Economic risks in mining investments: A prospective analysis of capital expenditure estimation in copper mining projects

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Abstract

Mining projects are highly exposed to cost overruns, ahead of oil and gas, power generation and infrastructure projects. Precisely, warnings related to sharp increases in capital and production costs of around 40% are expected to be found in the corresponding literature. This paper analyses the economic risks related to capital cost presented by public investment offers in copper mining projects. To detect the economic risks of copper mining projects presented to the public, the research pays particular attention to the existing methodologies for the valuation of mining assets, as well as for the preparation of technical reports with internationally recognised codes that aim to offer the expert in charge of the valuation a series of guidelines to carry out this work. For this purpose, an in-depth study and analysis of four National Instrument 41-101 technical reports of current copper mining projects selected following criteria of geographic, business, exploitation and size diversification is carried out: Arctic Project (Northwest Alaska, United States), Kutcho Project (British Columbia, Canada), Josemaría Copper-Gold Project (San Juan, Argentina) and Eva Copper Project (Queensland, Australia). The research concludes that it would be advisable that mining companies and, especially, Competent persons responsible for preparing technical reports apply the recommended practices, being extremely conservative with the ranges of precision and contingencies contemplated in each phase. It should be a significant turning point for the sector, which, to prosper and reinforce investment decisions, must leverage transmitting trust, transparency, