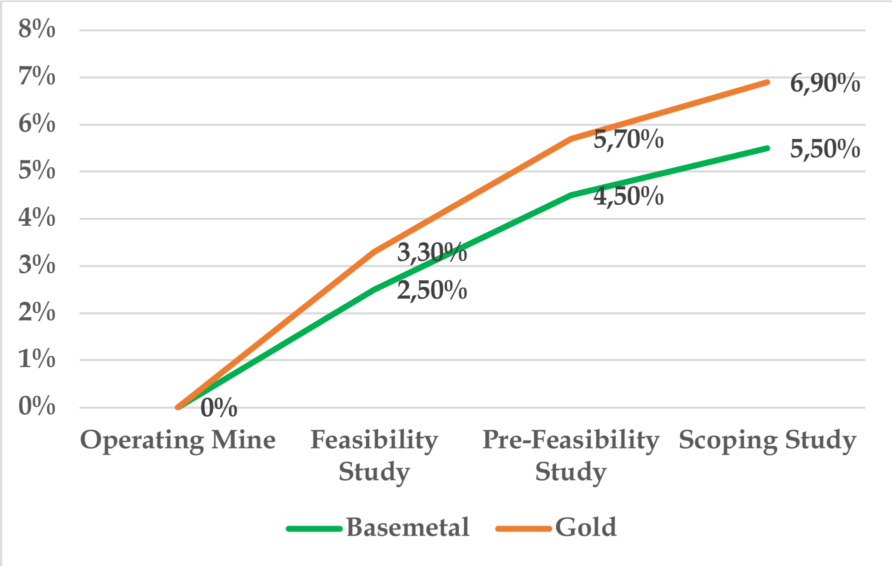

Figure 15. Project risk for gold and base metal projects (Smith, 2016)

The RADR computations in Indonesia over the past two decades are presented in Figure 16. Before 2004, Indonesia's RADR reached 25%. However, since 2005, it has gradually decreased, with the lowest RADR recorded in 2020 at 13%. Subsequently, it increased to 17%.

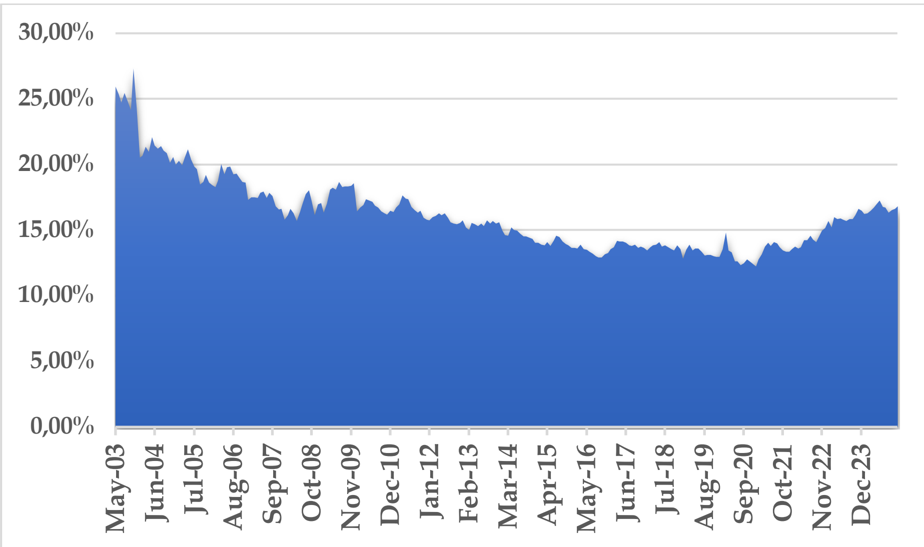

Figure 16. RADR of Indonesia from May 2003 to December 2024

The initial costs were categorized into property acquisitions, the exploration program, road and stockpile construction, and jetty installation. These costs were derived from the actual expenses associated with the property. The costs for property acquisitions amounted to IDR 50 billion, while the exploration program totaled IDR 31.59 billion. The construction of an 8 km road incurred costs of USD 15 billion. The expenses for stockpile construction were IDR 850 million, and the costs for jetty installation were IDR 3 billion. Additionally, the pre-stripping costs were IDR 2 billion. The exchange rate for the US dollar was IDR 15,866 to the Indonesian Rupiah in 2024.

Table X: Input parameters to compute the NPV

Initial Investments	Cost (US$)
- Acquisition	3,151,393
- Exploration	1,991,050
- Road	945,418
- Stockpile	53,574
- Jetty	189,084
- Pre-Stripping	126,056
TOTAL	**4,969,747**

The NPV was calculated using the forecasted nickel prices and the MRP, which were simulated using the MC, ANN, and ANN-BA models. The ANN model yielded the highest NPV at US$ 58.74 million, as the forecasted nickel price reached US$ 52 per ton over the last 12 months. In contrast, the forecasted nickel price from the MC simulation was US$ 37 per ton, resulting in an NPV of US$ 25.34 million, while the ANN-BA model forecasted a nickel price of US$ 40 per ton, leading to an NPV of US$ 29.63 million. The NPV from the ANN-BA model is 15% higher than that of the MC simulation but 98% lower than the ANN model. Additionally, the RADR from the ANN model indicates a close alignment with the MC simulation over the last 12 months, at 15.87% and 16.05%, respectively. Meanwhile, the ANN-BA model recorded a RADR of 16.77%.

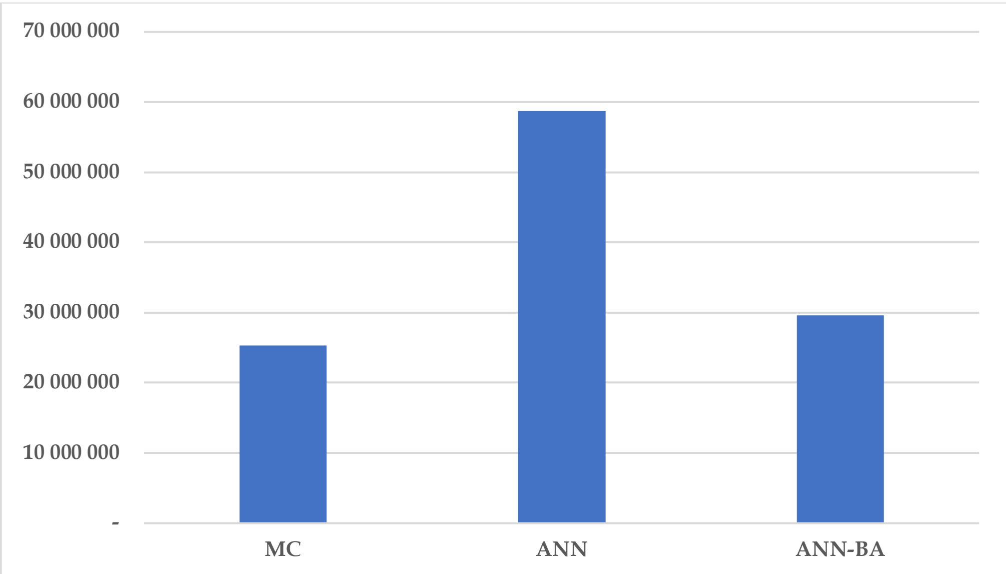

Figure 17. The comparison of NPV optimization using MC simulation, ANN and ANN-BA models

The RADR is one of the fundamental parameters that can significantly affect the NPV. When the RADR increases, the NPV tends to decrease, and vice versa. This study examines the impact of changing the RADR from 10% to 20% and quantitatively analyzes its influence on the NPV. The findings confirm that for every 1% increase in the RADR, the NPV decreases by approximately 2%. Consequently, with the RADR set at 10%, the NPV is calculated to be US$ 34.00 million. In contrast, when the RADR is set at 20%, the NPV is reduced to US$ 27.82 million.

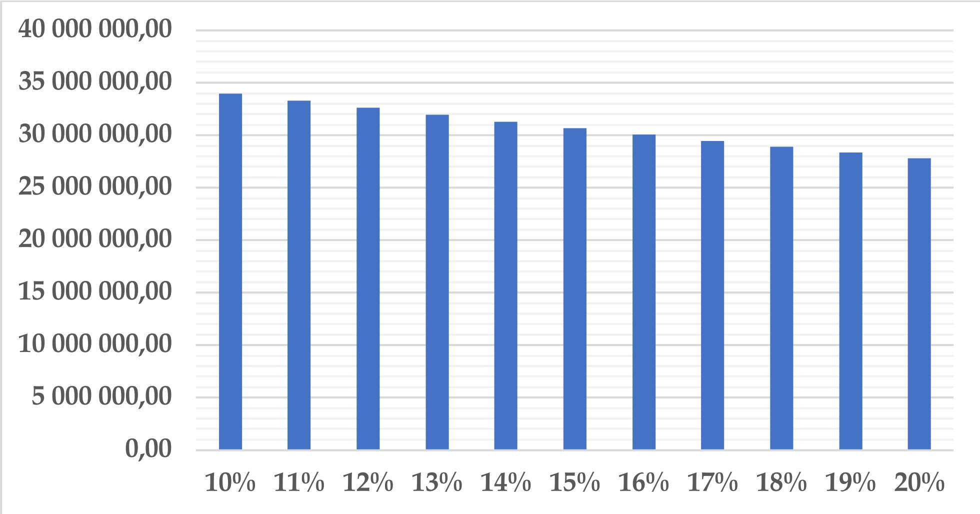

Figure 18. The NPV sensitivity based on the RADR

Comparison with the expected value (EV) method
The NPV optimization using the ANN-BA is compared with the EV method, which is widely recognized as a valuable tool for assessing early-stage exploration.

The EV formula, as shown in Equation 1, involving the professional exploration team to optimize P_e and P_g. The future value of the property, as derived from the EV calculation, is analyzed using the decision tree analysis (DTA) model. All input data for the DTA are simulated through MC methods to determine the potential NPV of the property (Kruezer, et al., 2008).

The DTA model provides the possible future value for each exploration stage. The P_e and P_g increase every with each exploration stage. In the mapping and hand auger drilling stage, the P_e and P_g are 0.47 and 0.00012, respectively. The initial valuation is \$3.15 million, and the exploration cost is \$28,362. Consequently, the EV is -\$28,191. This value is derived from a MC simulation, which indicates a minimum value of -\$155,974 and a maximum value of \$74,345, with an average value of -\$33,963. In the feasibility stage, the P_e and P_g are 0.90 and 0.30, respectively. The initial valuation is set at US\$ 14.24 million, with exploration costs amounting to US\$ 0.28 million. The minimum NPV of this property at this stage is US\$ -37.08 million, while the maximum NPV is US\$ 71.22 million. Consequently, the average NPV of the property at this stage is US\$ 17.19 million. The NPV derived from the EV computation aligns with the range of the ANN-BA at US\$ 29.63 million.

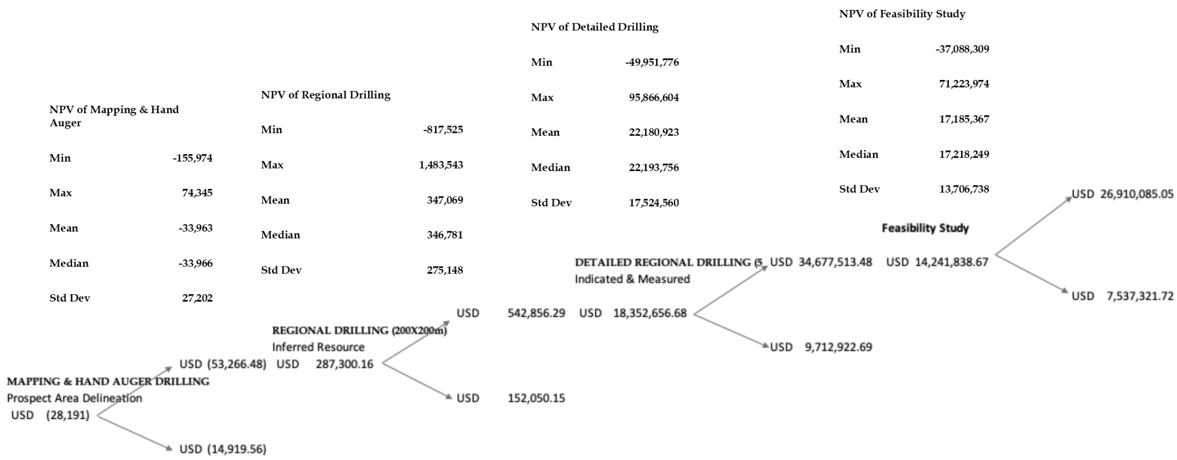

Figure 19. The possible NPV results incorporating the DTA and MC simulation. The NPV ranging from US$ -37.08 to US$ 71.22 million

CONCLUSIONS

The ANN-BA model proposed in this paper is utilized to forecast nickel prices and the MRP. The forecasted nickel prices and MRP are intended to calculate the NPV in early-stage exploration projects. The results of this forecasting demonstrate that the ANN-BA model is more accurate than both the MC simulation and the traditional ANN method. This high level of accuracy in forecasting nickel prices and MRP reflects the model's strong performance in estimating NPV during early-stage exploration. The NPV estimation using the ANN-BA model is robust when compared to the probabilistic EV method. The NPV calculated by the ANN-BA model is US$ 29.63 million, which falls within the range of the EV, from US$ -37.08 million to US$ 71.22 million. Additionally, the Risk-Adjusted Discount Rate (RADR) plays a critical role in optimizing NPV. This study confirms that for every 1% increase in RADR, the NPV decreases by 2%.

The findings of this study suggest that the ANN-BA is a powerful tool for estimating the Net Present Value (NPV) of early-stage exploration projects, as it can evaluate its forecasting performance by testing each selected input variable. In this case, the forecasted nickel prices and MRP demonstrated the lowest errors, with values of 15 and 0.002, respectively, when using RMSE, and 13 and 0.001, respectively, when using MAE.

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Over 20 years involving as a professional in mineral resource estimation and geostatistics. Currently, just submitted the journal for grade estimation using the artificial neural network (ANN) and the Archimedes Optimization Algorithm (AOA). Over 12 years working for mine valuation from exploration through production using the market., cost and income approaches. Involving the net present value, decoupled NPV and real options in valuing the mineral properties including managerial flexibility. Providing consulting, training and advice for energy & metal price forecasting using quantitative methods from econometric, time-series stochastics, machine learning and hybrid models.

Revenue and capital uncertainty in cash flow analysis

A. McDonald

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The Income Approach valuation "requires determination of the present value of future cash flows over the useful life of a Mineral Asset" (SAMVAL, 2016). The most common method in this approach is the discounted cash flow, which comprises four money-related sections: revenue, capital costs, operating costs and legislative costs (environmental, social and governance aspects, taxes, royalties, etc.). In this paper, I review the uncertainties associated with the revenue (metal prices) and capital cost components of the cash flow.

Forecast metal prices are all premised on assumptions of future macro-economic and supply/demand conditions. A consensus price forecast is typically the median, or average, of forecasts from multiple sources; what is seldom considered is the range from highest to lowest within those forecasts. Certain jurisdictions require the use of observable inputs (International Financial Reporting Standard, IFRS 13) such as spot or three-year trailing average prices.

The completed construction cost of many mining projects has exceeded the original feasibility study budget by between 50% and over 100%. Inclusion of a contingency of <10% at feasibility study level does not adequately cater for the cost overruns seen in practice.

A valuation derived using the Income Approach is required to specify a preferred value within a range of values. By assessing the degree of uncertainty in the real metal price forecasts and capital estimates, I discuss what should be considered in evaluating the sensitivity of a project to such uncertainties, while presenting a value range that is still meaningful.

INTRODUCTION

The Income Approach valuation "requires determination of the present value of future cash flows over the useful life of a Mineral Asset" (SAMVAL, 2016). The most common method in this approach is the discounted cash flow (DCF), which involves determining the net present value (NPV) of forecast cash flows. A DCF comprises four money-related sections: revenue, capital costs, operating costs and legislative costs (environmental, social and governance aspects, taxes, royalties, etc.). The uncertainties associated with revenue (metal prices) and capital cost components are examined below.

REVENUE UNCERTAINTY

Companies typically want a hurdle rate of 15% to 20% to determine whether a project is economically viable. I recall a feasibility study we had completed some years ago, where the internal rate of return (IRR) was 6%. The client was not impressed and insisted we conduct extensive re-engineering and optimisation studies. Following more than a year's work, we managed to increase the IRR to 10%. At that point, the client's chief financial officer provided revised metal price forecasts - the IRR jumped to 22%!

Although a project (or mine) is generally most sensitive to changes in revenue as illustrated in the simple spider-diagram in Figure 1, the above example highlights that the choice of metal price can play a much more significant role in revenue sensitivity than technical inputs such as plant feed grade or plant recovery.

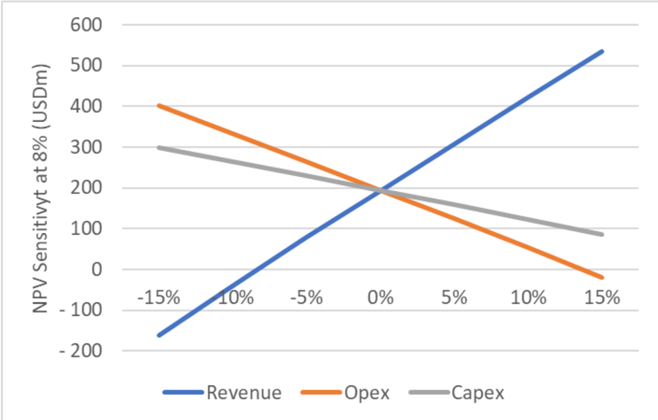


Figure 1. Illustrative spider diagram, showing typical cash flow sensitivities to changes in revenue, capital cost and operating cost.

Uncertainty in Forecast Prices

Forecast prices are all premised on assumptions of the future macro-economic and supply/demand conditions, which can change dramatically overnight. A consensus price forecast is typically the median, or average, of forecasts from multiple sources; what is seldom considered is the range from highest to lowest within those forecasts.

Appendix 1 provides for illustrative purposes the consensus median, minimum and maximum real price forecasts for copper (Cu), gold (Au) and palladium (Pd) compiled in December 2020 (UBS, 2020), and compares these with the historical prices from 2020 to date. The comparisons are consistent with the observations of McDonald (2016), which highlighted the inherent uncertainties in any metal price forecast and the importance of sensitivity analyses on cash flow outputs.

Some investment banks are not prepared to provide forecasts beyond three to four years into the future. The statistical support of forecasts from year four onwards becomes weaker, which is invariably around the time when the first ore in a project implementation starts to be processed.

Appendix 1 shows further that the range from highest to lowest values within the real price forecasts for Cu, Au and Pd, relative to the median are considerable, as reproduced in Table I. The highlighted cells in Table I show the most significant deviations from the median, expressed as percentages, which are considerably more than the usual ±15% range used in revenue sensitivity analyses.

Table I. Percent variation in minimum and maximum real forecast prices to median real forecast prices

Item	2020	2021	2022	2023	2024	LT (2020 real)
Copper (USD/lb)						
Min (relative to Median)	-1.8%	-11.8%	-11.9%	**-15.7%**	-14.5%	-8.3%
Max (relative to Median)	1.2%	8.4%	20.2%	**24.9%**	11.3%	13.4%
Gold (USD/oz)						
Min (relative to Median)	-12.0%	-9.3%	-12.0%	-13.9%	**-21.7%**	-18.9%
Max (relative to Median)	3.6%	**28.9%**	19.4%	18.8%	19.4%	12.3%
Palladium (USD/ oz)						
Min (relative to Median)	-5.7%	-14.3%	-23.7%	**-28.3%**	-21.3%	-27.3%
Max (relative to Median)	1.2%	24.7%	21.0%	36.4%	36.6%	**84.1%**

The percentages represent a quasi-statistical approach as relative differences instead of absolute values are used. The percentages facilitate sensitivity analysis within Excel.

Somerville (2015) recommended that a sensitivity analysis should be done using a range that matches the annual price volatility of the commodity across several market cycles. From my interpretations in Appendix 2, suitable sensitivity ranges for the three commodities are given in Table II. For emerging commodities with insufficient price history, such as lithium, a sensitivity range from maximum to minimum within the historical period is suggested.

Table II. Percent variation in minimum and maximum historical prices to median historical prices

Item	Per Appendix 2
Copper (USD/lb)	
Min (relative to average)	-32%
Max (relative to average)	+35%
Gold (USD/oz)	
Min (relative to average)	-25%
Max (relative to average)	+30%
Palladium (USD/ oz)	
Min (relative to average)	-66%
Max (relative to average)	+212%

While the sensitivity ranges in Table II are wider than the highlighted ranges in Table I, there is general support for expanded sensitivity ranges on metal prices to be used. It would appear that the sensitivity range is commodity-specific, i.e., a standard range should not be used for all commodities.

Observable Inputs

Certain jurisdictions require the use of spot or three-year trailing average prices at the effective date of the DCF, which would be observable inputs in terms of IFRS 13 (2011).

Reugh (2012) reported that, due to concerns raised by the British Columbia Securities Commission, American Manganese Inc. agreed to use a three-year trailing average price in evaluating the economic feasibility of its Artillery Peak Project. This provided a more conservative price forecast in a rising market relative to the expected case used in the study. Use of the three-year trailing average generated a negative NPV; the result - American Manganese had to withdraw its Mineral Reserve announcement. Companies that report across various exchanges can be faced with the use of forward prices for one exchange and trailing prices for another.

The spider diagram in Figure 1 shows an NPV at 8% discount of USD194m, based on the use of three-year trailing average prices. If the spot prices and consensus forecast prices at the time of the study were used instead, the NPV changes to USD448m and -USD56m respectively. This shows it is essential to include the spot and trailing prices (observable inputs per IFRS 13) in a cash flow evaluation, to assess the sensitivity of the project's future-looking business plan to the cyclicity of metal prices.

CAPITAL COST UNCERTAINTY

The accuracy limits of the capital cost estimate get tighter as the project advances from concept phase (or scoping study) through pre-feasibility study to feasibility study, generally given as ±50%, ±25% and ±15% respectively (e.g., S-K 1300, 2018).

EY Global's survey of mining industry leaders showed that the key risk for 2025 is capital (Mitchell, 2024). Miners are expected to manage capital discipline, meet higher stakeholder expectations and manage resource nationalism in certain geographies. The latter may require miners to form joint ventures with local companies to derisk investment (Mitchell, 2024); potentially impacting capital efficiency.

Cost Overruns

The completed construction cost of many mining projects has exceeded the original feasibility study capital budget, stated to have ±15% accuracy, by between 50% and over 100%. The class action by shareholders in the 2000s, where the capital cost for Nova Gold's project in Canada had increased by more than 131%, always comes to mind (see for example Terhune, 2020). Terhune (2020) argued that the industry's cost overrun is multi-faceted, where poor engineering assumptions, a lack of understanding of key risks, aggressive timelines and bias all play a role.

Kuestermeyer (2019) presented the five top contributing factors to capital cost overruns (Figure 2), which generally align with those of Terhune (2020). Kuestermeyer (2019) concluded that average capital overruns for mining projects were up to 60%. Major contributing factors were seen to be underestimation in the feasibility study, with project completion costs during project development/construction higher than expected (e.g., owner's costs, indirect costs, contingency and Engineering, Procurement and Construction Management labour costs).

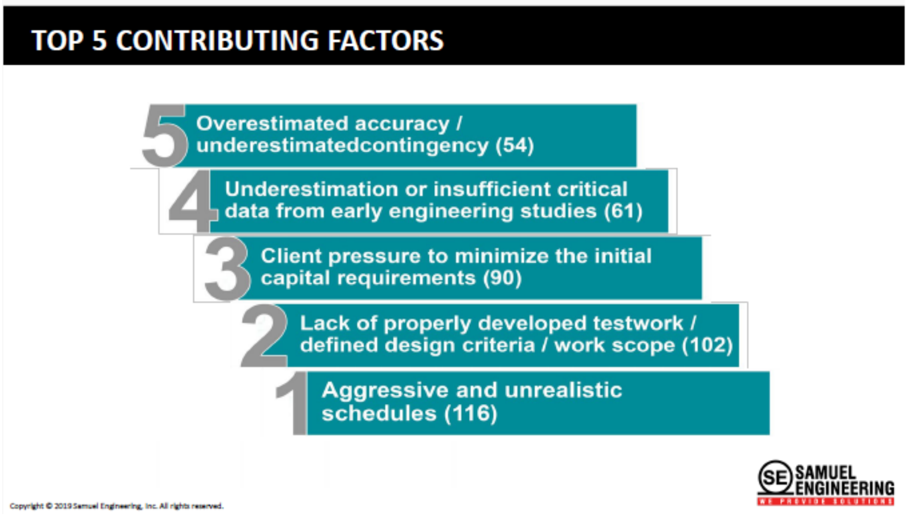


Figure 2. Top five contributing factors in cost overruns [source: Kuestermeyer, 2019].

"Aggressive and unrealistic schedules" and "Client pressure to minimise the initial capital requirements" in Figure 2 suggest that too much optimism is applied in feasibility studies to ensure that the project(s) can be financed. Varis (2025) commented that "We are saying [to investors] 'give us money, we want to build this major project, but we are going to probably come in 50% over and our schedule is probably going to be 70% longer than we told you it is going to be".

MacKenzie and Cusworth (2016) cited the results of five studies into capital cost overruns, as summarised in Table III.

Mencarini *et al.*, (2024) estimated that cost and scheduling challenges affected 83% of major projects undertaken since the COVID-19 epidemic. Cost overruns were at least 79% higher than initial budget estimates for mega projects (>USD1bn), while schedule delays averaged 52% higher than initial time frames (Mencarini *et al.*, 2024). Less than 10% of mega projects (>USD1bn) and 20% of major projects (<USD1bn) managed to avoid cost overruns and schedule delays (Mencarini *et al.*, 2024).

The costs of developing the underground project at the Karowe diamond mine in Botswana had "spiralled out of control", with completion of the project expected in 2028, two years late (McKay, 2025). Horizonte Minerals revealed that the construction costs for its nickel deposit in Brazil would be nearly double what it had forecast (Farchy, 2025).

Table III. Cost overruns (studies cited by MacKenzie and Cusworth, 2016)

Results of study	No of Projects	Cited reference
Average cost overrun 25%	63 (1980 to 2001)	Bertisen and Davis (2007)
Average cost overrun 26%	16 to 60 (1965 to 2002)	Bullock (2011)
Only 25% delivered within time and budget	56 (post 2002)	Biery, Holland and Young (2009)
69% of projects faced average cost overrun of 62% (31% delivered in line with scope, schedule, or cost)	108 recent projects	EY (2015)
Vast majority with significant cost overruns Average schedule slip ca. 20% (but up to 80%) Av. performance 12 months after start-up – 20% lower	30 (2006 to 2013)	IPA (2015)

The above examples suggest that a sensitivity range for a capital budget to cater for cost overruns should be -10% to at least +60%.

Impact of Project Delays

A 12-month delay on a two-year construction period (50% delay) is simulated to increase the capital budget in a cash flow analysis by 25%, as shown in Table IV.

Table IV. Simulated impact of project delays on capital budget

Aspect	Proportion of Project Budget	Simulated Impact on Capital Budget
EPCM costs (assume 2-year build)	17%-20% of direct costs	+10%
Owners' costs, preproduction costs	5%-10% of direct costs	+5%
Escalation	Usually excluded	+5% (in US Dollar terms)
Opportunity cost from delayed production	Not applicable	+5%

Confidence in the Capital Estimate - Contingency

A low contingency does not mean a high accuracy (or confidence in the capital estimate), and a high contingency does not mean a low accuracy (Albrecht, 2015). Contingency is a measure of how well you have defined your project; accuracy is a measure of how confident you are that you have defined the right project (Albrecht, 2015). S-K1300 (2018) stipulates that a contingency for capital cost estimates for mining projects at initial assessment, preliminary feasibility study and feasibility study stage should be ≤25%, ≤15% and ≤10% respectively.

The need for project cost contingency arises because the set of possible cost outcomes is not normally distributed (Figure 3; from Lawrence, 2007). Contingency bridges the gap between the base estimate (the mode) and the outcome probability point (usually the 50/50 outcome point, or the median) (Lawrence, 2007).

Design allowances (not part of contingency) included in the Management Reserve in Figure 3 would be intended to cover a probability of a project overrun (Lawrence, 2007; Emerald, 2016). Lawrence (2007) further made the point that contingency is not a fund for scope changes, since it is related to the project scope as estimated/defined. The contingency may also be a hedge against improper or incomplete estimates and can differ across various components of the project (Rupprecht, 2004).

The capital cost estimate should always be expressed with reference to a level of desired probability (e.g., this is a ±10% estimate, within an 80% probability range) (Lawrence, 2007), or as cost ranges (the minimum possible cost and the maximum possible cost) (Emerald, 2016).

Presenting a capital estimate of, say USD500m, to the nearest cent (e.g., USD500 258 175.93) does not increase one's confidence in the accuracy of the estimate. Within the typical accuracy ranges of capital estimates, to present a total with this level of significant figures is in fact meaningless. At feasibility study stage, the designs are generally not yet of sufficient detail to enable construction to commence, so quantities extracted from the designs remain *estimates.* Perhaps capital cost estimates should be rounded to appropriate significant figures to reflect the uncertainty in the estimate, like the reporting of mineral resource and mineral reserve tonnage estimates.

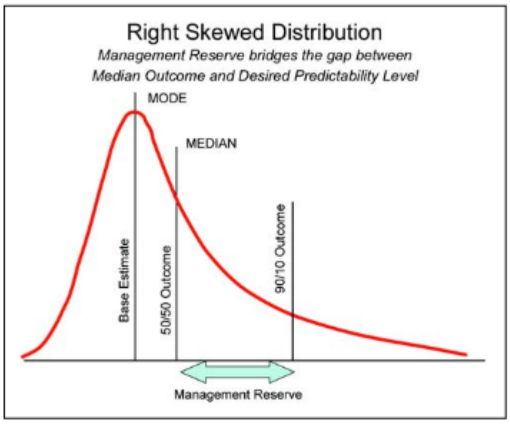


Figure 3. Right skewed distribution of capital costs [source: Lawrence, 2007].

Inclusion of a contingency of <10% at feasibility study level still does not adequately cater for the cost overruns seen in practice, as shown above.

HOW TO ADDRESS THE UNCERTAINTIES

A valuation based on a cash flow model is not a fact, but rather an estimate of the most probable of a range of outcomes based on the assumptions made (Aronsohn, 2020). Valuation uncertainty is not the same as market risk (Aronsohn, 2020). In a DCF model, the cash flow inputs are based on current expectations of future performance and are therefore uncertain (Aronsohn, 2020).

The sensitivity of the NPV of the after-tax cash flows of a mining project to variations in revenue, capital and operating costs has been typically evaluated in the range -15% to +15%. This range is clearly not sufficient to cover the volatility in metal prices, range of outcomes in project capital costs and degree of contingencies to be applied, as discussed above.

While Figure 1 gives a visual snapshot of project sensitivity, it is more informative to present the data in a twin-sensitivity table where the effect of combined changes in revenue and capital cost is shown. Based on the above review, wider sensitivity ranges for revenue and capital cost are considered to cater for the identified uncertainties, say -30% to +40% for revenue and -10% to +100% for capital costs (+60% for cost overruns, +25% for project delays (Table IV) and +15% for contingencies/allowances.

By flexing the revenue sensitivities to -10.7% (instead of -10%) and +11.2% (instead of +10%), the project's sensitivity to capital cost changes under respectively consensus forecast prices and spot prices is incorporated into Table V [The NPVs at 8% discount for forecast prices (-USD56m) and spot prices (USD448m) are highlighted in blue].

The extreme range of -USD1 509m to USD1 156m in Table V would be too wide, i.e., meaningless, in terms of VALMIN (2015), yet these are probable outcomes with essentially equal chance of occurrence, which is not the case. Skewed probability distributions (as shown in Figure 4) are then applied to the revenue and capital sensitivities, to generate a probability-weighted revenue-capital sensitivity plot, as shown in Table VI.

Table V. Illustrative twin-sensitivity of project NPV to changes in revenue and capital cost, with expanded sensitivity ranges

NPV at 8% (USDm)	Revenue Sensitivity							
Basket Price (USD/oz)	1 217	1 390	1 553 (Consen)	1 738 (3-yr Av.)	1 813 (Spot)	2 086	2 259	2 433
Capital Cost Sensitivity	-30%	-20%	-10.7%	0%	+11.2%	+20%	+30%	+40%
-10%	-504	-211	18	264	517	713	935	1 156
0%	-596	-290	-56	194	448	646	869	1 090
+10%	-687	-371	-131	122	379	578	801	1 023
+20%	-778	-453	-208	50	309	509	734	957
+30%	-870	-537	-285	-23	238	440	666	889
+40%	-961	-622	-364	-98	167	370	597	821
+50%	-1 052	-710	-443	-173	95	300	528	753
+60%	-1 144	-801	-524	-249	22	228	458	684
+70%	-1 235	-893	-606	-326	-52	156	387	615
+80%	-1 326	-984	-688	-404	-127	84	317	546
+90%	-1 418	-1 075	-772	-483	-202	11	245	475
+100%	-1 509	-1 167	-856	-562	-278	-63	173	405

Note: Basket price is the weighted price for the combined Pt, Pd, Rh, Au, Ru and Ir prices times the prill splits.

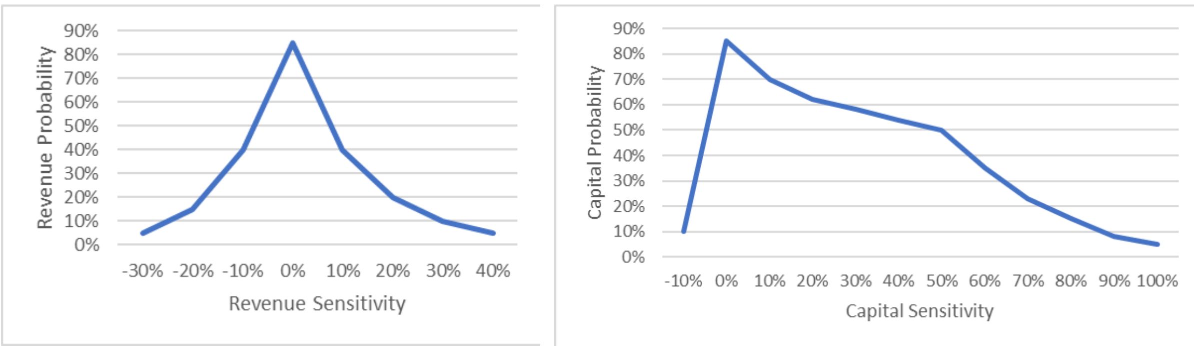


Figure 4. Skewed probability curves for revenue and capital cost.

Table VI. Illustrative probability-weighted twin-sensitivity of project NPV to changes in revenue and capital cost

Weighted NPV Sensitivity at 8% (USDm)		Revenue Sensitivity							
		-30%	**-20%**	**-10.7%**	**0%**	**+11.2%**	**+20%**	**+30%**	**+40%**
		Revenue Probability of Lower/Higher Occurrence							
Capital Cost Sensitivity	**Capital Cost Probability of Overrun Occurrence**	5%	15%	40%	85%	40%	20%	10%	5%
-10%	10%	-3	-3	1	22	21	14	9	6
0%	85%	-25	-37	-19	140	152	110	74	46
+10%	70%	-24	-39	-37	73	106	81	56	36
+20%	62%	-24	-42	-51	26	77	63	45	30
+30%	58%	-25	-47	-66	-12	55	51	39	26
+40%	54%	-26	-50	-79	-45	36	40	32	22
+50%	50%	-26	-53	-89	-74	19	30	26	19
+60%	35%	-20	-42	-73	-74	3	16	16	12
+70%	23%	-14	-31	-56	-64	-5	7	9	7
+80%	15%	-10	-22	-41	-52	-8	3	5	4
+90%	8%	-6	-13	-25	-33	-6	0	2	2
+100%	5%	-4	-9	-17	-24	-6	-1	1	1

I consider that the entries in Table VI should be interpreted for valuation purposes as follows:

- The sum of all probability-weighted entries is USD122m – this is the most probable value per the cash flow approach. Note that the 85%/85% probability entry of USD140m is reasonably aligned to this;
- Range - minimum of -USD89m to maximum of USD152m (highlighted in Table VI).

CONCLUSIONS

In a cash flow model, the uncertainties in the metal price forecasts should be addressed by considering the percentage differences between the median forecast and the maximum and minimum forecasts, in conjunction with the range in price volatility over several commodity cycles per Somerville (2015). These will provide the minimum and maximum range limits for assessing revenue sensitivity, which are likely to be commodity-specific. In this paper, I considered that -30% to 40% was suitable for illustrative purposes. In addition, comparative NPVs at different discount rates using spot and three-year trailing average prices should also be presented as a further test on project sensitivity.

The range limits for capital cost sensitivity in a cash flow analysis should be widened to cater for the probability of cost overruns, project delays and contingency shortfalls. Based on the reviews in this paper, I recommend that this range should be -10% to +100%, even for a feasibility study. This would support the conclusion of Nieto *et al*, (2024) that Competent Persons responsible for preparing technical reports should be extremely conservative with the ranges of precision and contingencies contemplated in each phase.

The impact of delays in project implementation cannot properly be assessed by a simple factor on the capital costs, as used above. The cash flow analysis would have to model this by postponing the start of the mining operations. In the process, the impact of extended capital cost period and opportunity cost for lost sales/revenue can be assessed.

Given the uncertainty in the forecast metal prices and capital cost estimates vs completed construction costs, it is unlikely that a cash flow analysis can truly satisfy the ±10% confidence requirements of a feasibility study for a mining project. It is therefore critical to evaluate the sensitivity of a project to such uncertainties.

Aronsohn (2020) cautioned that any report should provide a clear understanding of the valuation with minimum complication. However, as discussed above, uncertainties in metal price forecasts and probability of capital cost overruns are significant and could "expose the commissioning entity or a third party relying on the valuation to significant risk or loss" if not fully disclosed (Aronsohn, 2020). Aronsohn (2020) concluded that:

- Any test of valuation uncertainty should address the impact on the reported value of reasonable and likely alternative assumptions;
- The objective of any uncertainty analysis is to provide information about the variability of the value at the effective date of the valuation;
- When quantifying the impact of uncertainty, the interdependence between significant inputs should be considered.

The twin-sensitivity plot with expanded sensitivity ranges and evaluated on a probability-weighted basis as presented in this paper satisfies these conclusions.

NOMENCLATURE

Au	chemical symbol for gold
Cu	chemical symbol for copper
DCF	discounted cash flow
IFRS	International Financial Reporting Standard
IRR	internal rate of return
lb	pound, imperial weight unit
NPV	net present value
oz	troy ounce (unit of measurement for precious metals)
Pd	chemical symbol for palladium
USD	United States Dollar
USD/lb	US Dollar per pound
USD/oz	US Dollar per ounce
USDm	million United States Dollars

APPENDIX 1

Set out here are the consensus median, minimum and maximum real forecast prices provided by participating commercial and/or investment banks for Cu, Au and Pd as issued in December 2020 (UBS, 2020), which are used for illustrative purposes. The detailed forecasts and names of the participating banks have been removed to maintain confidentiality. The information is sourced from a MS Excel file in which UBS AG provided input, which was shared with the author by Mr D Riley of Sedibelo Resources Ltd in May 2021. The deviation of the minimum and maximum from the median in each year is reported as a percentage difference.

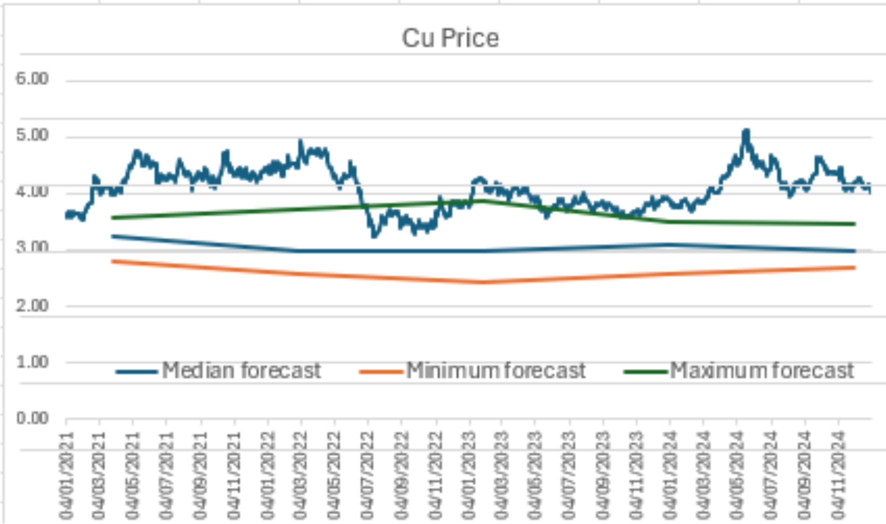
The median, minimum and maximum real forecast prices from each data set are superimposed on the historical Cu, Au and Pd prices over equivalent time periods. The vertical scales of the real forecast prices are adjusted to align with those of the historical prices. The horizontal scales are stretched to as closely as possible match the two timelines.

The real Cu price forecasts track the actual prices, though somewhat lower, understating value. The real Au price forecasts all track down in the later periods, completely opposite to what was witnessed in the market (understating value). The real Pd price forecasts track the actual price, where the minimum forecast provides the better fit for the longer term (the median would overstate value).

These findings are consistent with the observations of McDonald (2016). Forecasts are dependent on market conditions, sentiment and are unable to predict surprise events.

Copper

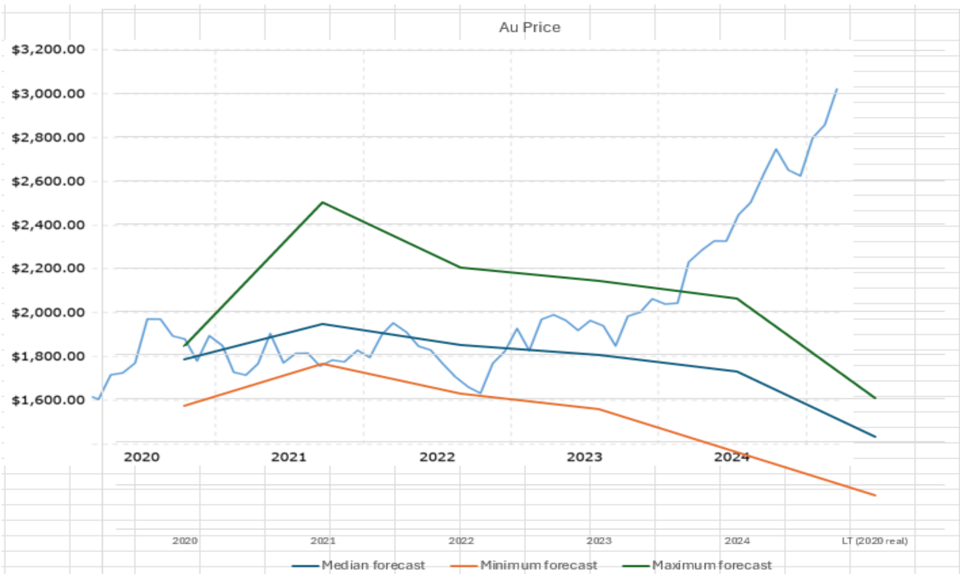
Copper (USD/lb)	2020	2021	2022	2023	2024	LT (2020 real)
Consensus (Median)	2.77	3.23	3.02	3.00	3.10	3.00
Minimum	2.72	2.85	2.66	2.53	2.65	2.75
Maximum	2.80	3.50	3.63	3.75	3.45	3.40
No of forecasts	20	21	18	17	12	14
Min (relative to Median)	-1.8%	-11.8%	-11.9%	-15.7%	-14.5%	-8.3%
Max (relative to Median)	1.2%	8.4%	20.2%	24.9%	11.3%	13.4%



Historical Cu prices sourced from: Macro Trends, https://www.macrotrends.net/1476/copper-prices-historical-chart-data, accessed 23 March 2025.

Gold

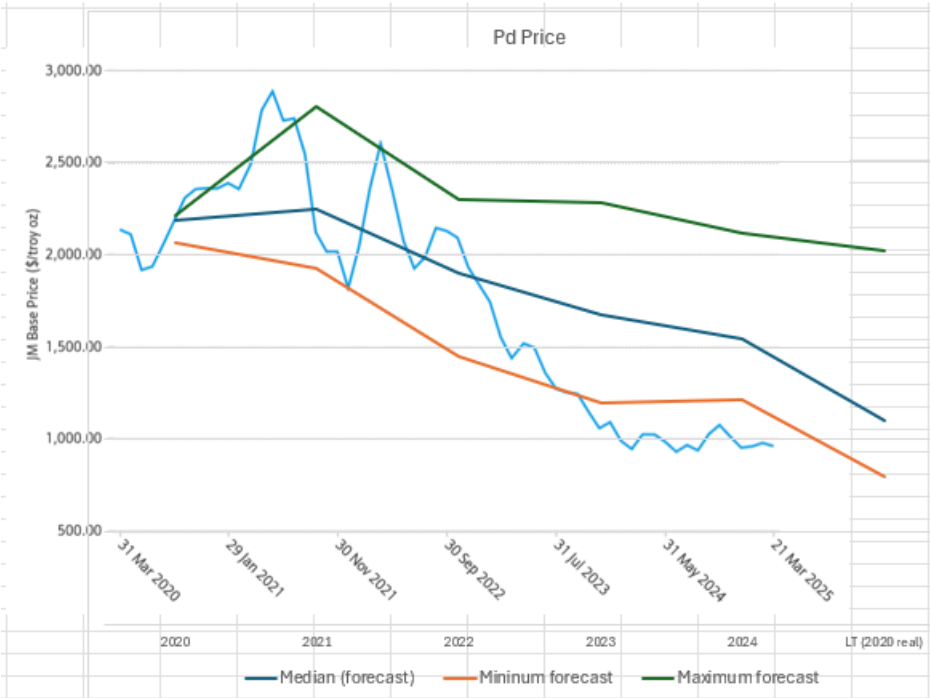
Gold (USD/oz)	2020	2021	2022	2023	2024	LT (2020 real)
Consensus (Median)	1 777	1 940	1 843	1 800	1 725	1 425
Minimum	1 563	1 760	1 622	1 550	1 350	1 155
Maximum	1 841	2 500	2 200	2 138	2 060	1 600
No of forecasts	21	22	20	17	12	12
Min (relative to Median)	-12.0%	-9.3%	-12.0%	-13.9%	-21.7%	-18.9%
Max (relative to Median)	3.6%	28.9%	19.4%	18.8%	19.4%	12.3%



Historical Au prices sourced from: Macro Trends, https://www.macrotrends.net/1333/historical-gold-prices-100-year-chart, accessed 23 March 2025.

Palladium

<u>Palladium (USD/ oz)</u>	2020	2021	2022	2023	2024	LT (2020 real)
Consensus (Median) Minimum Maximum	2 189 2 064 2 215	2 245 1 925 2 800	1 900 1 450 2 300	1 673 1 200 2 281	1 549 1 219 2 116	1 100 800 2 025
No of forecasts	16	16	14	12	8	11
Min (relative to Median) Max (relative to Median)	-5.7% 1.2%	-14.3% 24.7%	-23.7% 21.0%	-28.3% 36.4%	-21.3% 36.6%	-27.3% 84.1%



Historical Pd prices sourced from: Johnson Matthey, https://matthey.com/products-and-markets/pgms-and-circularity/pgm-management/, accessed 23 March 2025.

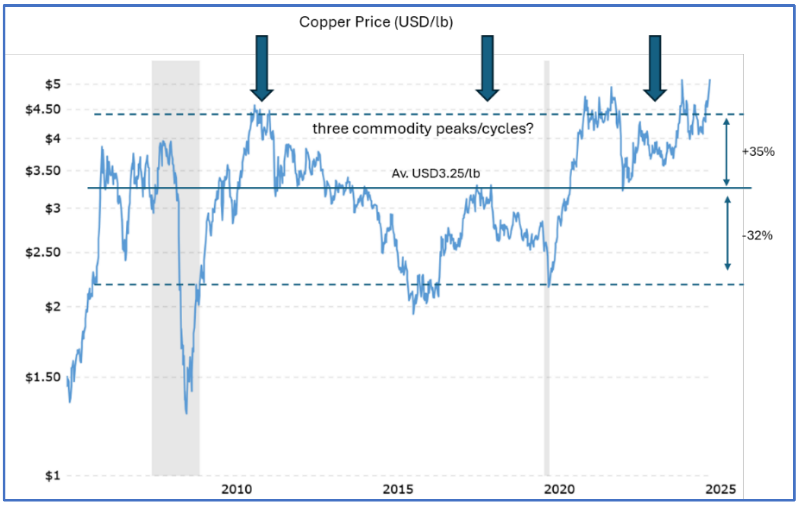
APPENDIX 2 – INTERPRETED COMMODITY CYCLES

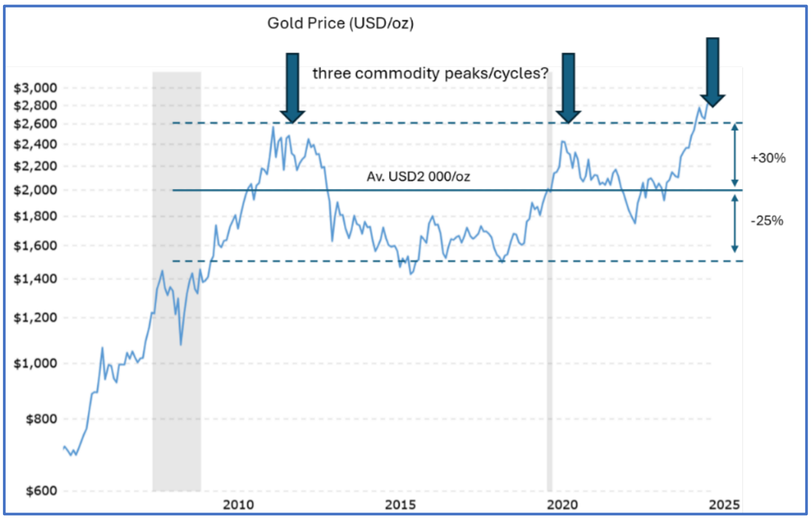
Set out below are historical prices for Cu, Au and Pd. Within each historical price chart, the following interpretations are introduced:

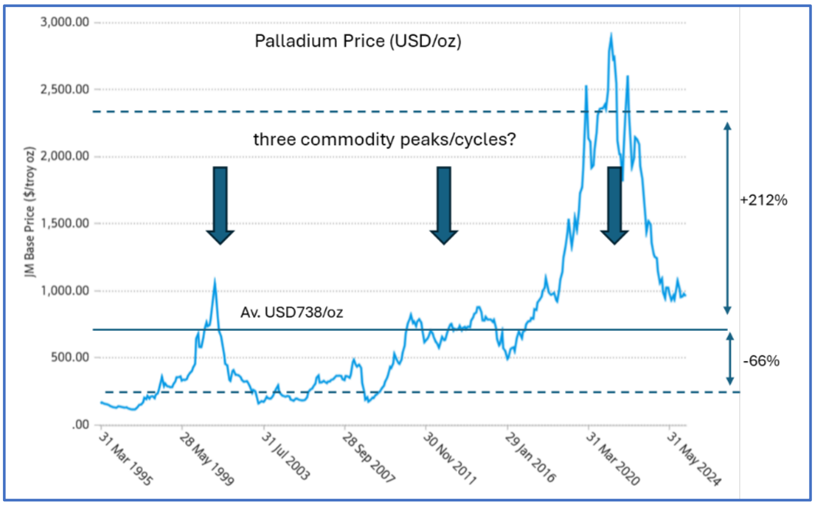
- Peaks of potential commodity cycles marked by arrows;
- The average price to use as reference (solid line);
- The maximum and minimum prices during the timeframe (dashed lines).

Following the recommendations of Somerville (2015), the interpreted ranges for sensitivity analyses to assess the influence of price volatility of Cu, Au and Pd are as follows:

Item	Range below/above Average
<u>Copper (USD/lb)</u> Min (relative to average) Max (relative to average)	 -32% +35%
Gold (USD/oz) Min (relative to average) Max (relative to average)	 -25% +30%
<u>Palladium (USD/ oz)</u> Min (relative to average) Max (relative to average)	 -66% +212%







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The challenge and opportunity of integrating environmental, social and governance-sustainability metrics into strategic long-term mine planning

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The minerals and metals extractive industry operates at the intersection of multiple ecosystems and society, resulting in mining operations developing as complex adaptive systems (CAS). These systems evolve in response to internal and external influences to exhibit adaptive and emergent behaviours in response to economic, environmental, social, and governance (ESG) factors throughout the life of a mine. These ESG system factors continuously adapt to shifts in regulation, ecological concern, and social dynamics making integration of stakeholder ESG impacts into life-of-mine (LOM) planning crucial. Concurrently multi-generational sustainability expectations will diverge from initial project optimisation assumptions, affecting LOM planning assumptions and closure cost requirements, necessitating scenario-driven, dynamic LOM perspectives. To address these challenges, ESG factors should be effectively integrated into strategic long-term planning tools and processes. This involves identification and quantification of ESG criteria for inclusion as economic modelling attributes to reflect financial impacts of evolving ESG demands over anticipated LOM strategic scenarios. Such an approach offers improved insights into likely operational economic envelopes under diverse scenarios, guiding mineral resource modifying factors, LOM planning, and mine closure strategies.

INTRODUCTION

Mining is a complex adaptive system that operates at the intersection of natural and industrial ecosystems with society and evolves in response to internal and external influences whilst exhibiting emergent behaviour over time. Mining and beneficiation activities therefore have significant spatial and temporal impacts on the environment and on society, and as such they continuously adapt to shifts in regulation, ecological concerns and social dynamics. In this context, multi-generational sustainability expectations will diverge from the initial business planning assumptions necessitating a strategic, scenario driven, dynamic, life-of-mine (LOM) planning approach. To address these challenges, the economic, environmental, social, and governance (ESG) system factors should be effectively integrated into strategic long-term planning tools and processes.

Characterising the spatial and temporal dimensions of mineral resource development projects is thus critical for understanding their present and future risk and opportunity profiles. This involves identifying and quantifying critical ESG-sustainabiity (S) criteria for inclusion as economic modelling attributes that reflect financial impacts of evolving ESG demands over the anticipated LOM. Such an approach offers improved insights into business economic envelopes under diverse scenarios, guiding mineral resource modifying factors, LOM planning and mine closure strategies.

Thus, the identification, quantification and inclusion of ESG-S criteria, at an appropriate estimate level, in LOM planning and optimisation is necessary, and acknowledgement of spatial and temporal impacts, through scenario-based planning, is necessary to identify likely business operating envelopes and enable system optimisation.

Mining activities have both temporal and spatial impacts over life-of-mine

Mining activities are integrated from discovery to relinquishment which results in cumulative ESG-S impact with the characteristics of the mineral resource being the primary driver of this cumulative impact. Mineral deposit geometallurgy drives processing technology selection, scale, recovery, capex and opex requirements whilst the geometry and physical nature of the orebody define mining method and technology selection, scale, dilution, lead time to production, capex and opex. Concurrently market demand and pricing evolve in a shifting ESG context. The timeline of this cumulative impact from discovery to relinquishment can be decades to hundreds of years, depending on the nature and scale of the orebody.

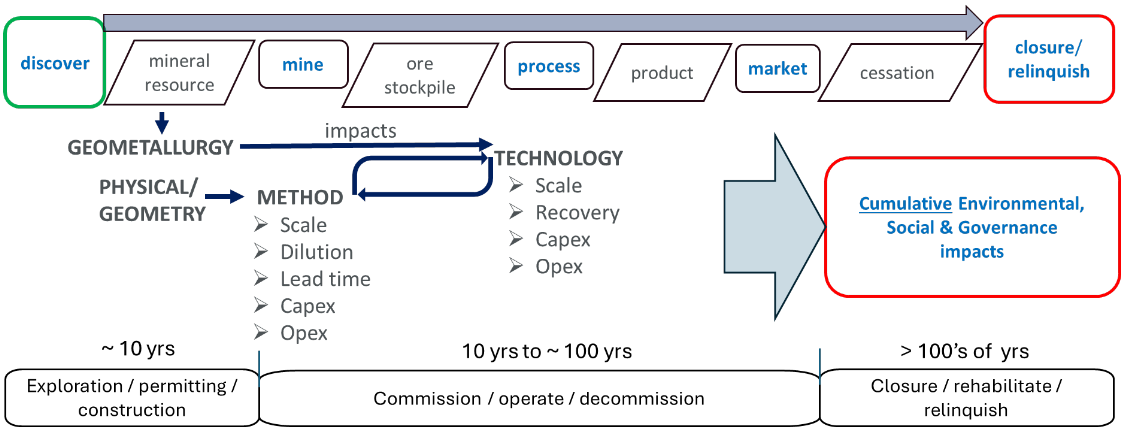

Figure 1. Mining activities: Integrated from discovery to relinquishment with cumulative impacts.

Lechner *et al.*, (2017) broadly considered the impact of coal mining on society, the environment and economy relative to time and location. The core messaging of the study being that social and economic impacts (both positive and negative) predominately impact local and regional areas during the construction and operating phases whilst environmental aspects persist spatially across all areas, from local to global extent, across all timescales.

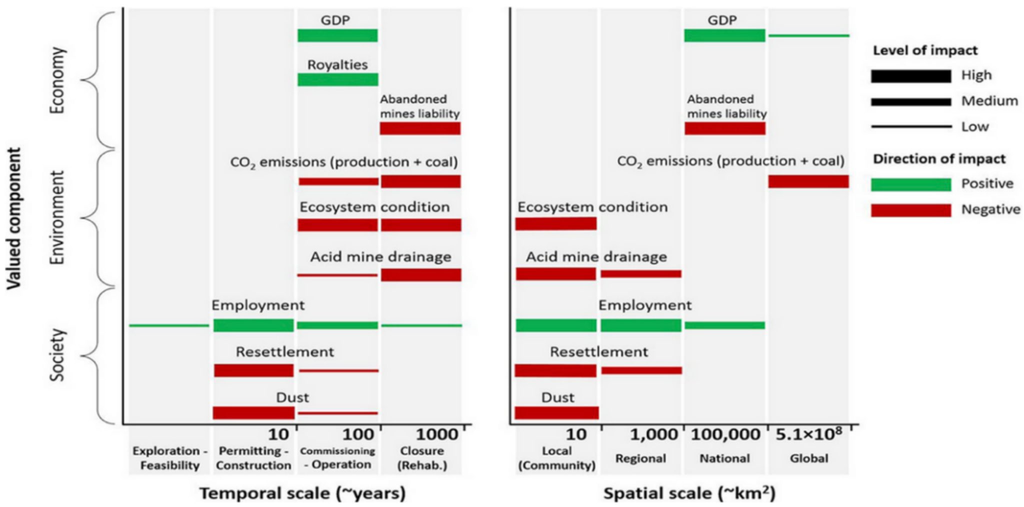

Figure 2. Temporal and spatial impacts over life-of-mine (after Lechner, A.M., et al., (2017)

Mining impact indicators - Integration

Mineral and metal extractive processes have social and environmental impacts which influence sustainability aspects such as the natural ecosystem, water resources and community livelihoods, health and safety which can be characterised by various indicators. Consider a simple example of vegetation loss associated with mining activities: vegetation loss increases erosion and affects species viability which in turn affects overall ecosystem health which can be measured by indicators such as biodiversity and genetic diversity. Depending on where this occurs (spatial) and when (temporal), is driven by mining operations over the LOM. The primary challenge lies in identifying and quantifying the causal relationship whilst taking cognisance of the temporal and spatial nature of extractive operations.

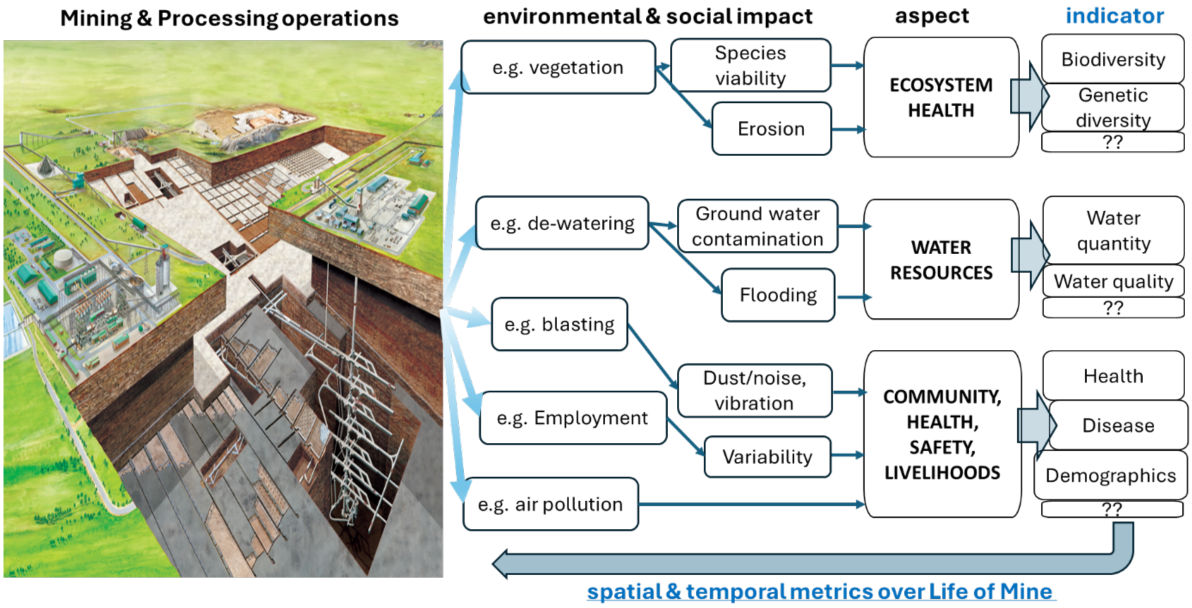

Figure 3. Example of the relationship of mining activity to ESG indicators.

Given that the fundamental asset of any mining company is the mineral endowment, it is rational to embed ESG decision factors as early as possible into LOM planning processes. A possible mechanism lies in improved application of ESG criteria in Mineral Reserve modifying factors. Modifying factors are the criteria considered in converting a Mineral Resource to a Mineral Reserve and embrace consideration of mining, metallurgical, economic, marketing, legal, and ESG factors. An interesting approach by Nehring and Knights (2024) applies ESG factors through the Quality Function Deployment (QFD) logic to LOM planning from initial Mineral Resource definition to relinquishment as indicated in Figure 4.

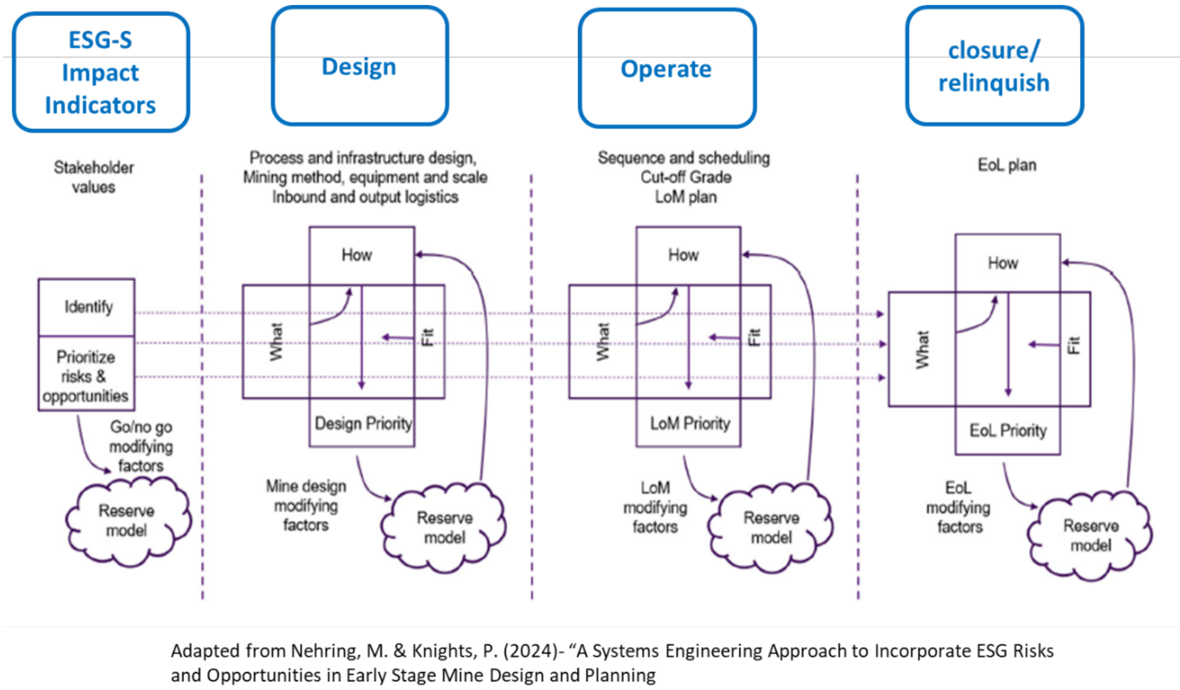

Figure 4. Integrated mine design and planning – ESG indicators and modifying factors.

Identifying the impact of ESG factors on extractive activities and how they relate to stakeholder (not only shareholder) value is followed by prioritisation of risk and opportunities to create a first set of go/no-go factors which provide a first filter for Mineral Resource definition. At the design stage, consideration of the impact of ESG factors on Mineral Reserve definition is done through the QFD logic of What factors, How do they impact design, Does the approach adequately address the concern (the Fit) and How does the combination of the What, the How, and the Fit impact design which in turn affects the resource to reserve conversion modifying factors? This logic is reapplied in the operational phase for ongoing operational LOM planning and ultimately closure planning.

However, implementation of this modifying factor-based approach relies on adequate identification and quantification of impact indicators; understanding how they may vary over time and effective integration with mine planning tools and processes. The conceptual relationship of ESG indicators as spatial and temporal metrics to mine planning via modifying factors is represented in Figure 5 where the key enabler is inclusion in the Mineral Resource block model. The block model which underpins the mine design and optimisation activities can be utilised to link ESG-S indicators to specific geometallurgical domains. Similarly digital terrain models, augmented with ESG risk/opportunity dimensions, can inform surface spatial impacts over time.

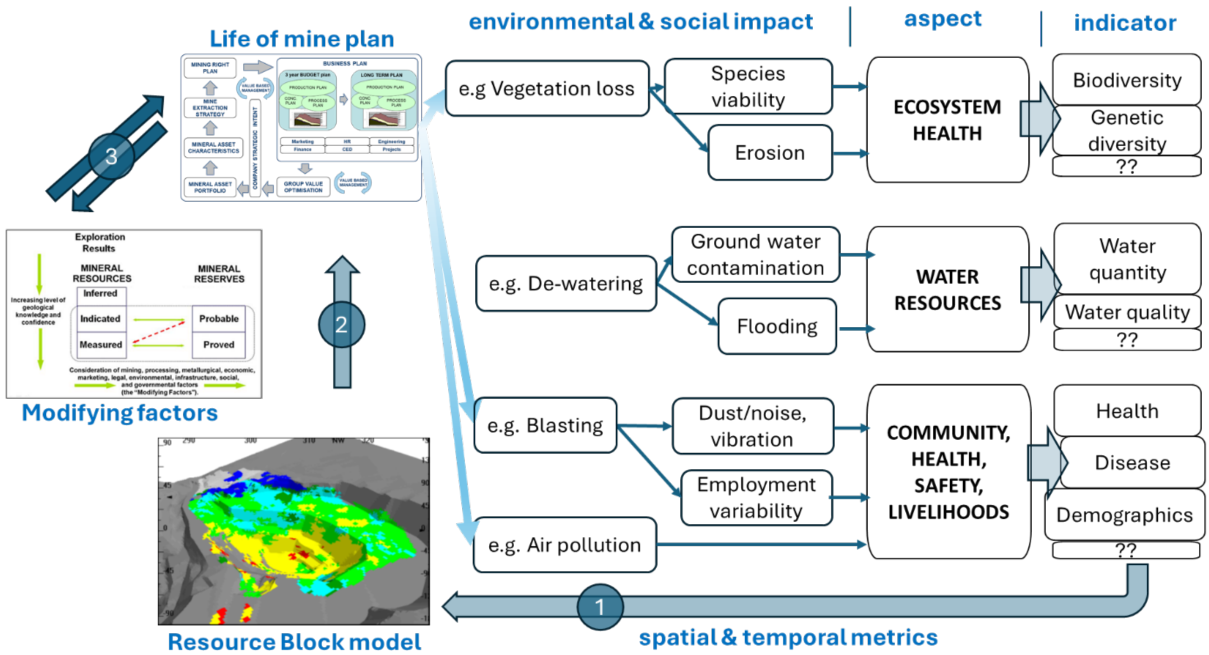

Figure 5. Integrated mine design and planning – ESG indicators and resource block model.

As a specific example, Figure 6 expands on the concept of energy demand for mining and recovery operations linked to SO_2 emissions based on chemical and physical properties in the block model geometallurgy domains as articulated by Manjengwa (2025). For a given domain, the energy demand per unit production is converted to SO_2 emissions associated with coal-fired electrical energy utilised for extraction that results in environmental and social impacts for which the remedial costs for a scheduled extraction location at a given time can be estimated. The associated ESG-S impacts, mitigations, cost, location, and time thus feed from block model data into the modify factors and LOM planning and optimisation processes.

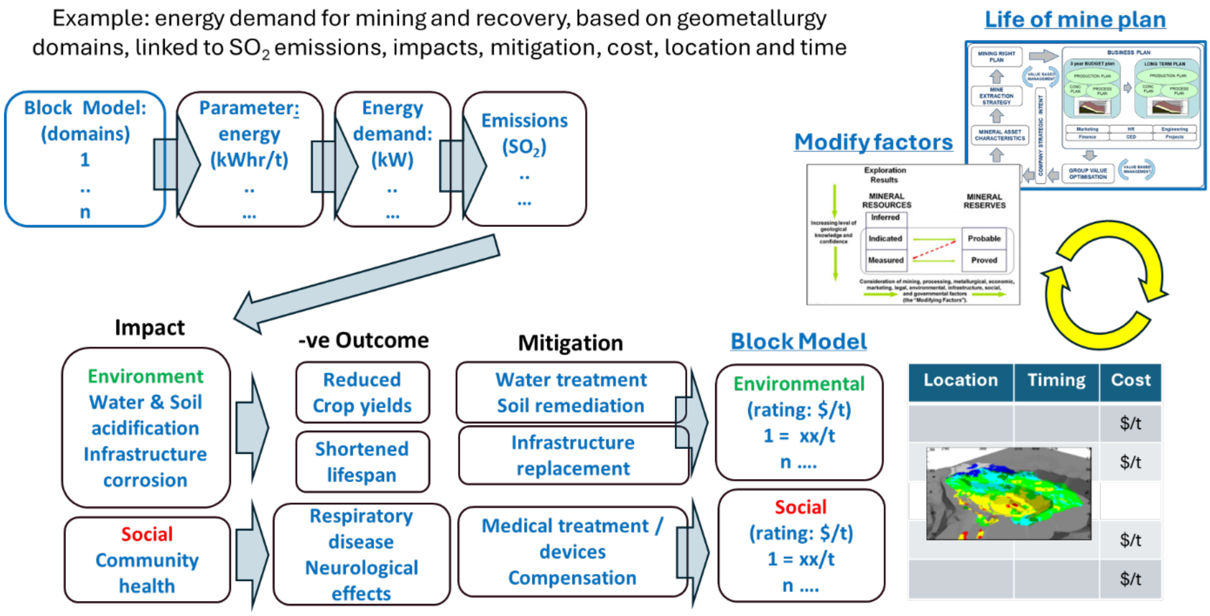

Figure 6. Integrated mine design, planning, and execution – block model and ESG-S impact indicators.

ESG, Modifying Factors and life-of-mine planning
Initial evaluation of Reasonable Prospects of Eventual Economic Extraction (RPEEE) is a crucial factor for conversion of Mineralisation to a Mineral Resource. Application of ESG-S factors may feature on a go/no go basis for well-defined situations related to, for example, highly endangered biodiversity or extreme human toxicity cases. However, for most orebodies effective inclusion of ESG factors into the Mineral Resource to Mineral Reserve conversion process requires that ESG modifying factors are included in planning and optimisation activities and estimated at the same level of accuracy (pre-feasibility/feasibility study level) as other technical and financial elements over the expected spatial and temporal impact zones. This requires spatially and time-dependent ESG economic attributes for orebody geozones and surface topographies developed through scenario-based planning.
In this context stakeholder value drivers are varied and evolve with societal expectations over time and can cover dimensions such as:

- **Environment** (GHG emissions, biodiversity, water use and access, water quality, air quality, noise, non-mineral waste: recycling, tailings and mineral waste management).
- **Society** (culture and heritage aspects; land access and resettlement; meaningful participation; mutual benefits; social licence to operate).
- **Workforce** (occupational health and wellbeing; inclusion and diversity; skills, training, and career development).
- **Local communities** (social dimensions, livelihoods, benefits, community education, community health and safety; human rights and governance; meaningful participation).
- **Customers** (commercial licence to operate; security of supply; product quality and consistency; growth; product stewardship and trust; circularity).
- **Suppliers** (commercial licence to operate; supplier capacity building; product stewardship and trust; circularity).
- **Government** (tax and royalty contribution; employment growth; local, municipal, and provincial development).
- **Shareholders** (growth, returns, risk and opportunity).

Many of these stakeholder value drivers are quantifiable and can be included in a Resource block model. These are those that would fit into the 'yes/yes' quadrant of the 2 x 2 block model inclusion difficulty matrix in Figure 7 and typically are environment- or governance-related owing to relative ease of measurement and quantification e.g., water, land use rehabilitation or royalty-related. However, associated spatial, temporal and cost estimates are often coarsely defined e.g., large area rehabilitation at end of life of mine based on volume estimates and escalated cost without effective cross-linking to the social dimension such as post-closure landform utilisation.

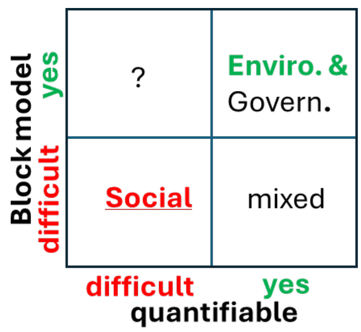

Figure 7. Block model / ESG factor inclusion difficulty matrix.

The social aspects in the 'difficult/difficult' quadrant are challenging and generally less well-defined but can pose significant risks to later mine life RPEEE and LOM planning. As an example, for a mine started in a low population density, rural area 50 years ago: two mine salary-educated generations later, in the midst of village and community infrastructure enabled by the mining company's social investment and sustained by mine employment; is it unreasonable that social expectations of water

availability would have changed from extracting and transporting water by containers from streams to piped, potable water to the home? It is thus important to capture the when, where, how and at what cost dimensions in LOM planning, relative to the directly associated ore extraction blocks, to effectively address the modifying factors. Scenario-based long-term planning would enable translation into business-level, strategy-driven initiatives to ensure accountability, mitigate cost to mining operations, reduce risk to RPEEE at end of LOM and allow ultimate relinquishment of mining rights.
Overall, there is a need to reconsider approaches to:

- Identification and prioritisation logic for ESG impacts.
- Impact quantification logic and associated mitigation estimates.
- Block model integration; and
- Spatial and temporal impact logic through scenario-based planning.

An identification and prioritisation logic for ESG impacts has been proposed Yu *et al.*, (2024) in the development of a Mining Area Sustainability Index (see Figure 8). This initial work analyses and prioritises nine ESG-S indicators based on impact but unfortunately currently lacks direct linkages to mine planning and optimisation processes. It also does not address the so-called 'Tangible Uncertainties' or 'Known Unknowns' which are best quantified through scenario-based strategic long-term planning. Tangible Uncertainties are the recognised uncertainties where outcomes cannot be predicted with sufficient certainty and are usually excluded from planning risk assessment e.g., evolution of environmental awareness and activism, social response to post-closure obligations, regulatory change, and innovation in remediation technology which can be addressed through scenario- based planning.

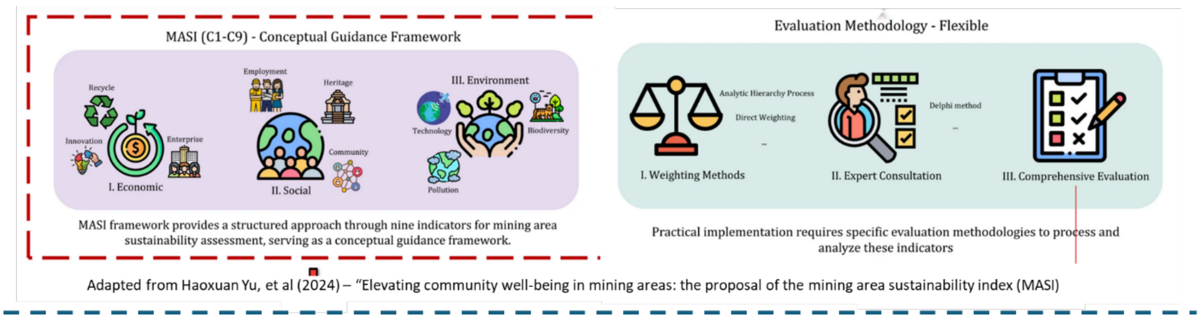

Figure 8. ESG indicator approach – Mining Area Sustainability Index (Yu. et al., 2024).

CONCLUSION

Mining is a complex adaptive system that operates at the intersection of natural and industrial ecosystems with society and, as an adaptive system, evolves in response to internal and external influences, with emergent behaviour, over time.

Mining extractive activities have significant spatial and temporal impacts on the environment and society which drive evolving ESG–S demands that continuously adapt to shifts in regulation, ecological concerns, and social dynamics. Concurrently, multi-generational sustainability expectations will diverge from initial business planning assumptions over time, necessitating strategic scenario-driven, dynamic LOM planning to address evolving RPEEE.

The effective inclusion of ESG-S criteria in mine planning is an evolving and challenging aspect of strategic long-term planning and mine valuation that requires attention, specifically:

- That the identification, quantification, and inclusion of ESG-S criteria, at an appropriate estimate accuracy, in LOM planning and optimisation processes is necessary to address closure and relinquishment risk.

- This can be achieved through ESG-S impact-attributed inclusion in Mineral Resource block models and LOM planning processes.

- Acknowledgement of spatial and temporal impacts, through scenario-based strategic long-term planning, can identify likely business operating envelopes, and enable value optimisation.

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Meeting mineral supply demand for the energy transition - improving mine project development timeframes

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INTRODUCTION

There are long lead times to bring new mining projects into production and these have a material consequence for meeting the increasing demand for metals and minerals arising from the transition to a green energy-powered economy.

Accelerating the development timeframes of new mines raises concerns with stakeholders over what this may mean for: 1) the confidence in investment and lending decisions, and 2) the responsible development and operation of these new projects/mines. This is especially pertinent since the mining industry is widely considered to still be on a journey to improving its approach to social and environmental dimensions. There is also concern that the primary causes of project delays are not well understood, and can have complex, cascading interactions throughout the development cycle. A wide range of factors are identified, including operational procedures, company governance frameworks, financing, policy and regulatory environments, community acceptance and technical challenges.

The paper provides preliminary perspectives on the challenges and opportunities for improving mine project development timeframes.

Aim

The aim of this project is to scope, at a preliminary level, the challenges and opportunities involved with fast and efficient development of mining projects. It is intended that this study will develop the methodology that underpins a more comprehensive future research programme (Phase 2). Ultimately, a practical guide will be produced that will be available to all stakeholders that details the key considerations associated with the responsible development of a new mine within an accelerated timeframe. This will include new approaches being developed or implemented by industry, governments and regulators to reduce project development timeframes and present the risks and proposed controls to effectively provide for responsible decisions and activities when accelerating the development of new mines.

We frame the investigation against the question whether the current mine development and mining practices are as efficient as they could be in technical and policy coordination terms without compromising the environmental, social and governance (ESG) aspects of the operations, community consultation and consent.

The prospect of faster (accelerated) and effective mine development offers several significant advantages, such as working towards the timely delivery of the much-required energy transition mineral and metal (ETMs) resources and products to meet the globally-set decarbonisation / green energy transition targets, as well as quicker financial returns on investment.

Preliminary Outcomes

Currently, the long timeline (>20 years) for developing a mining project is identified as a key challenge for individual countries and globally to address the dual priorities of climate action and economic recovery, influencing how mining companies respond to the supply demand for metals and minerals (Owen *et al*., 2022)[1].

Our research indicated that if metal and mineral supply through mining is central to achieving the energy transition process, then any shortening of the entire process requires decisions to be grounded on sound ESG principles to prevent unexpected hold-ups in the process and to facilitate streamlined permitting processes with clear timeframes. In examining the opportunity for accelerating the development of new mining projects, it is important to understand and incorporate how social and environmental concerns can be addressed comprehensively when planning and executing large-scale mining operations in the expected timeframes, or if this may place a limit on the ability to accelerate timeframes.

Overall, while company's internal mine project assessment and study processes, effective environmental impact assessment, and improved management and permitting processes provide an opportunity for project development acceleration, it is essential to balance speed with a holistic approach to manage the risks associated with mining project development. Bonakdarpour *et al*., 2024[2] note a mine's development is itself a resource-intensive undertaking which is typically a long and costly process. As such, alignment on the end-goals among the government agencies is one of the keys to the success of the green energy transition.

In this preliminary review, we have mapped out the typical processes for permitting, approval and investment decision-making that apply to mining project development. This draft framework notes the importance of embracing innovative and sustainable practices in current and accelerated contexts. Additionally, we review current industry-standard mine project development processes and considerations, highlighting common knowledge gaps, to provide a framework to better risk-manage the acceleration of the timelines to support the transition to green energy, and that align with the global sustainability goals.

Since the intent is for this preliminary investigation to feed into the scoping of a future comprehensive study (Phase 2) we identify several questions for consideration, as well as provide interpretations and recommendations for consideration in the presentation.

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Is the net present value of a preliminary economic assessment indicative of the market value of a mineral property?

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A preliminary economic assessment, also known as a scoping study, is often the initial evaluation of a mineral property after mineral resources have been delineated. Its main purpose is to determine if the property offers sufficient encouragement to justify further expenditures to collect more data for more rigorous economic analysis. For gold properties in Canada and USA, a discount rate of 5% is commonly used for cash flow analysis in the preliminary economic assessment to calculate the net present value (NPV)—that is, the present-day value of projected future cash flows. This paper examines whether the NPV at this discount rate is a reliable indicator of the property's market value.

To investigate this question, information was compiled on numerous properties in Canada and the USA with preliminary economic assessments completed over the past decade. For properties that were bought and sold, the after-tax NPV from the preliminary economic assessment was compared with the market value reflected in the transaction. For properties that did not transact, the after-tax NPV was compared with the adjusted market capitalisation (AMC) of the junior company for which the property was the major asset. In these cases, the AMC served as a proxy for the property's market value.

The analysis indicated that the NPVs reported in preliminary economic assessments were significantly higher than both the transaction market values and the AMCs. To reconcile these differences, an implied discount rate in the range of 15% to 25% would generally be required.

Keywords: Preliminary Economic Assessment, Net Present Value, Discount Rate, Market Value, Mineral Property Valuation, Gold Properties

INTRODUCTION

A preliminary economic assessment (PEA), a Canadian term for a scoping study, is often the first stage of economic evaluation of a mineral property. Its purpose is to formulate a general idea of how the property might be developed, to assess its economic potential and, if there is sufficient encouragement to justify further expenditures, recommend collecting additional data for more rigorous economic analysis.

It is important to distinguish between evaluation and valuation. Evaluation refers to an assessment of the physical, technical, legal, economic, or other aspects of a mineral property that may inform an investment decision. Evaluations include feasibility studies, prefeasibility studies, PEAs, and scoping studies. Valuation, on the other hand, refers to the estimation of the value of a mineral property in monetary terms.

PEAs and scoping studies can have accuracy ranges of ±30 % to ±50 % or more for capital and operating costs and, in our experience, the reality is rarely on the minus side. Technical and cost parameters and the results of scoping stage studies are more uncertain than those of more advanced evaluation stages, such as prefeasibility and feasibility studies. A scoping study therefore represents higher risk than more advanced studies.

One measure of the overall risk of a mineral project is the discount rate used in the economic model. Theoretically, the discount rate should decrease as the project is de-risked from the PEA or scoping stage to prefeasibility to feasibility stage.

Most PEAs on gold properties in Canada and USA reviewed for this paper apply a 5% discount rate for the discounted cash flow model to derive net present value (NPV) of the property. This paper investigates whether the NPV at a 5% discount rate is indicative of the value of a mineral property at the PEA stage.

This question is addressed empirically by comparing the NPV in a number of PEAs on gold properties in Canada and USA with the market value of transacted properties and with adjusted market capitalisation (AMC) of non-transacted properties. AMC is the number of outstanding shares at the date of the announcement of the PEA results multiplied by the average of the share price at the announcement date and the following seven trading days, adjusted by working capital. The working capital adjustment accounts for the company's cash and short-term liabilities at the time of the PEA, in order to better isolate the estimated market value of the property.

Cautionary statement
The authors note the following with respect to this paper:

- Information used in this paper is from public sources and the proprietary S&P Global Market Intelligence database subscribed to by SLR.
- The authors accept responsibility for any inaccuracies in the assumptions, estimates, or interpretations used in the data compilation and analysis of the data.
- The analyses, interpretations, opinions, and conclusions expressed are solely those of the authors.
- The names of the gold properties and the companies involved have been excluded to maintain focus on the underlying concepts and analysis.

Data used in this study
Two datasets were compiled for this study, both for properties on which a PEA was carried out. One dataset comprises properties that transacted after the results of the PEA were disclosed, for which the NPV in the PEA was compared to the transaction value. The second dataset includes properties that did not transact after the results of the PEA were disclosed. For these properties the NPV in the PEA was compared to the adjusted market capitalisation of the company that held the property as its major asset, which was used as a proxy for market value of the property. All NPVs are on an after-tax basis, except for one transacted property where the after-tax NPV was not reported. In that case, since the property was located in a low-tax jurisdiction, the pre-tax NPV was used.

Characteristics common to the two datasets are:

- Properties for which gold was the dominant commodity
- PEA results were disclosed during the period 2013 to 2024
- All properties are located in Canada or the USA

For the transacted properties:

- Transactions were disclosed from 2016 to 2024
- Most transactions occurred within one to two years of the PEA date

For the non-transacted properties:

- Each property was the major asset of a publicly listed junior company

SLR subscribes to a proprietary mining database, S&P Global Market Intelligence (S&P), which was used to identify gold properties in Canada and USA with PEAs from 2013 to 2024, as well as properties that transacted following PEA disclosure. Identified properties were screened to ensure they met the above criteria.

Detailed information on the PEAs, transactions, and share structures of the companies holding the properties, was obtained from SEDAR (Canadian Securities Administrators – System for Electronic Document Analysis and Retrieval), EDGAR (US Securities Exchange Commission – Electronic Data Gathering, Analysis and Retrieval), company websites, and other public sources.

All financial information is presented in United States dollars (US$), unless otherwise stated. Where applicable, exchange rates were based on the date of PEA disclosure. The data are in dollars of the day and have not been adjusted to current dollars.

Transacted properties data
After screening a larger number of transacted PEA properties, 16 were selected for this study. Of these, ten are located in Canada and six in the United States. Ten of the transactions were for the property as an asset, while six were corporate acquisitions in which the property was the major asset of the acquired company. One of the corporate transactions involved a company that held two PEA properties: the PEA results were compiled together for the purpose of this study.

For the 16 properties, transactions occurred after disclosure of PEA results, such that the transaction price represented the market value of the transacted property. The transaction date was taken as the date of the news release announcing the transaction. The transaction value was derived from the published terms of the deal, which typically included a combination of cash and shares. Where the transaction was for less than a 100% interest in the property, the deal value was adjusted to a 100% interest and modified for any applicable royalties.

The dataset includes details from each PEA, including capital cost (capex), operating cost, gold or gold equivalent (AuEq) ounces contained in mineral resources, gold or AuEq ounces theoretically recovered in the PEA, gold price used, discount rate, pre-tax and after-tax NPV, and internal rate of return (IRR). Capex included initial capital, sustaining capital, and closure costs.

The 16 transacted properties are coded from A to Q. Property M was eliminated at a later stage because it was identified as an outlier and involved a very small transaction value.

Transacted properties observations
In reviewing the data and observations for the transacted PEA properties, the following questions arise:

- How does the NPV of a scoping level study (PEA) compare with the market value of a mineral property?
- If there is a difference, what implied discount rate would be needed to match the NPV to the property value?

Table I lists pertinent data for the Transacted Properties in Canada and the USA. Most of the discount rates used in the PEAs are 5%, with three ranging from 7% to 8%.

Table I. Transacted gold properties with preliminary economic assessments

Property Code	PEA Year	Deal Year	Discount Rate	After-Tax NPV US$M	Deal Price US$M	Ratio Deal Price to NPV	Implied Discount Rate for NPV=Price
Canada Properties							
A	2013	2016	8.0 %	12.4	1.9	0.15	36 %
B	2013	2021	5.0 %	189.7	39.6	0.21	10 %
G	2017	2017	7.5 %	80.0	9.0	0.11	35 %
H	2017	2018	7.0 %	24.6	4.1	0.17	20 %
J	2018	2020	5.0 %	208.3	90.6	0.43	12 %
K	2019	2019	5.0 %	303.0	254.7	0.84	7 %
L	2020	2021	5.0 %	108.1	39.9	0.37	13 %
O	2020	2021	5.0 %	321.0	39.4	0.12	24 %
P	2022	2023	5.0 %	112.0	10.0	0.09	24 %
Q	2023	2023	5.0 %	1,170.0	41.2	0.04	30 %
Average				**252.9**	**53.0**	**0.25**	**21 %**
Median				**150.9**	**39.5**	**0.16**	**22 %**
USA Properties							
C	2015	2016	5.0 %	14.1	2.8	0.20	17 %
D	2016	2017	5.0 %	54.9	3.4	0.06	33 %
E	2016	2016	5.0 %	56.4	43.5	0.77	8 %
F	2016	2016	5.0 %	97.0	17.1	0.18	13 %
I	2018	2021	5.0 %	69.6	10.0	0.14	22 %
N	2020	2021	5.0 %	755.0	459.6	0.61	10 %
Average				**174.5**	**89.4**	**0.33**	**17 %**
Median				**63.0**	**13.6**	**0.19**	**15 %**
Canada and USA Properties							
Average				**223.5**	**66.7**	**0.28**	**20 %**
Median				**102.5**	**28.3**	**0.17**	**19 %**

Note that for all 16 of the properties, the after-tax NPV at the specified discount rate is higher than the property value as indicated by the deal price, in most cases significantly higher. The NPVs have an average of 223.5 and a median of 102.5, compared with the deal price average of 66.7 and median of 28.3. The large difference between the average and median values for both is due to the influence of a single high value.

This difference between the NPV and deal price for each property is highlighted in the next column (ratio deal price to NPV) that shows the ratio of the deal price to the after-tax NPV. The ratios range from 0.04 to 0.84, with most less than 0.5. The average ratio for the 16 properties is 0.28 and median 0.17. Since there is a large difference between most of the after-tax NPVs and the property values (as represented by the deal price), the implied discount rate required to align the net present value with the market value of each property was calculated. Projected annual cash flows from company reports were used, and the discount rate was varied until the NPV matched the deal value. The implied discount rate for each property is shown in the last column (implied discount rate for NPV=price) of Table I. They vary from 7% to 36% with an average of 20% and a median of 19%. The implied discount rates are shown in histogram form in Figure 1. The middle 50% of the implied discount rates range from 12% to 30%.

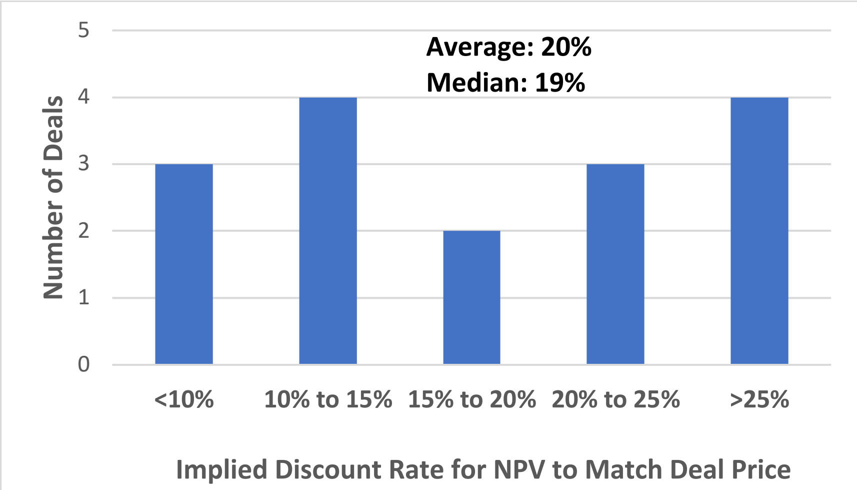

Figure 1. Implied discount rates for PEA net present values to equal deal prices.

Non-transacted properties data

After screening a large number of non-transacted PEA properties in Canada and USA, 48 were selected for this study. Of the initial large number identified in the S&P Global Market Intelligence database, many were eliminated for various reasons; for example, if the company held other significant resource properties whose value might influence the AMC, if the PEA property was under construction, or if the company had another property that was in production. An updated PEA was disclosed on some properties at a later date, in which case both PEAs were included in this study. In one case a company had PEAs on two different properties with similar dates: the results of the two PEAs were combined for the purpose of this study.

Details from each PEA were compiled, including capex, gold or gold equivalent (AuEq) ounces contained in mineral resources, gold or AuEq ounces theoretically recovered in the PEA, gold price used, discount rate, after-tax NPV, and IRR. Capex includes initial capital, sustaining capital, and closure costs.

Since the 48 selected properties did not transact, in the absence of a transaction, the AMC was used as proxy for the value of each property.
AMC of each junior company holding a PEA property was derived from public sources as of the date of the press release announcing the results of the PEA. Share price was obtained from historical price data on a variety of websites and number of shares issued was obtained mostly from company Management Discussion and Analysis (MD&A) documents filed on SEDAR, with allowance for any share consolidations. Share prices at the date of PEA press release and for the next seven trading days were averaged. No value was assigned to outstanding options and warrants. The market capitalisation was adjusted for cash and short-term debt, often reported as working capital, based on information in MD&A documents.

The 48 non-transacted properties were coded with numbers. Of the 48 properties, 28 are located in Canada and 20 in the USA.

Non-transacted properties observations

In reviewing the data and observations for the non-transacted PEA properties, the following questions are considered:

- How does the NPV of a PEA compare with the AMC of a mineral property?
- If there is a difference, what implied discount rate would be needed to match the NPV to the AMC?

Tables II and III list pertinent data for the Non-Transacted Properties in Canada and USA, respectively. Almost all of the discount rates used in the PEAs are 5%, except for two at 6% and one at 7%. Average and median values for the parameters shown are listed at the bottom of each table, and for the combined Canada and USA properties at the bottom if Table 3.

Table II – Non-transacted gold properties in Canada with preliminary economic assessments

Property Code	PEA Year	Discount Rate	After-Tax NPV US$M	Adjusted Mkt Cap US$M	Ratio Adj Mkt Cap to NPV	Implied Discount Rate for NPV=Adj Mkt Cap
2	2016	5.0 %	64.1	14.3	0.22	11 %
4	2016	5.0 %	513.3	46.7	0.09	14 %
5	2016	5.0 %	66.5	26.1	0.39	17 %
6	2016	5.0 %	66.6	22.1	0.33	29 %
7	2017	5.0 %	227.0	63.6	0.28	14 %
8	2017	7.0 %	24.3	4.4	0.18	20 %
11	2018	5.0 %	201.9	31.2	0.15	20 %
12	2018	5.0 %	14.1	4.6	0.33	20 %
15	2019	5.0 %	302.5	163.8	0.54	11 %
16	2019	5.0 %	101.7	44.2	0.43	16 %
18	2019	5.0 %	484.2	207.2	0.43	16 %
19	2020	5.0 %	83.3	9.7	0.12	35 %
22	2020	5.0 %	278.6	24,8	0.09	29 %
23	2020	5.0 %	596.5	111.2	0.19	15 %
24	2020	5.0 %	179.5	33.8	0.19	19 %
27	2020	5.0 %	329.2	17.2	0.05	27 %
28	2020	5.0 %	583.2	101.7	0.17	20 %
29	2021	5.0 %	255.9	79.5	0.31	16 %
30	2021	5.0 %	1,221.8	771.2	0.63	9 %
31	2021	5.0 %	191.3	135.2	0.71	8 %
33	2021	5.0 %	473.8	191.2	0.40	14 %
35	2022	5.0 %	190.4	28.5	0.15	14 %
36	2022	5.0 %	429.7	75.6	0.18	18 %
39	2023	5.0 %	288.5	29.1	0.10	21 %
43	2023	5.0 %	548.2	76.4	0.14	15 %
44	2023	6.0 %	168.0	25.4	0.15	24 %
46	2023	5.0 %	343.2	9.4	0.03	20 %
47	2024	5.0 %	671.3	129.4	0.19	17 %
Average Canada			**317.8**	**88.5**	**0.26**	**18 %**
Median Canada			**267.3**	**39.0**	**0.19**	**17 %**

Table III – Non-transacted gold properties in USA with preliminary economic assessments

Property Code	PEA Year	Discount Rate	After-Tax NPV US$M	Adjusted Mkt Cap US$M	Ratio Adj Mkt Cap to NPV	Implied Discount Rate for NPV=Adj Mkt Cap
1	2016	5.0 %	187.7	6.6	0.04	17 %
3	2016	5.0 %	38.4	7.9	0.20	25 %
9	2017	5.0 %	9.3	4.0	0.43	15 %
10	2018	5.0 %	69.6	9.7	0.14	20 %
13	2018	5.0 %	129.5	53.4	0.41	14 %
14	2018	5.0 %	83.9	3.5	0.04	28 %
17	2019	5.0 %	357.6	102.4	0.29	21 %
20	2020	5.0 %	36.3	3.9	0.11	28 %
21	2020	5.0 %	153.6	14.6	0.09	32 %
25	2020	5.0 %	606.0	109.7	0.18	20 %
26	2020	5.0 %	87.6	42.8	0.49	13 %
32	2021	5.0 %	64.0	20.0	0.31	49 %
34	2021	5.0 %	17.6	3.1	0.18	16 %
37	2022	5.0 %	46.1	6.9	0.15	29 %
38	2023	5.0 %	217.0	13.8	0.06	19 %
40	2023	6.0 %	121.0	66.4	0.55	17 %
41	2023	5.0 %	654.0	35.5	0.05	33 %
42	2023	5.0 %	61.8	8.4	0.14	33 %
45	2023	5.0 %	212.4	12.5	0.06	20 %
48	2024	5.0 %	550.0	14.7	0.03	20 %
Average USA			**185.2**	**27.0**	**0.20**	**23 %**
Median USA			**104.3**	**13.2**	**0.14**	**20 %**
Average Canada and USA			**262.5**	**62.9**	**0.23**	**20 %**
Median Canada and USA			**190.9**	**27.3**	**0.18**	**19 %**

Note that for all 48 of the Canada and USA properties, the after-tax NPV at the specified discount rate is higher than the AMC, in most cases significantly higher. The NPVs have an average of 262.5 and a median of 190.9 compared with the AMC average of 62.9 and median of 27.3. The difference between the average and median values for both Canada and USA properties is due to the influence of a few high values.

This difference between the NPV and AMC for each property is highlighted in the next column that shows the ratio of the AMC to the after-tax NPV. The ratios range from 0.03 to 0.71, with most less than 0.5. The average ratio for the 48 properties is 0.23 and median 0.18.

Since there is a large difference between most of the after-tax NPVs and the AMCs (as a proxy for the property value), the implied discount rate required to align the net present value with the adjusted market capitalisation was determined. Projected annual cash flows from company reports were used, and the discount rate was adjusted until the NPV matched the estimated market value. The implied discount rate for each property is shown in the last column of Tables II and III (implied discount rate for NPV=Adj Mkt Cap). They vary from 8% to 35% with an average of 20% and a median of 19%. The implied discount rates are shown in histogram form in Figure 2. The middle 50% of the implied discount rates range from 16% to 25%.

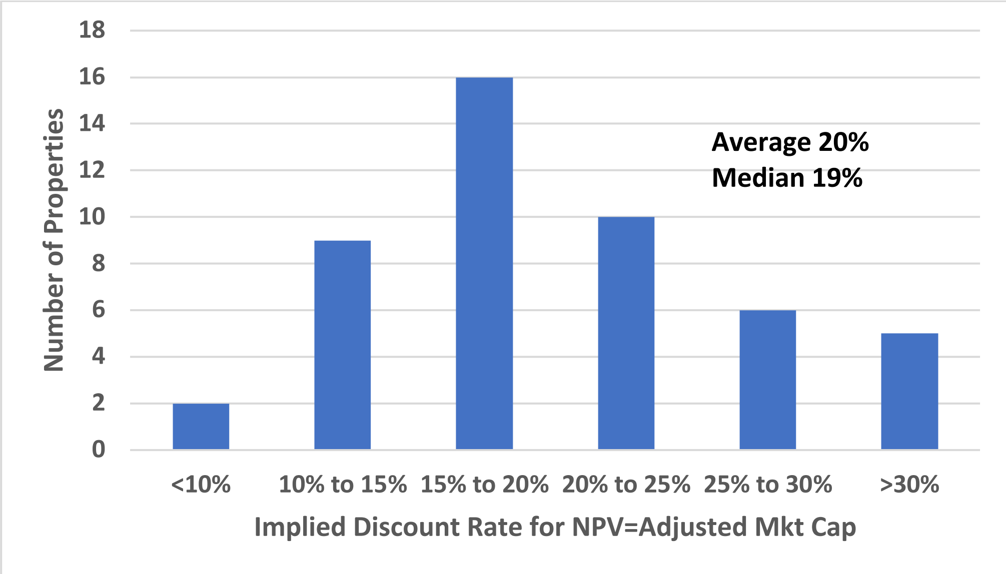

Figure 2 – Implied discount rates for PEA net present values to equal adjusted market capitalisations.

DISCUSSION

Table IV summarises the information and observations on the transacted and non-transacted properties with PEAs.

Table IV – Summary of observations on transacted and non-transacted properties

Parameter	Transacted Properties	Non-Transacted Properties
Number of Properties	16	48
PEA Discount Rates	13@5 %, 3@7 %-8 %	45@5 %, 3@6 %-7 %
NPV in PEA		
Average US$M	224	263
Median US$M	103	191
Deal Value or AMC		
Average US$M	67	63
Median US$M	28	27
Ratio of Deal Value or AMC to NPV		
Average	0.28	0.23
Median	0.17	0.18
Implied Discount Rate for NPV = Deal Value or AMC		
Average	20 %	20 %
Median	19 %	19 %
Middle 50 %	12 % to 30 %	16 % to 25 %

There is, in most cases, a significant difference between the NPVs and the property values for the transacted properties and between the NPVs and the AMCs for the non-transacted properties, both in average and median values. For the transacted properties, the property value is established by the transaction value. For the non-transacted properties, the AMC is used as a proxy for property value.

The significant difference is highlighted by the ratio of property value or AMC to the NPV. The ratio for the 16 transacted properties has an average of 0.28 and a median of 0.17. The ratio for the 48 non-transacted properties has an average of 0.23 and a median of 0.18. The similarity of the ratios suggests that the AMC of non-transacted properties is, overall, a reasonable approximation of property value.

As noted above, the NPVs at discount rates of mostly 5% are much higher than the property values or AMCs. The implied discount rates required to equalise the NPV to the property value or AMC for each property have an average of 20% and a median of 19%. It is clear that an NPV in a PEA or scoping-level study at a discount rate of 5% does not represent the market value of a mineral property.

In general, NPVs are very sensitive to the discount rate used in the discounted cash flow analysis. The example in Figure 3 shows how the NPV of a mineral property can decrease significantly with an increase in discount rate. The NPV at a 5% discount rate is US$ 431 million; at 10% it is US$ 307 million; at 15% it is US$ 219 million; and at 20% it is US$ 155 million.

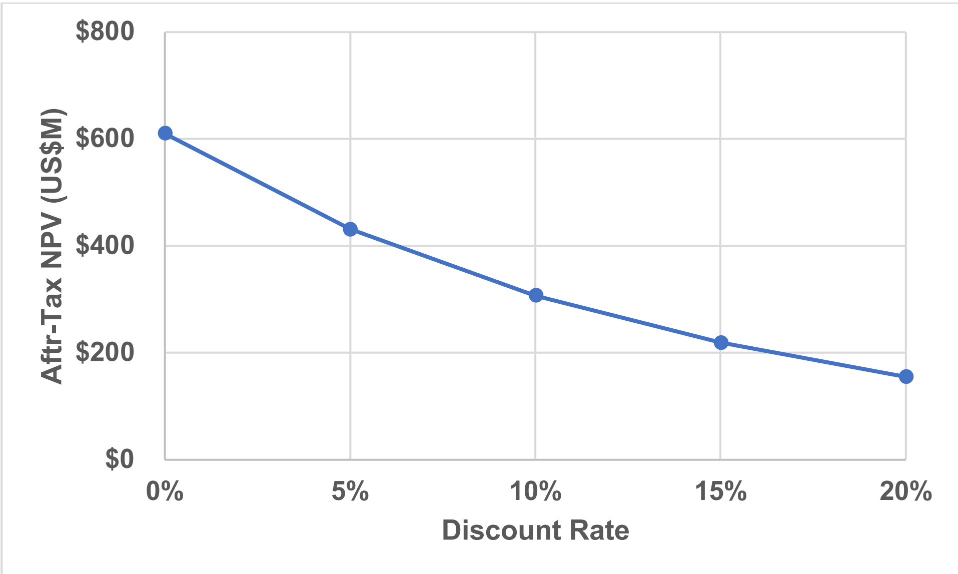

Figure 3 – Sensitivity of net present value to discount rate: example.

It appears that a 5% discount rate is commonly used as the default for preliminary economic assessments of properties in Canada and USA. Enquiries into the rationale for this practice typically yield the explanation that companies prefer their PEA-stage properties to be compared with peer projects that also apply a 5% discount rate. A 5% discount rate, however, does not appear to adequately reflect the cost of capital, the uncertainty or risk of a property at the PEA/scoping level, or country risk.

As noted in this paper, an NPV at a 5% discount rate does not represent the value of a gold property at the PEA or scoping-level stage. On average, a 5% NPV is approximately four times higher than the price paid for a transacted property and approximately 3.5 times higher than the AMC of a non-transacted property.

In Figure 1, the middle 50% of the implied discount rates that are needed for the 16 transacted property NPVs to equal the property values range from 12% to 30%. In Figure 2, the middle 50% of the implied discount rates needed for the 48 non-transacted property NPVs to equal the AMCs ranges from 16% to 25% In order to represent the market value of a mineral property, a PEA or scoping study should use discount rates more in the range of 15% to 25% rather than 5%.

CONCLUSIONS

This study includes mineral properties in Canada and USA with PEA/scoping-level studies over the past decade - 16 that transacted and 48 properties that have not transacted.

For the transacted properties, the NPVs are higher and mostly significantly higher than the market values of the properties. A discount rate of 5% was used for the NPV in most of the PEAs, with three ranging from 6% to 8%. In order to align the NPV with the market value of each property, implied discount rates ranging from 7% to 36% were required. The average implied discount rate was 20% with a median of 19%, and the middle 50% of the implied discount rates ranged from 12% to 30%.

For the non-transacted properties, the NPVs are higher and mostly significantly higher than the AMC of the properties. The AMC is used as a proxy for property value. A discount rate of 5% was used for the NPV in most of the PEAs, with three ranging from 6% to 7%. In order to align the NPV with the AMC of each property, implied discount rates ranging from 8% to 35% were required. The average implied discount rate was 20% with a median of 19%, and the middle 50% if the implied discount rates ranged from 16% to 25%.

It is clear that an NPV in a PEA or scoping level study at a discount rate of 5% does not represent the market value of a mineral property. In order to represent the value of a mineral property, in our opinion, a PEA or scoping study should use discount rates more in the range of 15% to 25% rather than 5%.

Abbreviations
PEA – Preliminary Economic Assessment
NPV – Net Present Value
AMC – Adjusted Market Capitalisation
DCF – Discounted Cash Flow
IRR – Internal Rate of Return
AuEq – Gold Equivalent
MD&A – Management Discussion and Analysis
SEDAR – System for Electronic Document Analysis and Retrieval
EDGAR – Electronic Data Gathering, Analysis, and Retrieval

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The east-west divide in valuation of mineral assets with specific emphasis on gold market transactions

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As the world's largest gold producer, China's mining transactions are often considered to exhibit a pricing difference compared to similar projects in other international mining jurisdictions. This study outlines the key differences and discusses the potential reasons for this variance, focusing on regulatory differences, valuation approaches and methods, project scale and development status. We also compare China's distinct market characteristics with western frameworks that adhere to common public reporting standards, such as JORC, NI43-101 or SAMREC. In China, many deals do not disclose commercial terms unless the projects are associated with companies listed in Hong Kong, which increases valuation asymmetries and highlights regulatory misalignments. Our market valuation approach emphasises key factors to consider in domestic Chinese transactions when conducting comparable transaction and peer group analysis.

INTRODUCTION

In acquiring mineral assets around the world, the investment community is cognisant of perceived variances in different regions of the world. In this vein, it is evident that transactions relating to mineral assets in China often show a variance to the price paid for similar assets in many western countries including Australia, South Africa, Canada and the United States (US). This paper sets out several potential reasons for this pricing variance, with a focus on the Australian and Chinese markets.

Gold industry in Australia and China

The Australian and Chinese gold markets were chosen to compare the East-West divide relating to the cross-border valuation of mineral assets, as gold is a fungible commodity that is widely abundant in both Australia and China and is actively traded in both jurisdictions.

Market

Within international markets, gold represents both a currency and a commodity. Many argue that it is more often regarded as a store of monetary value than a commodity, as it is rare and has perceived inherent value, like a currency. During times of economic or political uncertainty (e.g., economic recession or coups), when the expected or actual returns on bonds (both government and commercial), equities, and real estate decline, interest in gold investing tends to increase, driving up its price. Gold can also be used as a hedge to protect against economic events such as currency devaluation or inflation.

However, while gold has some industrial use, unlike a currency, it is limited. Less than 10% of gold is used in medical and industrial applications.

It is often reported that the gold “above ground” remains fairly liquid. World Gold Council (2025) data show that while total annual demand for gold is around 4000–4500 t, approximately two thirds of yearly gold demand is directed into Jewellery manufacture. Jewellery in many countries represents liquid wealth. Gold used for personal adornment often makes its way back into circulation after a few years or several generations. As noted by World Gold Council (2025) data, a small amount of gold (approximately 330 t) annually is used in medical and industrial applications, while the remainder is used for investments and exchange-traded gold funding purposes.

Supply
According to World Gold Council (2025) data, global gold production has remained relatively stable over the past 5 years, averaging approximately 3600 t annually. Among the leading producers, China and Australia have consistently ranked in the top three producing nations.

China has been the world's largest gold producer since 2007. In 2024, China produced approximately 370 t of gold (World Gold Council, 2025). Most of China’s gold output is produced in the resource-rich provinces of Shandong, Henan, Jiangxi, Yunnan, Gansu, Inner Mongolia, and Xinjiang. The Chinese gold mining sector is largely dominated by one state-owned enterprise, China National Gold Group Corporation, and several enterprises publicly owned and partially owned by the state, including Shandong Gold Mining Co Ltd (Shandong), Zijin Mining Group Co Ltd (Zijin), Zhongjin Gold Corp Ltd (Zhongjin), Chifeng Jilong Gold Mining Co Ltd (Chifeng), Lingbao Gold Group Co Ltd (Lingbao) and Zhaojin Mining Industry Co Ltd (Zhaojin).

Australia currently ranks as the third-largest gold producer globally, after China and Russia. In 2024, Australia produced approximately 289 t of gold (World Gold Council, 2025). Gold deposits are dispersed across all Australian states and the Northern Territory, although production is heavily concentrated in Western Australia, which accounts for approximately 67% of Australia’s national output (Geoscience Australia, 2025). New South Wales contributes a further 12%, while Queensland accounts for approximately 6% of Australia’s annual gold production (Geoscience Australia, 2025).

Gold market characteristics
While refined gold is a fungible commodity, the sources of gold can vary vastly, which gives rise to several differences when comparing gold mines and projects across jurisdictions. Varying styles of gold mineralisation may be attributable to differences in mineralogy, geometry, and concentrations in deposits. As such, alternative types of mining and processing introduce various complexities and result in differing costs of extraction and refining.

Despite these complexities, the gold market provides the best commodity for this analysis regarding the East-West valuation divide given the fungible nature of gold (i.e., gold produced in China is effectively the same as that produced in Australia).

Mineral Resources and Ore Reserves reporting codes
For domestic Chinese gold and other mineral assets, Mineral Resources and Ore Reserves are reported in accordance with the Chinese standard rather than internationally recognised reporting codes under the Committee for Mineral Reserves International Reporting Standards (CRIRSCO) framework, such as the Australasian Code for Reporting of Exploration Results, Mineral Resources and Ore Reserves (JORC Code, 2012), The National Instrument (NI 43-101) Standards of Disclosure for Mineral Projects and the South African Code for the Reporting of Exploration Results, Mineral Resources and Mineral Reserves (SAMREC Code, 2016). The Chinese Mineral Resource and Reserve Reporting System (GB/T 13908-2020 and GB/T 17766-2020) and the JORC Code (2012) represent two distinct frameworks for reporting Mineral Resources and Ore Reserves. While both aim to ensure transparency and consistency in public reporting, they differ significantly in their core philosophy, approach, structure, purpose, legal enforcement, and international applicability.

The JORC Code (2012) provides a framework where a Competent Person (CP), or a qualified individual who is a member of a Recognised Professional Organisation, applies professional judgment to estimate, classify and report Mineral Resources and Ore Reserves based on geological confidence and Modifying Factors (e.g., mining, metallurgical, economic, and environmental considerations). The CP bears personal responsibility for the estimate and its disclosure, guided by the code's principles. The JORC Code (2012) is widely used in Australia and internationally; it is mandatory for companies listed on the Australian Securities Exchange (ASX) and has been adopted by international stock exchanges such as the Hong Kong Stock Exchange (HKEx).

Under the JORC Code (2012), Mineral Resources are classified into three categories – Inferred, Indicated, and Measured – based on geological confidence. Only Indicated and Measured Mineral Resources can be converted into Ore Reserves (Probable and Proved) after considering all Modifying Factors. This two-tier system ensures that only economically viable resources are reported as Ore Reserves. Reports for public disclosure of such estimates must be prepared by a CP who meets strict professional qualifications and experience criteria. The JORC Code (2012) also aligns with the global CRIRSCO framework, making it compatible with other international codes such as SAMREC (South Africa) and Pan-European Reserves and Resources Reporting Committee (PERC) (Europe). The JORC Code (2012) is enforceable by Australian regulators, the ASX and the Australian Securities and Investments Commission, with legal consequences for non-compliance or misleading disclosures.

In contrast, the Chinese standard GB/T 17766-2020 is highly prescriptive and rules-based. It provides detailed, specific technical requirements and formulae that must be strictly followed. This prescriptive nature relies heavily on quantifiable criteria mandated by the standard, such as minimum sampling point spacing requirements for each commodity type and category, as well as fixed formulas for cut-off grade calculation. The qualified institution and its personnel are responsible for adhering to the rules, rather than an individual CP. Table I shows certain specific requirements for gold.

Table I: Statistics of the value multiples of rock gold deposit

Geological complexity	Measured	Indicated	Inferred
Class I (simple)	• Drill spacing within 80 m	• Drill spacing 80-160 m • Volumes limited to material directly between drill holes	• Drill spacing greater than 160 m • Can include material 80–160 m beyond the last sampling point
Class II (medium)	• Drill spacing within 40 m	• Drill spacing 40-80m • Volumes limited to material directly between drill holes	• Drill spacing greater than 80 m • Can include material 40–80 m beyond the last sampling point
Class III (complex)	• Drill spacing within 20 m	• Drill spacing 20-40m • Volumes limited to material directly between drill holes	• Drill spacing greater than 40 m • Can include material 20–40 m beyond the last sampling point

Source: Chinese standard GB/T 17766-2020 and DZ/T 0205-2020.

As an example of the difference between the Chinese and JORC Mineral Resource estimation and classification, the Beidong orogenic gold project in China was considered. Under Chinese exploration guidelines its geological complexity was classified as Class II and drill spacing is set at 60 m by 60 m for Indicated Resources and 80 m by 120 m for Inferred Resources. Indicated volumes are limited to material directly between drillholes, while Inferred can include areas on wider spacing extending 30–60 m beyond the last sampling point. In contrast, there are no prescribed drill spacings according to the JORC reporting guidelines. When applying modern geostatistical methods under the JORC approach which include variography, it yielded different optimal spacings for Indicated and a broader envelope for Inferred. As a result, the resource tonnage reported under JORC was 126% higher than that reported under the Chinese system.

This example suggests that under a JORC-based approach, the total reported resource tonnage is higher than under the Chinese system. However, JORC classification relies more on quality of estimation (for example, the slope of regression). As such, fewer tonnes are classified as Measured and Indicated compared with the Chinese classification.

China's Mineral Resource review is managed by the Ministry of Natural Resources (MNR), with technical reviews conducted by national, or provincial, resource evaluation centres. The process requires submitting a resource report that undergoes expert review and, in some cases, an on-site inspection. Once the review is completed, the report is officially approved and filed. To apply for a mining licence, it is mandatory to prepare a development plan, as a minimum. A development plan is comparable to a scoping study or conceptual study in the western context. The associated capital and operating cost estimates used in such a development plan typically have a low level of accuracy. Compliance is mandatory for exploration licensing, mining right applications, and stock exchange filings within China.

On August 5, 2025, the China Association of Mineral Resources Appraisal (CAMRA) issued the "Rules for Reporting Solid Mineral Resources and Reserves (2025)." These rules were trial implemented in 2020, and accepted by all CRIRSCO (Committee for Mineral Reserves International Reporting Standards) members by 2024. The rules are grounded in China's national standard, "Classification for Mineral Resources and Mineral Reserves" (GB/T 17766-2020), and CRIRSCO's "International Reporting Template for the Public Reporting of Exploration Targets, Exploration Results, Mineral Resources, and Mineral Reserves" (June 2024).

The Chinese system is primarily applied for domestic government oversight and reporting. Foreign investors, or valuation firms, evaluating with Chinese assets may need to reconcile both systems to ensure clarity and compliance across jurisdictions. In summary, while the JORC Code (2012) emphasises international market disclosure and investor confidence, the Chinese system is tailored towards domestic regulatory control and state resource management. Understanding the differences between these frameworks is essential for companies and stakeholders operating across jurisdictions.

Valuation codes

The valuation of mineral assets associated with companies listed on the ASX (Australia), HKEx (Hong Kong), Shanghai Stock Exchange (SSE) (Shanghai), and the Shenzen Stock Exchange (SZSE) (Shenzhen) is shaped by fundamentally different regulatory frameworks and underlying Mineral Resource and Ore Reserve reporting standards. These differences have a material impact on mineral asset valuation results.

Mining companies listed on the ASX and HKEx operate under internationally aligned, principles-based systems. The ASX requires Mineral Resources and Ore Reserves to be reported under the JORC Code (2012), while the HKEx mandates resource and reserve reporting under globally recognised standards such as the JORC Code (2012), NI 43-101, or SAMREC, as signed off by a CP. For mineral asset valuation purposes, the Australasian Code for the Public Reporting of Technical Assessments and Valuations of Mineral Assets (VALMIN Code, 2015) is the accepted reporting guideline, requiring assessments to be conducted by a specialist or, as defined by the HKEx Listing Rules, a Competent Evaluator. The VALMIN Code (2015) requires that mineral asset valuations for public reports be based on Mineral Resources and Ore Reserves reported under the JORC Code (2012). It emphasises that the discounted cash flow (DCF) methodology be based on reasonable, market-derived assumptions (e.g., commodity prices, costs, discount rates) applied with significant flexibility by the valuation specialist. Independence requirements are often enforced, and comprehensive public disclosure of all material assumptions, methodologies, risks, and conclusions is mandatory. This approach prioritises competence, transparency, materiality, reasonableness, and independence.

In contrast, China's securities exchanges operate under strict oversight from the China Securities Regulatory Commission and the MNR. Companies with domestic mineral assets must classify resources and reserves using the national standard GB/T 17766-2020. Mineral asset valuations are highly prescriptive. Only appraisers licensed by the MNR and working for an MNR-registered appraisal institution are allowed to conduct mineral valuation assessments. These appraisers must comply with national standards and technical guidelines, following rigid and formulaic methodologies. While broadly aligned with international practice, prescribe key assumptions may not reflect market-based inputs. Both the valuation appraiser and the appraisal institution share legal and professional responsibility for the accuracy and integrity of the valuation report. Chinese mining project valuation practices, primarily guided by national standards like the Chinese Mineral Valuation Standards, serve a fundamentally different purpose: regulatory compliance, state-owned asset management, resource tax assessment, domestic financing, and approvals. Consequently, the resultant valuations are heavily rules-based and compliance-driven. Valuations are almost exclusively based on resources and reserves classified under Chinese national standards (GB/T 17766-2020), which differ significantly from JORC/CRIRSCO estimates. There is typically a heavy reliance on methods under the cost valuation approach for early-stage assets and standardised income valuation approaches for advanced-stage assets. DCF models must use prescribed discount rates and assumptions as set by regulators or standards, rather than market-derived forecasts, thus offering less flexibility for expert judgment on project-specific risks. Some DCF models are based on inputs from development plans, where capital and operating cost estimates may not accurately reflect the actual costs.

For Chinese mineral assets, key constraints include the mandatory use of 3–5-year historical commodity price averages, as forward projections are prohibited, and government-prescribed discount rates. This results in standardised valuation outcomes. For comparison, while both the ASX and HKEx have adopted principles-based approaches, relying on individual specialists' professional judgment, the SSE/SZSE enforce prescriptive rules. This creates potential differences in output. The ASX and HKEx valuations may reflect real-time market conditions through assumptions assessed by specialists, whereas Chinese domestic valuations prioritise state-defined uniformity.

The SSE and SZSE have recently permitted exceptions for overseas assets. Companies may report Mineral Resources and Ore Reserves under the JORC Code (2012) or equivalent standards and may conduct valuations using VALMIN Code (2015) based methodologies. However, this flexibility exclusively applies to assets located outside of China. Domestic mineral projects remain bound by GB/T and MNR's rigid appraisal rules.

Impact on valuation

Even though Australia and China use the same definition of Market Value, the differences between the Australian and Chinese systems have a material impact on value outcomes, making them largely incomparable. The prescriptive nature of GB/T 17766-2020 dictates the input data for any Chinese valuation. A Mineral Resource and Ore Reserve estimate for the same deposit will often differ materially under the JORC Code (2012) versus GB/T due to different classification rules (e.g., spacing requirements, cut-off grade formulas, rigidity in Modifying Factors). This directly impacts the projected mine life, production profile, and operating costs fed into the valuation model.

Furthermore, the methodological differences are profound. VALMIN-compliant valuations prioritise market-based assumptions and expert risk assessment within a DCF framework, reflecting investor perspectives. Chinese valuations – bound by standardised formulas, prescribed discount rates (often lower than market expectations), and regulator-set price forecasts – often yield different Net Present Values. The emphasis in Chinese practice is on technical compliance and administrative needs, whereas VALMIN focuses on transparency and market risk for investment decisions. Consequently, a valuation prepared under Chinese standards for regulatory purposes may not reflect the "Market Value" required for an international transaction governed by VALMIN or similar codes, and vice versa.

These frameworks reflect broader regulatory priorities: HKEx and ASX emphasise market transparency and global investor needs, while SSE and SZSE prioritise state oversight and standardisation for domestic assets. Investors comparing mineral asset valuations across these exchanges must account for differences in resource and reserve reporting, as well as in commodity pricing and discount rate assumptions. Though limited convergence is emerging for overseas holdings, China's domestic valuation regime remains uniquely formulaic, creating inherent challenges for cross-jurisdictional analysis.

Market valuation approach

The Market Approach is based primarily on the principle of substitution and is also called the Sales Comparison Approach. The mineral asset being valued is compared with the transaction value of similar mineral assets under similar time and circumstance on an open market (VALMIN Code, 2015). In this case, two valuation methods are used:

1. Comparative transaction analysis involving standalone gold assets.
2. Comparison of listed companies traded on a stock exchange holding one or more underlying gold asset, also known as peer trading analysis.

Comparative gold transaction analysis

Australian and Chinese gold transactions were compiled using the S&P Capital IQ Pro subscription database. The review assessed asset transactions involving gold projects from both countries at various development stages that were completed between 2015 and 2025. In total, 201 transactions were identified for which sufficient information was available to estimate a resource multiple. The implied multiple was then expressed in US$/oz terms. This implied multiple was estimated using the transaction value (at the implied 100% acquisition cost) and the total contained Mineral Resources supporting the transaction. Given the gold price volatility and future price uncertainty, the August 2025 average US dollar gold price of US$3 368/oz was used to normalise the implied multiples and inform the market analysis.

Of the 201 transactions, 196 involved Australian assets and 5 related to assets in China. This disparity in the number of transactions between jurisdictions is testament to the opaque nature of transaction disclosures in China. The transactions in China include a single transaction for two operating gold mines, while the remaining four were exploration projects.

The data summarised in Table II, which includes both countries and spans all stages of development, range from US$0.02/oz to US$775.53/oz on a normalised basis.

Table II: Analysis of gold transaction data involving mineral assets with defined Mineral Resources

	China only		**Australia only**		**Australia and China**	
	Raw resource multiple (US$/oz)	**Resource multiple (US$/oz)**	**Raw resource multiple (US$/oz)**	**Normalised resource multiple (US$/oz)**	**Raw resource multiple (US$/oz)**	**Normalised resource multiple (US$/oz)**
All transactions						
Count	5	5	196	196	201	201
Minimum	21.05	49.60	0.02	0.02	0.02	0.02
Average	64.37	154.17	33.71	70.69	34.47	72.77
Median	75.08	124.32	14.06	31.42	14.74	33.62
Maximum	105.65	286.43	387.57	775.53	387.57	775.53
Percentile 5%	21.95	51.51	0.54	1.36	0.56	1.43
Percentile 25%	25.52	59.16	3.74	8.20	3.84	9.06
Percentile 75%	94.54	251.32	34.96	74.34	35.51	77.77

Percentile 95%	103.42	279.41	135.70	293.85	130.25	293.58
Projects in advanced exploration to development stage						
Count	4	4	166	166	170	170
Minimum	21.05	49.60	0.02	0.02	0.02	0.02
Average	56.83	129.88	25.18	53.01	25.93	54.81
Median	50.30	91.74	11.79	24.88	12.81	26.60
Maximum	105.65	286.43	387.57	775.53	387.57	775.53
Percentile 5%	21.72	51.04	0.43	0.82	0.44	0.91
Percentile 25%	24.40	56.77	2.96	7.35	3.10	7.74
Percentile 75%	82.72	164.85	26.95	59.71	27.29	60.04
Percentile 95%	101.06	262.11	100.75	188.38	103.91	196.28
Operations on care and maintenance						
Count	–	–	11	11	11	11
Minimum	–	–	2.29	4.27	2.29	4.27
Average	–	–	29.43	52.27	29.43	52.27
Median	–	–	11.00	20.20	11.00	20.20
Maximum	–	–	164.54	299.51	164.54	299.51
Percentile 5%	–	–	2.61	4.56	2.61	4.56
Percentile 25%	–	–	3.44	6.22	3.44	6.22
Percentile 75%	–	–	29.31	52.35	29.31	52.35
Percentile 95%	–	–	105.53	189.55	105.53	189.55
Operating mines						
Count	1	1	19	19	20	20
Minimum	94.54	251.32	3.84	10.78	3.84	10.78
Average	94.54	251.32	110.67	235.86	109.86	236.63
Median	94.54	251.32	96.14	214.86	95.34	224.91
Maximum	94.54	251.32	320.92	642.15	320.92	642.15
Percentile 5%	94.54	251.32	31.81	49.58	33.36	51.74
Percentile 25%	94.54	251.32	53.11	115.16	54.87	129.64
Percentile 75%	94.54	251.32	139.81	294.06	134.23	293.80
Percentile 95%	94.54	251.32	302.41	594.09	301.39	591.42

Source: S&P Capital IQ Pro (2025)

The frequency distribution of all transactions (Figure 1) shows that the data are skewed, with the mean greater than the median. Also, 90% of the data fall between US$1.43/oz and US$293.58/oz.

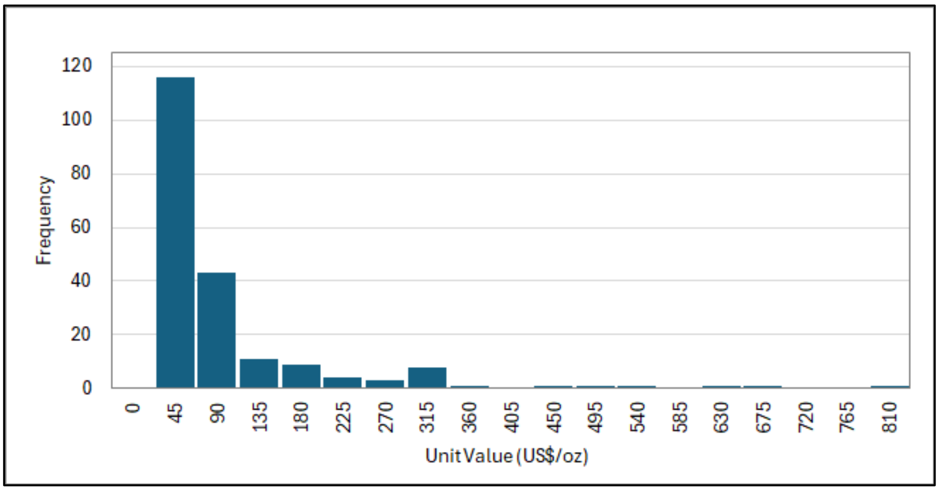


Figure 1. Frequency distribution of all transactions

Projects in the advanced exploration to development stage returned average and median values of US$54.81/oz and US$26.60/oz, respectively. Operating mines have average and median values of US$236.63/oz and US$224.91/oz, respectively. This clearly illustrates that the mineral assets unit value increases with the increasing development stage.

Figure 2 shows all the Australian transactions plotted as blue dots. All Chinese transactions are plotted as orange dots. Two Kalgoorlie Consolidated Gold Mines (KCGM) transactions are plotted as yellow dots in Figure 2.

Within the Chinese dataset, Hong Kong-based China Mining Resources Group Ltd acquired two gold mines from Hong Kong-based Fung Wai Enterprises Ltd. The two gold mines, Sunjiagou and Q1403N, cover a total area of 13.78 km^2 with a total Mineral Resource of 440,218 oz, and are located in the Tongguan and Luonan counties in the Shaanxi province. The transaction occurred at an implied multiple of US$251.36/oz on a normalised basis (US$94.54/oz on a raw basis).

Figure 2 shows the Chinese transaction implied multiples of these two operating gold mines at US$251.36/oz falls between the 25th US$129.64/oz and 75th US$293.80/oz percentiles of the operating mines transaction dataset as shown by the two verticals lines.

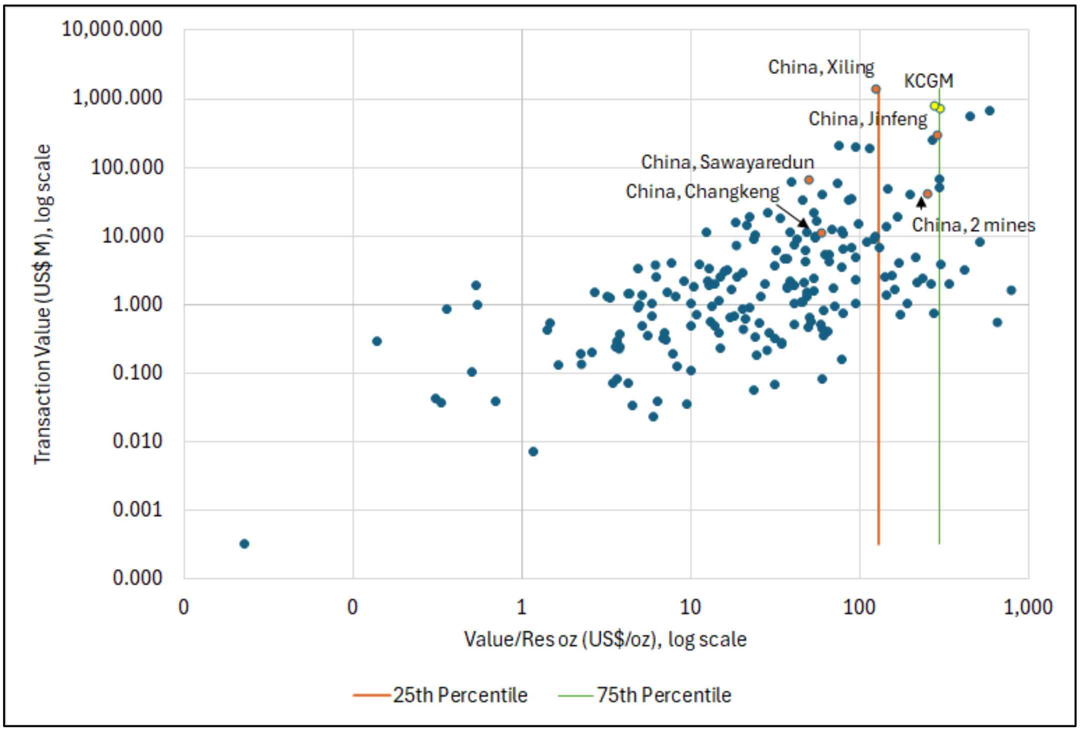


Figure 2. Transactions analysis of transaction value per resource ounce, normalised basis

By comparison, the purchase of KCGM via two separate transactions by Saracen Mineral Holdings Ltd in December 2019 and Northern Star Resources Ltd in January 2020 took place at US$294.59/oz and US$271.88/oz on a normalised basis, respectively. KCGM has a long history of significant production and a reported Mineral Resource of 11.66 Moz at the time of the transaction.

This analysis suggests that the China Mining Resources Group Ltd transaction at the implied multiple of US$251.36/oz lies within reasonable bounds and, as such, no clear difference is evident. However, evidence suggests that other Chinese advanced exploration gold projects did transact at a premium to equivalent Australian assets with the average for at US$53.01/oz compared to the average for China at US$129.88/oz (Figure 2).

While this might suggest that gold assets in China typically transact at a premium to that equivalent in Australia, the Chinese dataset is small with one isolated gold mine transaction and four advanced exploration projects. Therefore, it cannot be decisively concluded that this is consistently the case.

Gold peer trading analysis

In this study, 23 companies focused on gold exploration and production were assessed. These companies are listed on the ASX, HKEx and SSE (Table III). Of these, 12 are producers and 7 are exploration/development companies. Only three companies are both producers and dually listed on the HKEx and SSE.

In the peer group for analysis, only six listed companies represent China as public companies with sufficient information: Zijin, Shandong, Zhaojin, Zhongjin, Lingbao and Chifeng.

Table III: Peer group gold companies

Companies	Producer / explorer	Country	Enterprise value[1] (US$ M)	Equivalent attributable Resources[3] (Moz)	Attributable production 2024 (AuEqoz[2])	EBITDA[4] 2024/25 (US$ M)
Zijin	Producer	China	117 985.5	373.15	4 913 668	8347.4
Newmont	Producer	Australia	84 001.7	420.69	6 849 000	9857.0
	Producer	China	32 361.8	71.29	1 727 979	2041.4
Gold Fields	Producer	Australia	32 350.8	118.16	2 071 000	2523.5
Northern Star	Producer	Australia	18 706.0	62.42	1 644 509	1813.5
Zhaojin	Producer	China	15 508.4	38.10	856 014	554
Zhongjin	Producer	China	14 279.1	40.39	796 767	1182.0
Chifeng	Producer	China	7248.6	25.53	513 078	631.7
Genesis Minerals	Producer	Australia	3952.0	14.50	134 451	199.7
Ramelius/Spartan	Producer	Australia	3835.9	10.32	293 033	399.9
Lingbao	Producer	China	3011.2	5.39	656 448	189
Capricorn Metals	Producer	Australia	2973.7	6.26	113 007	123.6
Regis Resources	Producer	Australia	2275.3	6.70	417 713	466.7
Catalyst Metals	Producer	Australia	1154.7	5.26	109 784	114.9
Bellevue Gold	Producer	Australia	1013.6	3.20	95 560	98.6
Black Cat	Exploration	Australia	428.6	2.64		
Meeka Metals 1	Exploration	Australia	308.4	1.24		
Antipa Minerals	Exploration	Australia	258.8	2.68		
Ausgold	Exploration	Australia	233.1	3.04		
Rox Resources	Exploration	Australia	197.8	2.47		
Calidus Resources	Producer	Australia	153.8	1.94	57 700	
Saturn Metals	Exploration	Australia	129.7	1.84		
Horizon Gold	Exploration	Australia	59.4	2.14	4 913 668	8 347.4

Source: S&P Capital IQ Pro (2025)

Notes: [1] As at 6 September 2025.

[2] Gold Equivalent (AuEqoz) has converted the copper, silver, molybdenum and gold at the average August 2025 metal prices of US$9770.58/t, US$37.70/oz, US$73 600/t and US$3340.15/oz, respectively.

[3] Resources – resources inclusive of reserves.

[4] EBIDTA – earnings before interest, taxes, depreciation, and amortisation.

Domestic gold production in China is hindered by a lack of scale and investment, although that has changed significantly in the past few years. The oldest and largest gold mining company in China is the state-run China National Gold Group Corporation, which accounts for approximately 20% of gold production in the country. S&P Capital IQ Pro (2025) provides the following descriptions of the publicly owned enterprises that all have some state ownership.

Zijin is principally involved in gold mining and smelting, though the company also produces copper, lead, zinc, silver, and iron products in smaller quantities as by-products. While gold is the major commodity produced, the company holds a diversified portfolio across commodities and geographically. Therefore, it is not entirely focused on gold in China.

Shandong operates as a series of gold mining and production businesses. It provides gold exploration, processing, and outsourcing of gold smelting services. It also operates gold jewellery purification and non-ferrous metal production businesses. The company operates its businesses through four segments. The Gold and Non-ferrous Metals Refining segment engages in production and sales of gold and others. The Investment Management segment engages in investments in equity funds and provision of futures contracts trading services. The Trading segment engages in trading gold bullion and non-ferrous metals. The company operates its businesses in the Chinese domestic and overseas markets.

Zhongjin engages in the mining, smelting, and sale of non-ferrous metals in China. Zhongjin claims to be the first listed company specialising in gold production in China. While the company's primary product is gold, it also produces by-product silver, electrolytic copper, sulfuric acid, iron ore, and other products.

Zhaojin is an investment holding company that engages in exploration, mining, processing, smelting, and sale of gold and other metallic products in China and internationally. It has three operating divisions: Gold Operations, Copper Operations, and Other.

Lingbao primarily engages in mining, processing, smelting, refining, and sale of gold products in China. It is also involved with trading, jewellery, machinery, engineering and recycling of waste. In addition, it imports and exports gold products. Lingbao is a very diversified enterprise.

Chifeng is primarily engaged in gold and non-ferrous metal mining and exploration of gold, zinc, lead, copper, and molybdenum deposits. It is also involved in copper smelting activities. It engages in recycling waste electrical and electronic products.

In Australia, there are no state-run gold exploration and mining companies. All companies are listed enterprises that are largely publicly funded and listed on the ASX. Given this disparity, this analysis may not truly reflect the divide between East and West valuations.

Despite this, the analysis of enterprise value (EV) multiples EV/resource oz, EV/production oz and EV/EBITDA are illustrated in Figures 3 (a), (b) and (c). The statistics of this analysis are listed in Table IV.

Table IV: Statistics of the value multiples

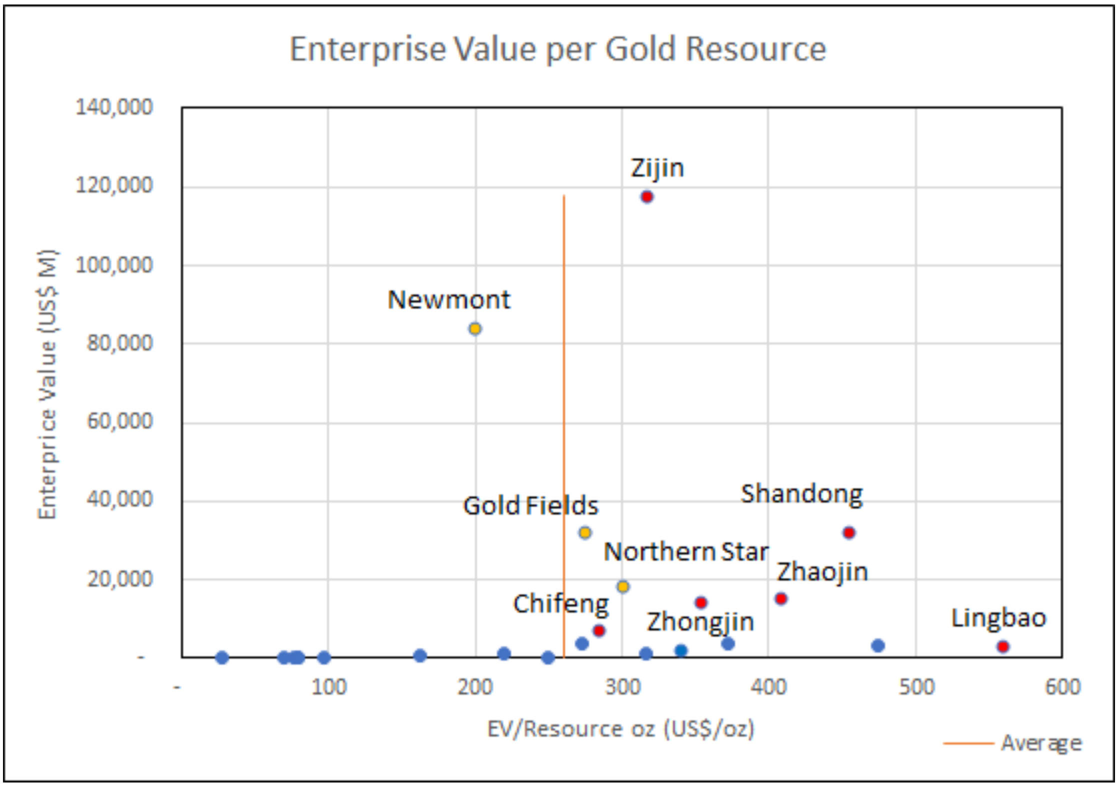
Statistic	**EV/resource oz**	**EV/production oz**	**EV/EBITDA**
Count	23	16	15
1st quartile	129.6	10 584.7	10.2
Average	260.2	14 674.3	13.9
Median	273.8	13 609.0	12.1
3rd quartile	346.6	18 269.8	15.9

Source: S&P Capital IQ Pro (2025)

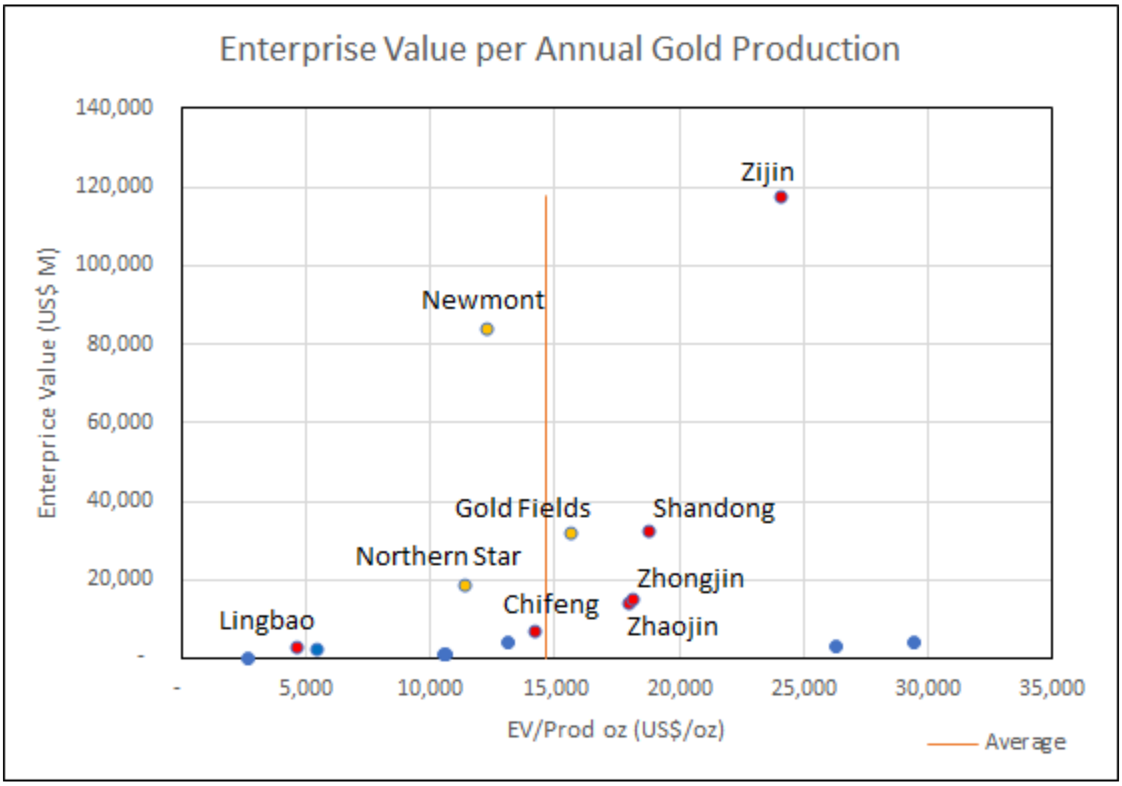
In this analysis, three Australian gold companies were used as benchmarks: Newmont Corporation, Gold Fields Limited and Northern Star Resourced Ltd. The first observation in Figure 3 is that Zijin and Newmont Corporation stand out with the highest EV on the y-axis. On the x-axis, there is a wide spread of unit values that differ in each of the value multiples of EV/resource, EV/production and EV/EBITDA.

When the average is greater than the median in a dataset as in this case (Table 3), the distribution of the data is skewed to the right. This means there is a tail on the right side of the distribution and most of the value multiples lie left of the average. This is the case for EV/production and EV/EBITDA.

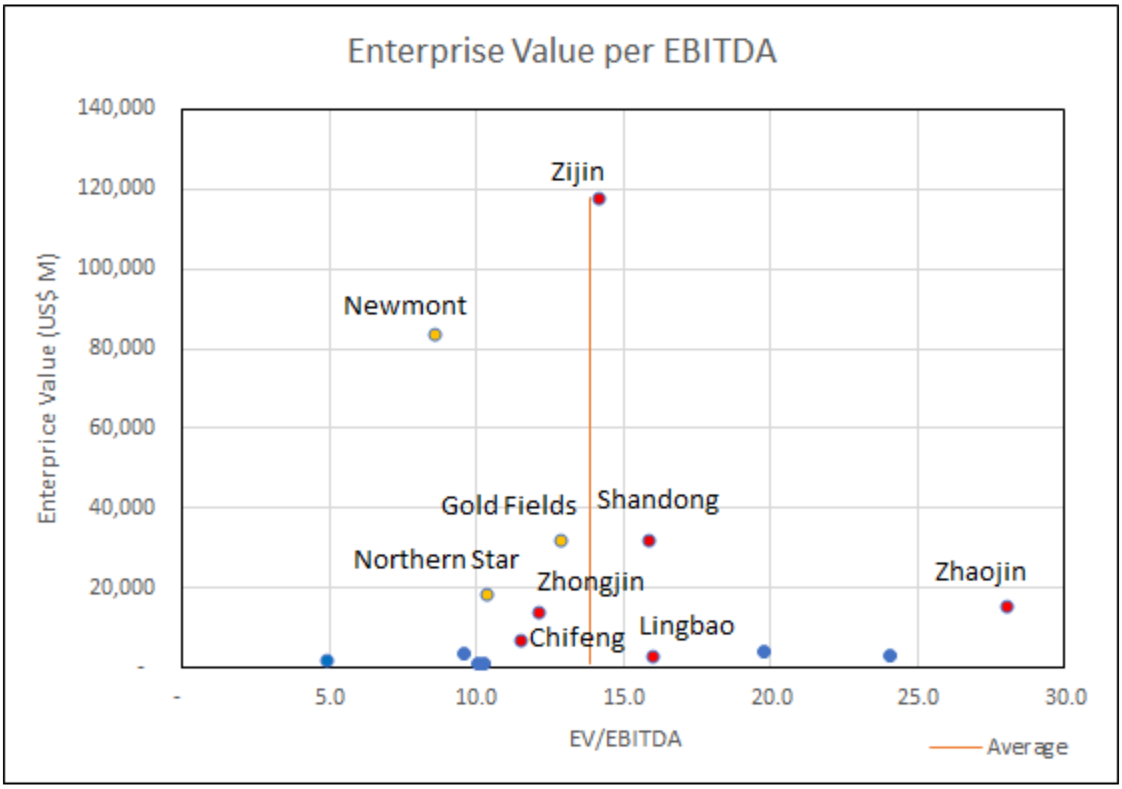
In the case of all three value multiples, Zijin, Shandong and Zhaojin lie right of the average (Figure 3) which might suggest they are valued at a premium to the broader market. However, it may also be argued that this premium is justified by the fact that all three enterprises are more vertically integrated and diversified than Australian exploration and mining companies which are typically only focused on gold.


Enterprise Value per Gold Resource
Enterprise Value (US$ M)
140,000
120,000
100,000
80,000
60,000
40,000
20,000
-
-
100
200
300
400
500
600
EV/Resource oz (US$/oz)
Average
Zijin
Newmont
Gold Fields
Shandong
Northern Star
Zhaojin
Chifeng
Zhongjin
Lingbao

(a)


Enterprise Value per Annual Gold Production
Enterprise Value (US$ M)
140,000
120,000
100,000
80,000
60,000
40,000
20,000
-
-
5,000
10,000
15,000
20,000
25,000
30,000
35,000
EV/Prod oz (US$/oz)
Average
Zijin
Newmont
Gold Fields
Shandong
Northern Star
Zhongjin
Chifeng
Zhaojin
Lingbao

(b)



(c)

Figure 3. Peer group valuation analysis

On a value to annual gold production multiple (Figure 3(b)), the positioning of the comparative companies is widely spread around the average and median of 14 674 and 13 609, respectively. Lingbao and Zijin form the low and high of the comparative group, respectively.

On a value to EBITDA multiple (Figure 3(c)), the positioning of most comparative companies' cluster around the average and median of 13.9 and 12.19, respectively. The exceptions to this are Newmont and Zhaojin, which form the low and high of the comparative group, respectively.

CONCLUSIONS

While there are clear differences between the Australian and Chinese reporting regimes arising from the distinct national objectives for each country's reporting codes for resources, reserves and valuation approaches, as well as regulatory requirements for publicly listed companies, it remains ambiguous as to whether Chinese companies do in fact transact at a premium to their Australian counterparts.

Reporting codes in China are prescriptive, while in Australia they provide a guiding framework and allow for professional judgment. While the Australian codes emphasise international market disclosure and investor confidence, the Chinese system is tailored for domestic regulatory control and state resource management. The impact on valuations is profound with VALMIN prioritising market-based assumptions and expert risk assessment, while Chinese valuations are bound by standardised approaches and assumptions.

Using a market approach based on both comparable market transactions and peer group analysis, it remains unclear as to whether Chinese operating gold companies transact at a premium to similar companies in Australia. However, evidence from market transactions involving advanced exploration assets in China indicate that they transact at a premium to their counterparts in Australia.

Further analysis is warranted given the transaction dataset relating to Chinese mineral assets remains small, due in part to public disclosure differences between the two jurisdictions and the designed intent of the reporting regimes within each country.

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Market approach valuations using company enterprise values

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The Market Approach is frequently used in the minerals industry since this valuation approach is appropriate at all stages of the project life cycle. It is therefore critical that there are sufficient underlying data that are reasonable and reliable. The underlying data are greatly limited by the relatively low frequency and volume of transactions in the minerals industry. Supplementary data can be derived from enterprise values, calculated from the share price of listed entities. Since the shares of listed companies are traded continuously, these can be seen as transactions in the underlying assets in real time. Using the Mineral Valuation Group Gold Industry In-Situ Valuation Report, we compare the evaluation of a gold asset using enterprise values for over 70 companies and 400 assets vs 13 gold transactions. The resultant overlapping evaluations illustrate consistent results across both data sources, and the publicly-announced transaction value falls within both value ranges, supporting the use of enterprise values calculated from the share price of listed entities as a good source of supplementary data for use in Market Approach valuations. The divergence in the resultant valuation ranges highlights the benefit of enterprise value data over transaction data in reflecting up-to-date market sentiment. In cases where there are almost no comparable transactions, the enterprise value data would be crucial to ensure sufficient relevant data for informed decision-making.

Keywords: Mineral asset valuations, market approach, enterprise values, transactions, gold

INTRODUCTION

Understanding the value of an asset is a fundamental requirement in the decision-making process for professionals in any industry. Valuations are used for various purposes including approving allocation of capital to a project, asset sale or purchase negotiation, or assessing the impairment risk for audit purposes. The minerals industry faces a fluctuating global economy, shifting geopolitical dynamics, increasing environmental and social governance, and rapidly evolving technologies (World Economic Forum, 2023). Mineral asset valuation methodologies should remain focussed on the fundamentals, while remaining mindful of this rapidly changing landscape. A focus on best practice, combined with consistent quality data, mitigates the risk of inaccurate valuations, which compromise investor interests.

When conducting a mineral asset valuation, best practice suggests the use of two of the following three valuation methodologies, as required by the leading compliance codes and guided by the International Mineral Valuation Committee (IMVAL). The following definitions have been adapted from the SAMVAL Working Group (2018):

- Cost Approach – this approach relies on historical and/or future amounts spent on the mineral asset.
- Income Approach – this approach relies on the 'value-in-use' principle and requires determination of the present value of future cash flows over the useful life of the Mineral Asset.
- Market Approach - this approach relies on the principle of 'willing buyer, willing seller' and the value of the mineral asset is determined as if in an arm's-length transaction.

The Market Approach is an appropriate valuation approach at all stages of the project life cycle, and the minerals industry relies heavily on this methodology. This is because the simplest way to understand the value of an asset is to compare it to a similar asset with a known value. Millions of residential properties are valued this way every day. This is also the way that the second-hand car market operates, and the way that many other assets change hands.

Considering the popularity and relevance of the Market Approach in the minerals industry, it is critical that the underlying data are reasonable, reliable and good quality as inadequate or uncertain data would affect the reliability of, or confidence in, a valuation statement (SAMVAL Working Group, 2018).

Mineral companies, like all other companies, are part of an economic cycle. Typically, when the commodity price is high or upward trending, demand for shares in companies holding these commodities is also high. This leads to additional funds being made available for exploration, extension of assets and increased production. Producers and investors are often willing to pay a premium for projects in these market conditions as production at higher prices will be more profitable.

Similarly, when the commodity price is low or downward trending, companies try to decrease the cost of production. Typically, exploration activities are reduced or even halted until commodity prices recover sufficiently. In these market conditions, companies may sell off non-core assets at a discount to generate cash for their flagship projects.

It is therefore important to ensure that transactions are as recent as possible when used as a proxy of value for other assets. Transactions taking place in a bull market are not good proxies of the asset value in a bear market and vice versa. Recent transactions accurately reflect the continuously changing investment environment, and thus the price investors are willing to pay for mineral assets.

For example, as countries become increasingly aware of the environmental costs of mining, they increase their focus on environmental regulations and the future of mineral assets in these countries becomes uncertain. This leads to companies selling assets in these countries at a great discount to recover whatever funds they can.

Many developing countries are increasing their focus on local ownership of mining projects. In other words, they require a certain portion of mining projects to be locally owned. These transactions are often completed at deeply discounted rates for the local shareholders as it is a legal requirement to have them on board.

Typically, valuators rely on transactions as their key data source, however, the above factors mean that there is a relatively low frequency and volume of relevant transactions, resulting in insufficient data that can be used to make an informed decision. In addition, the complexities involved with considering the confidence levels of in-situ Mineral Resources, and the comparability of assets require additional data and analysis to yield meaningful results (Mineral Valuation Group, 2025).

According to Mineral Valuation Group (2025), the most common ways in which valuators try to address these limitations are:

- **Increasing the comparable dataset size by using older data** - Where limited or no recent transactions have taken place, increasingly older transactions are used. This may not reflect the market conditions under which the transaction took place.
- **Using adjustment factors to make 'old' transactions recent** - Typically, old transactions are escalated using inflation indexes or factorisation based on commodity prices. These factors are subjective and are typically based on valuators intuition rather than supporting information. These factors also may not account for the market conditions under which the transaction took place.
- **Subjectively adjusting a dataset to be more comparable** - Due to the wide variety of factors that determine whether two mineral assets are similar (geological setting, Mineral Resource categories, project/company size, jurisdiction, mining method, development stage, etc.),

finding transactions for similar assets can be difficult. To address this, valuators will apply discounts or premiums to the transactions that are available to make them as comparable as possible. This is a subjective exercise and is typically based on valuators intuition rather than supporting information.

- **Goal seeking or subjective adjustments to align with the cash flow results** - Often, valuators will use a cash flow model to determine the value of a mineral asset, and then when conducting a valuation using the Market Approach, be strongly guided by the results of the cash flow model. Subjective adjustments are then made to ensure that the valuation result from the Market Approach aligns with the cash flow valuation results.

These adjustment methods are inherently subjective, and we therefore strongly discourage the practice of using factors to adjust data. A sufficiently large, current dataset of comparable mineral assets removes the need to subjectively adjust data to address the above identified limitations. A good source of supplementary data can be derived from enterprise values calculated from the share price of listed entities. This is particularly useful for commodities where there are few recent transactions in the public domain.

Since the shares of listed companies are traded continuously, these can be seen as transactions in the underlying assets in real time (Mineral Valuation Group, 2025). The challenge of this method is attributing the value of the listed entity to the underlying mineral assets in its portfolio.

To address these challenges, the Mineral Valuation Group has developed a database containing information on a mineral asset basis including ownership, location, geological setting and mineralisation, mining method, development stage, Mineral Resources in their associated categories, on a project-by-project basis for each company within the database. Data are sourced from publicly-listed companies that own these mineral assets, in addition to transaction data publicly available on the acquisition/disposal of assets.

To demonstrate the usefulness of supplementing transaction data with enterprise values, we will conduct a market approach valuation of a gold asset using enterprise values and compare the results to a market approach valuation using traditional transaction data using data sourced from the Mineral Valuation Group database. The example in this paper has been selected because it is recent and there are sufficient recent gold transactions to complete the comparison. This analysis can be expanded to include more assets and transactions to compare the results of the two data sources and further outline the benefits and shortcomings of the method over a larger data set.

Market Comparative Database

To address the limitations of the Market Approach set out above, we created a comprehensive commodity database. The database uses two main sources of data; namely data from publicly-listed companies that own mineral assets, and transaction data publicly available on the acquisition/disposal of assets. The transaction data and company data are captured and considered separately so that they can be used to supplement each other as required.

The database contains information on each mineral asset as a stand-alone asset, including its ownership, location, geological setting and mineralisation, mining method, development stage, the Mineral Resources and their respective categories.

In-situ resource values are calculated for each asset based on the methodology outlined below. All this information is compiled into a report, on a per commodity basis.

Fundamental Premise

The fundamental premise is that the value of a company involved in the exploration, development or extraction of minerals should be driven primarily by the in-situ Mineral Resources.

The following contributing factors play a primary role in the probability of profitably extracting the Mineral Resources:

- Mineral Resource confidence,
- development stage,
- jurisdiction.

All other plant, equipment, infrastructure and intellectual property associated with the company or project exist purely to increase the probability of profitably extracting the estimated Mineral Resources. Therefore, companies or projects that have a higher probability of successfully extracting the Mineral Resources profitably will have a higher in-situ resource value per unit of mineralisation.

Mineral Resources are captured inclusive of Mineral/Ore Reserves. We consider that the market will attribute a higher value in the enterprise value to projects with Mineral/Ore Reserves, which in turn increases the in-situ value per ounce, and therefore we do not value the Mineral/Ore Reserves separately. We capture the Mineral/Ore Reserve data for completeness, and the valuator can consider Reserve data during their valuation.

Data Gathering

There are two main sources of data used for the compilation of the database:

- Data from publicly listed companies that own mineral assets, and
- Transaction data publicly available on the acquisition/disposal of mineral assets.

Data from Publicly Listed Companies

Publicly traded/ listed companies that focus on mineral assets are identified. These companies primarily trade on the New York Stock Exchange (NYSE), the Toronto Stock Exchange (TSX), the London Stock Exchange (LSE), the Australian Stock Exchange (ASX) and the Johannesburg Stock Exchange (JSE). These companies vary from the largest mining companies globally, operating large production assets, to junior companies focussing on the development of greenfield assets. For each company added to the database, all relevant technical and financial data are captured.

For each mineral asset held by the company, the ownership, project location, geological setting and mineralisation type, mining method, development stage, as well as the Mineral Resources categories are captured.

This information is typically obtained from the company's annual report, annual information form and/or their Mineral Resource and Mineral/ Ore Reserve statement. Only Mineral Resources and Mineral/ Ore Reserves reported in accordance with international reporting codes as guided by Committee for Mineral Reserves International Reporting Standards (CRIRSCO) are used in the database.

Financial data are sourced from the latest published financial statements, typically published quarterly, for each company in the database. In addition, the share price for each company is obtained for the previous six months. Using the share price data, the market cap and enterprise value are calculated as:

$$\text{Market cap} = \text{share price} \times \text{shares outstanding} \quad [1]$$

$$\text{Enterprise value} = \text{Market cap} + \text{total debt} - (\text{cash} + \text{cash equivalents}) \quad [2]$$

Data from Transactions

The transaction value as well the relevant technical data on each mineral asset under consideration is captured, including jurisdiction, geological setting, mining method, development stage, and Mineral Resources.

Mineral Valuation Group only considers transactions finalised in the last three years to ensure the transactions considered reflect the current market sentiment.

Old transactions may very well not reflect the current market conditions or sentiment, greatly reducing their use as a proxy of value. We strongly discourage the practice of using factors to make 'old' transactions recent, or to adjust for differences in development stages or jurisdiction. This practice is unfortunately quite common due to the relatively limited volume of transactions.

Quality Assurance and Quality Control

All data are manually captured, and data scraping technologies are not used. This is because of the large variance in the way that companies report their technical data. For instance, some companies report only their attributable percentage in the Mineral Resources, while other companies report 100% of Mineral Resources declared for each asset regardless of their shareholding. Similarly, some companies report Mineral Resources inclusive of Mineral/ Ore Reserves, whilst other companies report Mineral Resources exclusive of (in addition to) Mineral/ Ore Reserves.

Historic data are maintained in the database and can be used to verify older data or value mineral assets at historic dates.

Data Processing

After the data has been checked for errors, the enterprise value or transaction amount is attributed to the in-situ Mineral Resources on an asset-by-asset basis by resource category. This is completed as follows:

Data Standardisation

As many companies often target multiple commodities/metals, it is important to standardise the data. Using the relevant commodity price as a weighting, the contained in-situ Mineral Resources are standardised for all projects contained in the database. This is completed for all the commodities for each asset that they report in their Mineral Resource statement. The reporting unit is also standardised, essentially creating 'unitless resources'.

Enterprise Value calculation

Using the 6-month average share price of the company, the Market Cap for each of the companies in the database is calculated. The Enterprise Value for each company is calculated by adding debt and subtracting cash and cash equivalents.

Core assumptions of the Data Processing Algorithm

To attribute the company's enterprise value to its in-situ Mineral Resources, the following key assumptions are made on in-situ values:

- Value of Measured Resources => Indicated Resources => Inferred Resources,
- Value of Production Assets => Pre-Production Assets => Greenfields Assets.

Additionally, a risk adjustment is made for the country in which the asset is located. This is to account for jurisdiction related risk i.e., an asset located in Canada should be worth more than an asset located in Zimbabwe, all else being equal.

Value Attribution

Every possible distribution of the Enterprise Value is calculated for the in-situ Mineral Resources for which the two core assumptions hold. For each asset, a low, mid, and high value are calculated. Each asset then has a simple triangular distribution fitted to these values. Combining the distribution curves for each asset, a distribution curve is generated for each Mineral Resource category. These are compiled into a global dataset, which contains data for each asset within each company.

The database is typically updated bi-annually and focusses on a single commodity at a time. Once all the companies and assets for that commodity have been updated, a report is created on a commodity-by-commodity basis. Each report provides data subsets in terms of the following groups:

- Global dataset,
- Development stage (production projects, pre-production projects, greenfields projects)

- Jurisdiction (African projects, South American projects, North American projects, Australian projects, and rest of world projects)
- Analysis of each company and their underlying assets,
- Transaction dataset, and
- Analysis of each transaction.

Example
To demonstrate the usefulness of supplementing transaction data with enterprise values, we will conduct a market approach valuation of a gold asset using enterprise values and compare the results to a market approach valuation using traditional transaction data, using data sourced from the Mineral Valuation Group database.

The example selected is based on a recent transaction announced in the public domain. This evaluation is intended as an evaluation of the value of the asset and is not intended to be compliant with any reporting code for the purpose of this example.

Doropo and ABC gold projects
On 1 May 2025, Resolute Mining Inc entered into a binding agreement to acquire the Doropo and ABC gold projects from AngloGold Ashanti for USD150m. The transaction includes a 2% royalty over the ABC project, and a USD10m contingent payment due upon the release of a Feasibility Study over the ABC Project that outlines a Mineral Reserve exceeding 1Moz of gold. Resolute will also transfer all its exploration permits in Guinea to AngloGold Ashanti (Resolute Mining Limited, 2025).

The Doropo and ABC projects are open pit gold exploration projects located in Côte d'Ivoire. Exploration is at an advanced stage for Doropo. An Inferred gold resource has been declared on the ABC project. The Mineral Resource estimates at the transaction date are summarised in Table I.

Table I. Summary of the Mineral Resources (Resolute Mining Limited, 2025)

Resource category	Tonnage (million tonnes (Mt))	Gold grade (grams per tonne(g/t))	Contained gold (million ounces (Moz))
Doropo Gold Project			
Measured	1.5	1.60	0.1
Indicated	75.3	1.25	3.0
Inferred	7.4	1.23	0.3
ABC Gold Project			
Inferred	72.0	0.90	2.2

Note: Mineral Resources are reported inclusive of Mineral Reserves.

The Mineral Valuation Group Industry In-Situ Valuation Report consists of 427 gold assets across all stages of development and locations, and 71 publicly traded companies that own or operate gold assets. For the purposes of this evaluation, only non-operating assets in Africa were considered. Multi-commodity assets were excluded. The subset of data considered consists of 33 non-operating, African assets.

Based on the above factors and compared to similar projects in the database, the Doropo and ABC gold projects are likely to fall in the interquartile range of the dataset of non-operating, African assets (i.e. the 25th to 75th percentile of values).
Based on the subset of data, a distribution curve is generated for each Mineral Resource category. The resultant in-situ resource value distribution graphs and the selected value ranges are illustrated in Figure 1, Figure 2, and Figure 3 for Measured, Indicated, and Inferred Mineral Resources, respectively.

The distribution graphs graphically illustrate the in-situ values for each resource category. The in-situ values in USD/oz are shown on the x-axis and the frequency distribution of project in-situ values on the y-axis. On these graphs, larger y-values point to a higher concentration of projects at a specific in-situ value.

The inset shows the interquartile range of the global dataset in comparison to the subset of data, i.e. pure gold, non-operating assets in Africa. Exploration projects in Africa, i.e., our subset of data, have low in-situ values when compared to the global data. The global dataset has generally higher in-situ values as it includes operating mines, vertically integrated companies with beneficiation capabilities in more preferred jurisdictions.

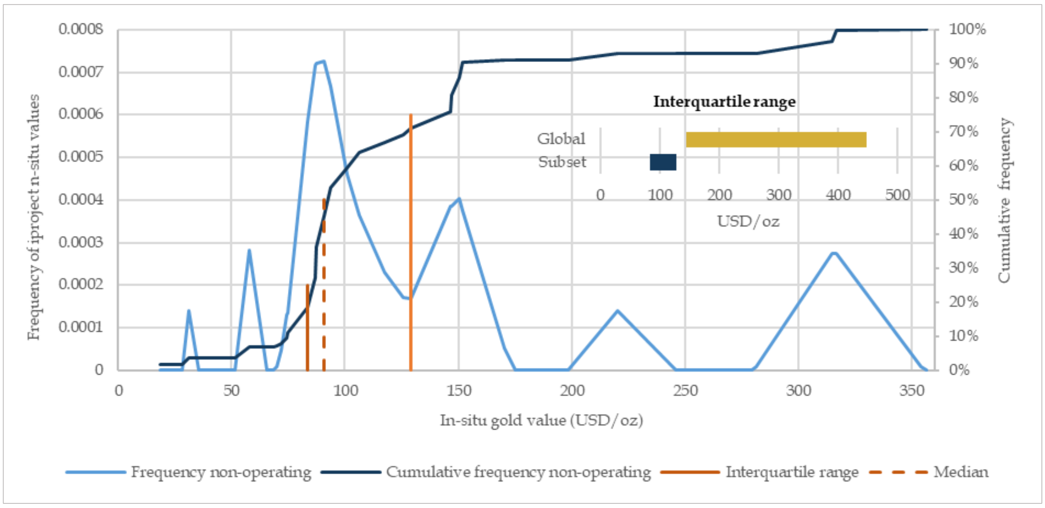

Figure 1. In-situ gold resource value distribution – Measured Resources.

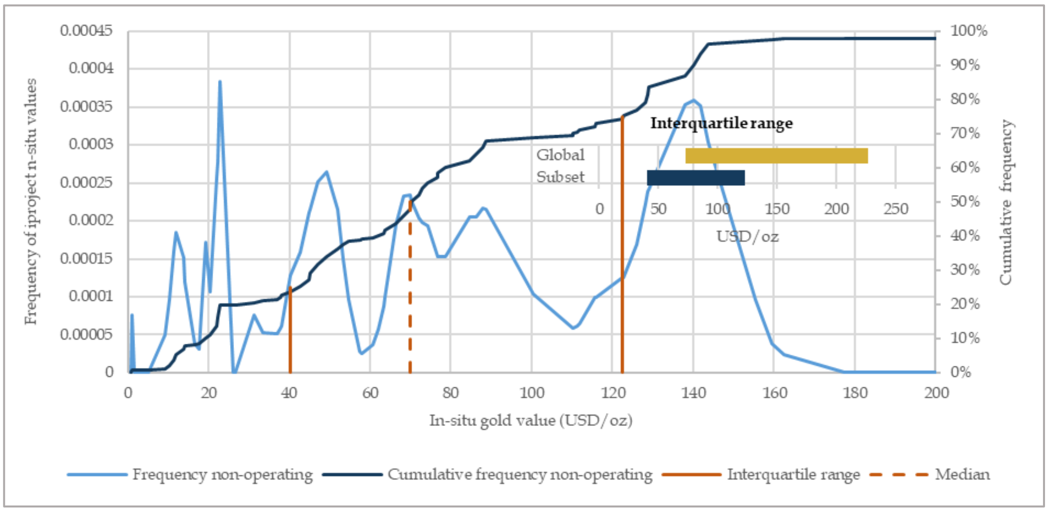

Figure 2. In-situ gold resource value distribution – Indicated Resources.

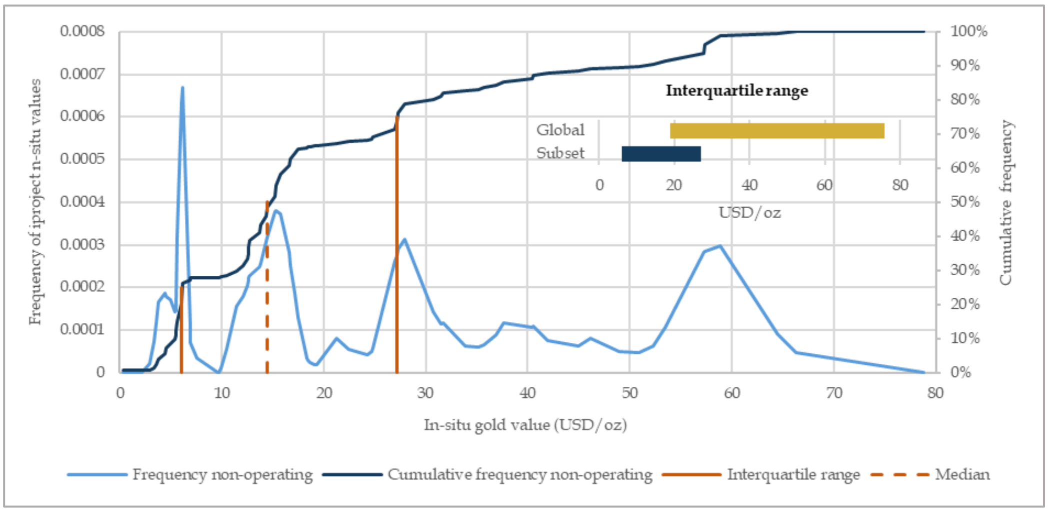

Figure 3. In-situ gold resource value distribution – Inferred Resources.

The in-situ value ranges and the resultant values for the Doropo and ABC gold projects based on enterprise values for the Doropo and ABC gold projects are summarised in Table II.

Table II. Doropo and ABC gold project evaluation results based on enterprise values

	Attributable gold (Moz)	In-situ resource value		Project value	
		Low (USD/oz)	High (USD/oz)	Low (USDm)	High (USDm)
Doropo project					
Measured	0.1	83.32	129.01	6.67	10.32
Indicated	3.0	40.30	122.56	122.11	371.36
Inferred	0.3	6.04	27.15	1.81	8.15
Subtotal	**3.4**	**38.30**	**114.32**	**130.59**	**389.82**
ABC project					
Inferred	2.2	6.04	27.15	13.05	58.64
Subtotal	**2.2**	**6.04**	**27.15**	**13.05**	**58.64**
Total/ Weighted Ave	**5.6**	**25.79**	**80.51**	**143.63**	**448.47**

The resultant value range is USD144m–448m for the Doropo and ABC gold projects.

Considering the above value range, the following additional factors can be used to narrow down the in-situ value ranges for the Doropo and ABC gold projects:

- The projects are not in an active mining area,
- The projects are situated in a remote location and significant infrastructure will need to be developed to support the mining and processing operations,
- The geology is well understood,
- Mining will be from open pit sources,
- Processing will be undertaken using existing technologies, and
- Côte d'Ivoire still ranks low on global indices for attractiveness and ease of doing business.

Transaction only example

For comparison purposes, we evaluated the Doropo and ABC gold projects using transaction only data. A total of 28 transactions involving gold assets were identified in the period 2023–2025. Multi-commodity transactions were excluded.

Table III summarises the gold transactions with the calculated USD per resource ounce value. Of these transactions, three are non-operating gold assets in Africa as highlighted in the table.

Table III. Summary of gold transactions from 2023 to 2024

Seller	Buyer	Transaction date	Key assets acquired	Dev stage	Jurisdiction	USD/ Resource oz
Bilboes Gold Limited[1]	Caledonia Mining Corp	Q1 2023	Bilboes	Pre-production	Zimbabwe	20.94
IAMGOLD Corp[2]	Zijin Mining	Q1 2023 Q1 2023	Rosebel Saramacca	Pre-production Greenfields	Suriname Suriname	62.72
Pure Gold Mining Inc[3]	West Red Lake Gold Mines Ltd	Q2 2023	Madsen mine	Care & maintenance	Canada	19.63
Sabina Gold & Silver Corp[4]	B2Gold	Q2 2023	Back River	Pre-production	Canada	29.21
Endeavour Mining[5]	Lilium Mining	Q2 2023	Boungou Wahgnion	Operating Operating	Burkina Faso Burkina Faso	141.26
Anglo Gold Ashanti[6]	B2Gold	Q3 2023	Gramalote	Brownfields	Columbia	21.05
ATAC Resources Ltd[7]	Hecla Mining Company	Q3 2023	Osiris Rakla	Brownfields Brownfields	USA USA	8.39
			Catch, PIL, Rosy, Connaught	Greenfields	USA	
IAMGOLD Corp[8]	Jaguar Mining Inc	Q3 2023	Pitangui & Acurui	Greenfields	Brazil	9.97
Marathon Gold[9]	Calibre Mining	Q1 2024	Valentine gold	Pre-production	Canada	50.45
Shanta Resources[10]	Saturn Resources	Q2 2024	New Luika Singida West Kenya	Production Pre-production Brownfields	Tanzania Tanzania Kenya	56.43
Reunion Gold[11]	G Mining Ventures	Q2 2024	Oko West	Pre-production	Guyana	108.26
Argonaut Gold[12]	Alamos Gold	Q2 2024	Magino	Operating	Canada	71.51
IAMGOLD Corp[13]	Managem	Q3 2024	Botog	Pre-production	Senegal	87.49

Sources: [1] (Caledonia Mining Corporation Plc, 2023), [2] (IAMGOLD Corporation, 2023), [3] (West Red Lake Gold Mines Ltd, 2023), [4] (GlobeNewswire, 2023), [5] (Endeavour Mining plc, 2023), [6] (Creamer Media's Mining Weekly, 2023), [7] (Business Wire, 2023), [8] (NS Energy, 2023), [9] (Equinox Gold, 2025), [10] (Creamer Media's Mining Weekly, 2024), [11] (G Mining Ventures Corp, 2024), [12] (GlobeNewswire, 2024), [13] (Mining Technology, 2023)

The transaction data considered consists of three non-operating, African assets. The transaction type was not considered. For this evaluation, the interquartile range was used to select the value range from the transaction database. The in-situ value ranges and the resultant values for the Doropo and ABC gold projects based on transaction only data are summarised in Table IV.

Table IV. Doropo and ABC project evaluation results based on transaction only data

	Attributable gold (Moz)	In-situ resource value		Project value	
		Low (USD/oz)	High (USD/oz)	Low (USDm)	High (USDm)
Doropo					
Measured	0.1	20.94	87.49	1.68	7.00
Indicated	3.0	20.94	87.49	63.45	265.09
Inferred	0.3	20.94	87.49	6.28	26.25
Subtotal	**3.4**	**20.94**	**87.49**	**71.41**	**298.34**
ABC project					
Inferred	2.2	20.94	87.49	45.23	188.98
Subtotal	**2.2**	**20.94**	**87.49**	**45.23**	**188.98**
Total/ Weighted Ave	**5.6**	**20.94**	**87.49**	**116.64**	**487.32**

The resultant value range is USD117m–487m for the Doropo and ABC projects. The same additional factors can be used to narrow down the resultant in-situ value ranges.

Discussion

The comparison of evaluation results for each valuation methodology is summarised in Table V.

Table V. Doropo gold project comparison of evaluation results

	Attributable gold (Moz)	Enterprise values		Transaction values	
		Low (USDm)	High (USDm)	Low (USDm)	High (USDm)
Doropo					
Measured	0.1	6.67	10.32	1.68	7.00
Indicated	3.0	122.11	371.36	63.45	265.09
Inferred	0.3	1.81	8.15	6.28	26.25
Subtotal	**3.4**	**130.59**	**389.82**	**71.41**	**298.34**
ABC Project					
Inferred	2.2	13.05	58.64	45.23	188.98
Subtotal	**2.2**	**13.05**	**58.64**	**45.23**	**188.98**
Total/ Weighted Ave	**5.6**	**143.63**	**448.47**	**116.64**	**487.32**

There is considerable overlap in the resultant value ranges between the enterprise values and the transaction values, with the enterprise values giving a narrower range.

In this example, we have completed the evaluation using the two data sources separately for comparison purposes. A valuator could similarly complete their valuation using both sources of data in conjunction with each other to inform their valuation range. The value ranges from both data sources would typically be further refined using project-specific details such as jurisdiction, mining method, geological setting, etc.

Using enterprise values as supplementary source of data can assist to create a sufficiently large, current dataset of comparable mineral assets. This removes the need to subjectively adjust data when transaction data alone is insufficient or not directly comparable. Consistent, good quality, recent data mitigates the risk of inaccurate valuations, which can affect the reliability of, or confidence in, a valuation statement and compromise investor interests.

This example can be expanded to a more detailed analysis that includes more assets and transactions comparing the results of the two data sources and further outlining the benefits and shortcomings of each data source over a larger data set.

CONCLUSIONS

The results of the enterprise value evaluation (USD144m–448m), and the transaction data evaluation (USD117m–487m) overlap, illustrating consistent results across both data sources. The publicly announced transaction value of USD150m for the Doropo and ABC projects falls within both value ranges, supporting the position that enterprise values calculated from the share price of listed entities form a good source of supplementary data for use in Market Approach valuations.

This example is based on the gold market, which is relatively large and active globally with significant numbers of gold assets, gold companies and numerous publicly-reported related transactions. Even so, only three recent transactions were considered comparable to the assets under consideration. This illustrates the usefulness of including enterprise values as a second data source to supplement the market valuation results.

Many other commodities, such as manganese, chromite, and graphite have very limited assets held by publicly listed companies and therefore there are almost no public transactions that can be used to form the basis of a mineral asset valuation. In these cases, the enterprise value data would be crucial to ensure sufficient relevant data for informed decision making.

Regardless of the data source, the valuator still needs to apply their mind and take into consideration factors that may impact both transaction values and enterprise data in the face of the rapidly changing landscape facing the minerals industry. These factors may include fluctuating commodity prices, the regulatory landscape, environmental factors or other asset-, company- or transaction-specific considerations.

This evaluation can be brought up to a compliant standard in conjunction with a second valuation methodology. This can also be a useful tool for investors and interested parties as a quick pass to determine if a valuation is reasonable prior to more detailed due diligence.

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The implementation of the value chain optimisation model at Valterra Platinum

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Valterra Platinum (previously Anglo American Platinum), in its effort to continuously improve valuation methodologies supporting its strategic planning process, developed an integrated Value Chain Optimisation Model (VCOM). Qerent was selected as the techno-economic modelling platform due to its complex modelling capability, allowing the integration between mining and processing. The role of the model is to provide a portfolio-level modelling environment covering the entire mine-to-market value chain to augment both tactical and strategic decisions. The model accepts inputs across multiple functions comprising mining, processing, marketing, and finance. The ability to analyse scenarios by adjusting various strategic levers within the model allows for more consistent and informed decisions, reinforcing the culture of data-driven decision making. VCOM has led to an increased availability of data, standardisation of calculation methodologies, with a reduction in human error in the collation of data. The benefit to the organisation is less time spent on data processing and increased insight by shifting efforts to the analysis and interpretation of outcomes. This paper covers the VCOM modelling solution design, how challenges were addressed, and the future development options for VCOM.

INTRODUCTION

Valterra Platinum is a primary producer of platinum group metals (PGMs) and was established through its demerger from Anglo American in 2025. This paper presents a case study on the implementation of a Value Chain Optimisation Model (VCOM) at Valterra Platinum, a solution designed to enhance mineral asset valuation and related decision-making through integrated scenario-based modelling aligned to its broader digitisation strategy.

The implementation of VCOM at Valterra Platinum builds upon a legacy of strategic planning frameworks previously established at Anglo American Platinum. As outlined by Smith, Anderson, and Pearson-Taylor (2009), the company has long emphasised centralised, data-driven planning methodologies to align operational and financial objectives in the long-term planning process.

Developing a robust long-term mine plan aligned to the company's strategic intent requires further consideration of both tactical and strategic planning horizons. Kloppers, Horn, and Visser (2015) emphasised that strategic planning defines the long-term direction of a mining business, focusing on value creation through scenario-based analysis and alignment with corporate objectives. Tactical planning, on the other hand, operationalises this strategy by addressing short-term to medium-term execution, ensuring that production targets and resource constraints are realistically managed. Their framework highlights the importance of a seamless interface between these planning horizons, supported by iterative feedback and cross-functional collaboration. This feedback and collaboration loop is supported through a structured, data-driven techno-economic planning environment provided by VCOM.

The importance of the integration of tactical and strategic planning horizons in mine extraction strategies has long been recognised. As asserted by Marais and Lombard (2014), the planning framework was designed to ensure that tactical execution is aligned with strategic intent, enabling consistent delivery of value across the mining portfolio. However, much of the existing published literature and historical planning efforts previously at Anglo American Platinum have centred largely on the mining process and mine plans, with limited emphasis on integration into the processing value chain.

The VCOM solution and supporting planning process developed in Valterra Platinum, as presented in this paper, addresses this gap by extending the principles of integrated planning, supported by a data-driven techno-economic environment identified previously in Anglo American Platinum, into the processing domain. This level of integration in the modelling environment is proposed by Lane, Milovanovic, and Bondi (2010), arguing that a dedicated model of the complete business is required to optimise the entire value chain due to its inherent complexity. VCOM addresses this need for a dedicated modelling environment integrating financial, operational, and strategic inputs from mining, concentrators, smelters, and refineries, enabling scenario-based valuation and optimisation across the full mine-to-market spectrum of Valterra Platinum. This represents a significant advancement in planning methodology, building on the foundation established in mine planning and applying it to the broader value chain.

VCOM models the combined production and financial long-term plans of Valterra Platinum's assets, offering a dynamic and integrated view of resultant portfolio value. Its flexible architecture supports scenario modelling across a range of strategic levers—closely aligned with those outlined by Venkatesh *et al.*, (2014), who emphasise the importance of portfolio-level modelling to support strategic decision-making in complex, multi-asset mining environments. These levers include:

- Valuation of the company portfolio at the current operation
- Valuation of the company portfolio with expanded operations
- Modelling of potential additions/closures/reconfigurations to the portfolio processing division
- Modelling of changes in the ownership settings of the portfolio's assets
- Modelling of varying financial inputs and macro commodity factors

The use of the VCOM model allows for asset and project evaluation, strategic pathway analysis, portfolio optionality, and commercial transaction models. A key advantage of VCOM is that it has allowed for a much quicker turnaround of results in testing these scenarios whilst fully integrating the procesing value chain.

The purpose of the paper is to provide an overview of the VCOM solution and its application within Valterra Platinum.

VALTERRA PLATINUM OPERATIONS

Valterra Platinum is the largest primary platinum group metal (PGM) producer in the world, with the latest owned mine production in 2024 at approximately 3.6 million ounces of PGMs (Valterra Platinum, 2025). The owned mines from which the company sources its ore occur in both the Bushveld Complex of South Africa and the Great Dyke of Zimbabwe (Gunn and Benham, 2009). This is depicted through Figure 1. The company further sources concentrate from a joint venture, Modikwa, located in Limpopo, as well as from third-party mines. Each of these mines is termed an asset.

The assets then supply concentrate to the processing division of Valterra Platinum, and are subsequently refined to provide final saleable metals. These metals include the PGMs (platinum, palladium, rhodium, iridium, ruthenium, and osmium) and base metals (nickel, copper, and cobalt). Gold is also additionally sourced as a saleable metal. Figure 2 shows an illustrative overview of the value chain from mine to market for the company.

Figure 1. Overview of Valterra Platinum operations (Valterra Platinum, 2025).

MINING	CONCENTRATING	SMELTING	CONVERTING	REFINING	MARKETING
4 Fully Owned Mines: - Mogalakwena - Amandelbult - Mototolo-Der Brochen - Unki 1- Joint Venture - Modikwa	6 Owned Concentrators: - Mogalakwena x 2 - Amandelbult x 2 - Mototolo-Der Brochen - Unki 1- Joint Venture - Modikwa	Primary Smelting: - Waterval Smelter - Polokwane Smelter - Mortimer Smelter - Unki Smelter Additional Smelter Units - Slag Cleaning Furnace - Polokwane Acid Plant	Converting: - Converter A - Converter B Additional Smelter Units - Tower Plant - Contact Plant	Magnetic Concentrator Plant Base Metal Refining Precious Metal Refinery	Sale of Metals to the general market for various purposes

Figure 2. Overview of the Valterra Platinum value chain adapted from Ndlovu, J. (n.d.).

Sulphuric acid, sodium sulphate, chrome concentrate, and silver are additionally sold as by-product streams obtained from the mining of the PGM ore.

PROCESSING DIVISION OF VALTERRA PLATINUM

The processing division of Valterra Platinum exists as one of the key steps in the value chain of the company, transforming the metal compounds within the concentrate of the owned mines and other third-party producers to a final saleable metal. Valterra Platinum contains the largest processing capacity of all primary PGM producers and is a key driver of the company's capability to fulfil market and customer requirements.

After concentrating the ore in concentrators adjacent to the mines, the resultant concentrate is then smelted and subsequently refined. The first step occurs at the smelters, where concentrate tonnes are processed within the furnace to form a slag and matte layer to separate the metal sulphide minerals from the gangue oxides. The matte formed – containing mainly base metal sulphides – acts as a collector for PGMs.

The mattes from the different smelters are then processed in a converter containing air (or oxygenenriched air) to oxidise iron sulphide. Within the converter, the sulphur is removed as sulphur dioxide gas, and the iron oxide (formed from the oxidation of iron sulphide) is combined with added silica to form a fayalitic slag (Gunn and Benham, 2009).

This matte is dispatched to the base metal refinery where the separation of PGMs from base metals occurs. In Valterra Platinum's process, however, matte is separated into magnetic (PGM-containing) and non-magnetic components in a magnetic concentrating plant. The magnetic portion is then sent directly to the precious metal refinery for purification (Ndlovu, n.d.).

In the refining process, hydrometallurgical methods are primarily used to treat the matte obtained from the converter. The residue from the magnetic concentrator plant is transferred to the precious metal refinery for separation and purification of the precious metals. The refining of the PGMs is achieved through methodically dissolving and precipitating the PGMs as salts or through the use of total leaching, which employs the method of sequential metal separation through solvent extraction. The overall processing flow sheet can be described in Figure 3:

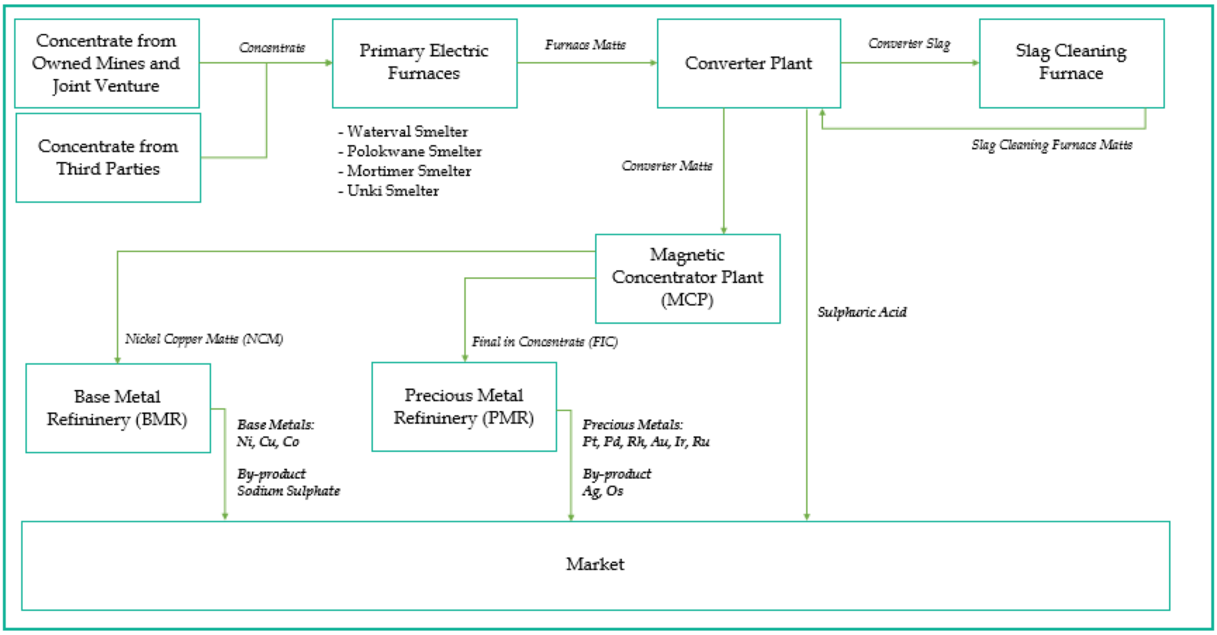

Figure 3. Processing flow diagram utilised in the VCOM infrastructure.

OVERVIEW OF THE VCOM SOLUTION

The VCOM was developed using the Qerent modelling platform, a configurable enterprise solution provided by Business Science Corporation (BSC). Qerent is not limited to techno-economic modelling; rather, it serves as a comprehensive modelling environment that integrates financial, operational, and strategic data across mining and processing in the full mine-to-market value chain. Its modular architecture enables scenario-based planning and decision support, allowing users to simulate and evaluate a wide range of business outcomes.

The VCOM planning environment facilitates the consolidation of inputs from various mining, processing, and financial planning processes, enabling production and valuation optimisation on an asset and aggregated portfolio level across tactical and strategic horizons. This flexibility makes it particularly well-suited to extending integrated planning beyond traditional mine planning into the processing value chain, where VCOM introduces new capabilities for strategic alignment and value-based decision-making.

At its core, VCOM serves as a data integrator, transforming diverse datasets and potential business configurations into actionable insights supporting scenario-based decision-making. By modelling each stage of the value chain, VCOM provides a portfolio view of the financial and operational performance of various scenarios. Key financial metrics like Net Present Value (NPV), Internal Rate of Return (IRR), Return on Capital Employed (ROCE), and All-in Sustaining Costs (AISC) are produced. These financial metrics are augmented by technical metrics demonstrating value chain impact, like work-in-progress stockpiles and capacity utilisation, providing insight to support decisions around capital allocation and strategic alignment. This scenario planning framework is depicted in Figure 4.

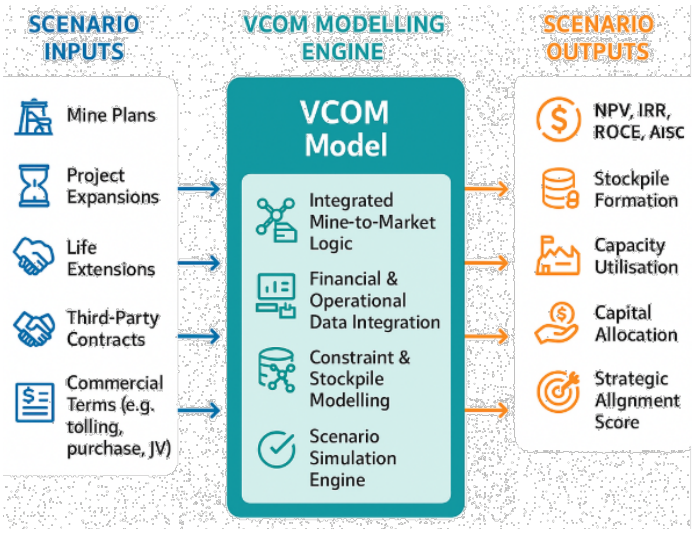

Figure 4. VCOM scenario planning framework.

VCOM operates utilising a 60-year forecast, which enables the tool to ultimately provide scenario-based long-term valuations of assets based on different input assumptions. It further supports tactical decision-making by determining how decisions made at the asset level in the short term could have medium-term and long-term impacts not only on the assets themselves but also on the portfolio as a whole. With consistent improvements during development, VCOM can run hundreds of scenarios in rapid succession, each with varying degrees of assumption, input, and value chain configuration differences to optimise an objective function like NPV.

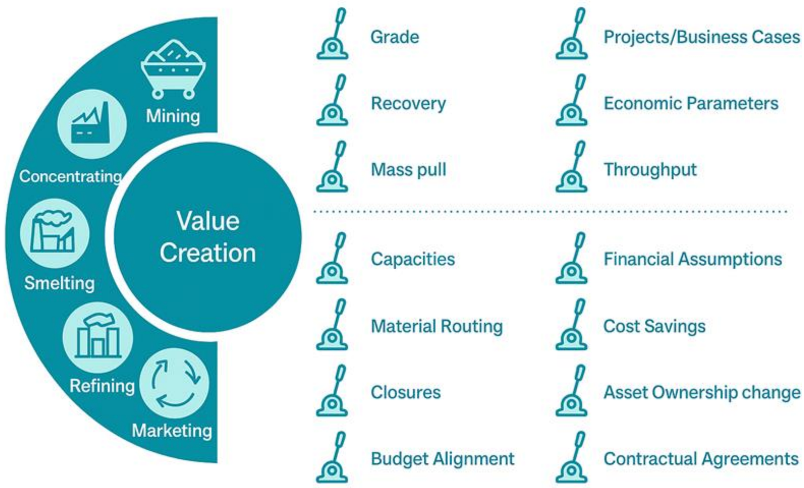

Figure 5. Illustration of various modelling levers in the VCOM tool set.

The flexibility of this tool allows for changes to be made to the model, supporting continuous improvement and sustainability in terms of its use and capabilities. As a result, key features include

- Flexibility across various methods of input from databases (SQL) or MS Excel inputs
- The use of templates with business logic to ensure consistent and scalable model updates
- The ability to connect to other Qerent models, such as the metal accounting model, to demonstrate alignment with production updates and forecasting
- The application of a dynamic library that captures an audit trail of scenarios

Figure 6 gives a high-level overview of the way the tool is utilised:

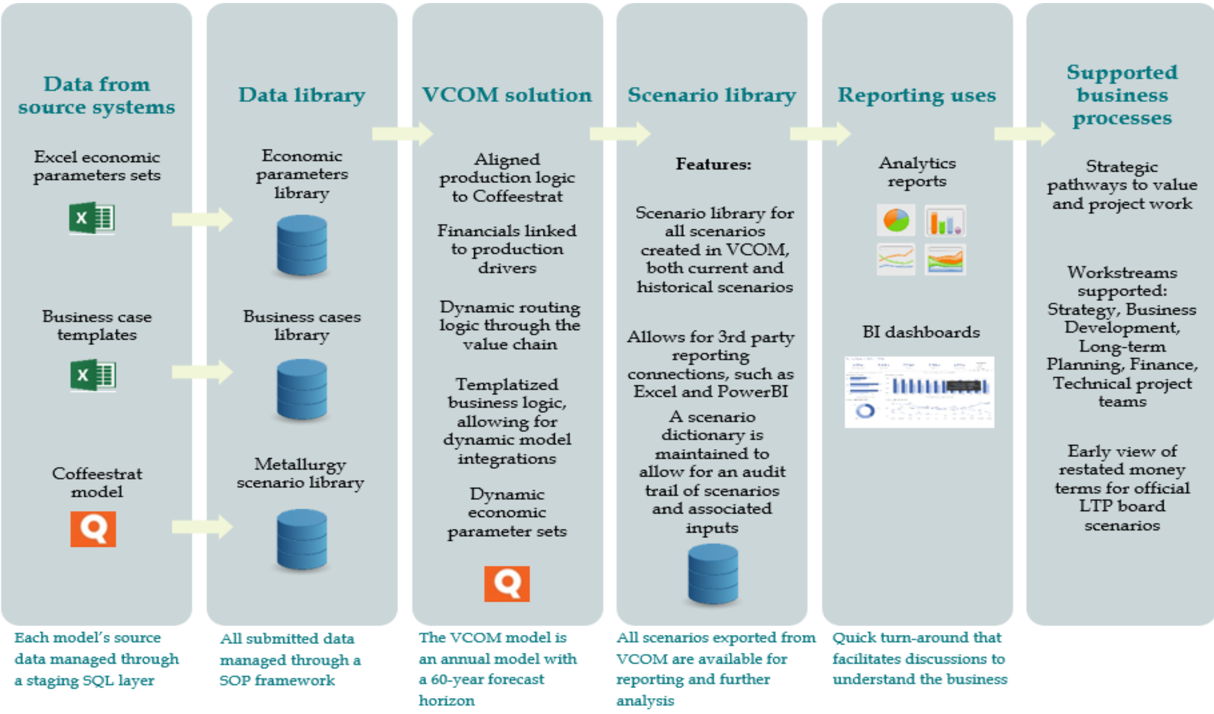

Figure 6. VCOM modelling process.

VCOM MODELLING METHODOLOGY

Underpinned by a robust technical architecture using the Qerent modelling software and the subsequent structured SQL databases, the tool ensures high-level data integrity, higher operability, and consistency amongst its outputs. The entire tool is broadly categorised into four different operable layers as described in Figure 7.

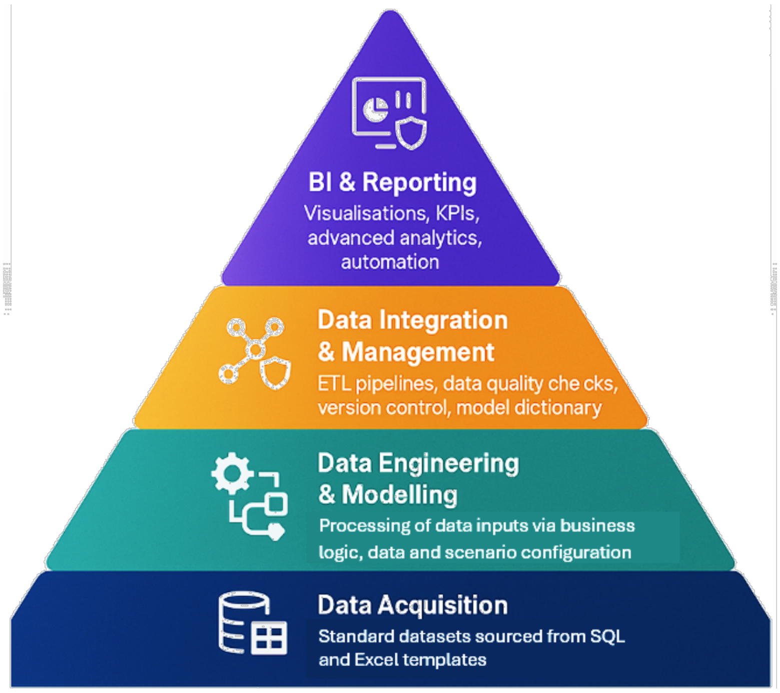

Figure 7. VCOM technical operations.

Since the VCOM valuation model underpins Valterra Platinum's strategy to optimise value across the mine-to-market value chain through disciplined capital allocation, it begins with economic assumptions and financial inputs in constant money terms to ensure consistent scenario analysis. The model supports both constant and real money terms, with built-in escalation logic for inflation, exchange rates, and commodity pricing. The model further acquires technical and production inputs that track material flow from concentrating through smelting, refining, and final sales, using technical logic aligned with agreed metal accounting frameworks.

In the data engineering and modelling layer, it simulates material stock dynamics, processing capacities, and throughput to determine saleable volumes and revenue. Activity-based costs are modelled honouring fixed and variable cost-volume relationships, with investment capital, stay-in-business capital expenditure and overhead costing integrated. A basic financial equation is demonstrated and used to report on earnings before interest, tax, depreciation, and amortisation and operating cash flow, followed by tax and working capital adjustments to calculate free cash flow. Free cash flow is discounted over the asset life to determine the NPV. VCOM's flexible architecture supports scenario planning using strategic levers—such as cost changes, capacity shifts, and ownership structures—enabling robust valuation, capital allocation, and portfolio optimisation.

Each of these layers is operated under a strict standard operating procedure (SOP), governing data upload, ensuring that the data quality is always at the highest possible level. Each data upload is tagged with metadata (user, date, reason, description), and validation checks confirm alignment at each layer between uploaded and imported data.

The outputs of the model are ultimately determined per scenario modelled. A consistent set of outputs has been flagged to be reported on within the reporting layer of the model and is exported to a SQL database. This database setup, according to a star schema, ensures that there are reporting capabilities in both Microsoft Excel CUBEs and other visualisation tools such as Microsoft Power BI. The insights and evaluations obtained from these outputs can then be further circulated to a wide range of stakeholders, from analysts to executive leadership.

SCENARIO PLANNING AND STRATEGIC USE CASES

Initially, VCOM was developed to address the limitations of siloed planning, where mining, processing, and marketing were evaluated independently. This fragmented approach made it difficult to identify value leakages or optimise decisions across the full value chain. To address this, VCOM was designed as a unified modelling platform that integrates the entire mine-to-market value chain using consistent logic, assumptions, and data structures.

It enables scenario planning, 'what-if' analysis, and the evaluation of strategic levers such as asset ownership changes, capacity adjustments, and contract variations. By aligning operational and financial data, VCOM supports capital allocation, commercial agreement evaluation, bottleneck resolution, and value optimisation—shifting the planning paradigm from a fragmented view to a fully integrated, value-driven approach. Outputs include key investment metrics required for decision making, including, but not limited to ROCE, IRR, NPV, payback, peak funding requirement, and AISC at varying discount rates or other economic parameters.

Asset and Project Valuation
The robustness of VCOM valuations at the portfolio level has resulted in its application to estimate project valuations for governance decision-making. The application of VCOM to estimate project valuation exposes possible constraints in the processing division and allows decision makers to assess the impact of stockpile formation that may result. Due to its ability to model mine to market, VCOM can determine the impact of projects on the processing value chain and its impact on the portfolio as a whole. Project viability may be impacted by constraints or bottlenecks in the value chain, resulting in a time-value of money impact resulting from the lock-up of revenue and potential increased cost and environmental impact of work in progress or stockpile management.

In addition to the valuation of mining projects at the asset level, VCOM is also utilised to estimate the portfolio valuation impact of processing projects, covering projects at the smelters, the converter, the magnetic concentrator plant, or the refineries.

The rapid pace of modelling has allowed VCOM to become the primary source of asset and processing project valuations, guiding strategic decisions supported by the portfolio impact of the projects.

Commercial Transaction Valuation
Valterra Platinum does not solely process material from owned mines and leverages available processing capacity to process material from third parties. The VCOM model provides the environment where the potential value to be derived from third-party processing may be evaluated. VCOM allows rapid testing of various production inputs, processing configurations, and commercial terms to identify the best technical and financial outcome for Valterra Platinum.

Portfolio Optionality
VCOM enables Valterra Platinum to explore a wide range of strategic pathways by modelling different combinations of mine plans, project expansions, life extensions, and third-party contract scenarios. These options are structured into a scenario matrix and tested in the model. Each scenario is run through VCOM, with results exported to a central cube report for comparison.

This allows the business to assess options based on key criteria such as stock build-ups, capacity utilisation, capital allocation, and long-term value creation. Scenarios are ranked based on techno-economic metrics and degree of strategic alignment, supporting informed, data-driven decisions that maximise value across the business, even in the face of uncertainty and evolving market conditions.

VCOM IMPACT ON INVESTMENT EVALUATION

The ability of VCOM to produce valuation estimates of both assets and the entire portfolio across the full value chain has been a cornerstone of its impact on data-driven decision making. VCOM has become an integral consolidation tool for the financial planning, strategic planning, and production planning workspaces.

Ensuring consistent alignment to relevant functional department models, VCOM allows for early identification of potential anomalies that may otherwise only have been identified post the reporting of modelling results. Model alignment reduces the amount of time required to perform reconciliations manually. In addition, the use of Qerent's calculation engine capabilities has reduced the amount of time required to evaluate strategic options, allowing for the turnaround time to improve from weeks to days, enabling more agile responses to market changes.

The improvement in data governance and management, which uses a specifically-devised model dictionary, has allowed for all models to be accounted for, stored, traceable, and reproducible. Instead of being stored on a spreadsheet, all data from scenarios lives in databases that are centrally controlled and managed with Information Management security and polices in place, ensuring that data is not lost or corrupted. As a result of this, it has improved the trust that stakeholders have in the tool.

Technological and digital improvements in any company are implemented to allow stakeholders to either perform their duties more effectively or make decisions more efficiently. VCOM has ensured a data-driven culture is spread through the organisation, where the tool is now a common defining feature in any major evaluation or project.

VCOM has enabled Valterra Platinum to evaluate entire portfolios covering the full value chain rather than isolated projects often limited to the mining impact only. This portfolio-level view supports optimal capital allocation, risk management, and long-term value creation.

CHALLENGES FACED BY VCOM DEVELOPMENT

The implementation of VCOM faced several stumbling blocks in its path to producing the substantive, sustainable outputs it produces today. As with any technological development, several challenges were faced, and various lessons were learned that can be offered to other companies seeking to emulate this digital transformation journey.

Initially, the model development was large and rather broad to allow for the input of data at different levels that were not necessarily required. Consistent monitoring, management, and upgrades to the model were required to avoid performance bottlenecks and ensure consistent usability. Through optimisation efforts, model size was reduced by 39% and calculation time improved by over 12x.

Due to the data inputs emanating from a variety of sources (long-term planning Excel sheets, budget input sheets, metal accounting SQL database, etc.), considerable effort was required to ensure the data was consolidated consistently. As a result, several validation tools and checks were developed to ensure alignment and accuracy.

Accordingly, to mitigate some of the issues faced, it was recognised that data governance procedures and a detailed modelling blueprint document are critical in ensuring the successful implementation of the model. The blueprint must define the business logic, data flows, and critical and niche structures of the data model. SOPs must denote the way the modelling must be accomplished, data validation procedures, and the dictionary must ensure version control, audit trails, and contain sufficient metadata for accountability purposes.

FUTURE WORK AND CONCLUDING REMARKS

The implementation of any system requires a transition period for all stakeholders to buy into the model and its outputs. To do so, it is important to have detailed engagements with shareholders to understand their requirements, motivations, and ensure that these are considered in the development phase. Additional time must be planned for training and cultural adaptation. The tool must be further enhanced for ease of use by the stakeholders, where possible, and is inclusive of ensuring sufficient data availability and access to validation checks. This allows for stakeholders to 'buy in' to the model and prevent them from reverting to older and less efficient (but trusted) models, creating double workstreams. These enhancements were critical to driving adoption and effective use.

VCOM continues to evolve as a strategic platform at Valterra Platinum. The potential next major step is transitioning to a web-based version, enabling multi-user access and real-time collaboration. This will allow different teams to link their models—such as monthly budget guidance, supply-demand, and financial statements—into a unified modelling environment. Power BI reporting may be further enhanced to provide tailored, interactive dashboards, improving transparency and stakeholder engagement. The introduction of AI tools is being considered to accelerate data analysis and insight generation, helping teams focus on strategic interpretation rather than manual processing. These developments reflect Valterra Platinum's commitment to continuous improvement and its ambition to lead digital valuation and strategic planning within the mining sector.

The implementation of VCOM marks a significant shift in how mineral asset valuation is approached—not only by unifying operational, financial, and strategic data, but by explicitly incorporating the downstream processing value chain into the strategic planning process. This represents a critical evolution from traditional mine-centric planning to a holistic, value-chain-oriented approach.

Importantly, VCOM also strengthens Valterra Platinum's ability to uphold the strategic pillar of disciplined capital allocation. By enabling detailed scenario analysis, constraint modelling, and portfolio-level valuation, the model ensures that capital is deployed where it delivers the greatest long-term value. This supports more rigorous investment decisions, enhances capital efficiency, and aligns project funding with both financial returns and strategic intent.

As the mining industry faces increasing complexity and volatility, Valterra Platinum's journey with VCOM offers a compelling blueprint for modernising valuation methodologies and embracing the power of integrated, data-driven decision support. With ongoing development and existing organisational support, VCOM is poised to remain the central modelling engine that drives smarter, faster, and more connected decision-making, anchoring Valterra Platinum's strategy in a fully integrated, data-driven, and capital-disciplined future.

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With over a decade of experience in mining and finance, I have built a career that began with the Anglo American Platinum Graduate Program in 2009 and became a CIMA professional in 2014. Currently, I am the Manager of Scenario Modelling within Anglo American Platinum's Corporate Development team, specifically within the Portfolio Management space. My primary focus is running robust combinations of projects that will shape the company's strategic direction and assist stakeholders with decision-making where multiple pathways for assets within our portfolio exist. I was deeply involved in creating the Value Chain Optimisation model (VCOM), which aims to maximize value through the full processing value chain, from mining to final saleable material

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Rivashan is an Senior Specialist in Data Analytics and Planning - having worked in the platinum smelting production space as a metallurgist and in the process control space as a control engineer. He now is in the Corporate Development department of the company. He is passionate about technology and the implementation thereof across the business to improve efficiency and enhance automation alongside his technical knowledge of the operating parameters in the processing of mined products.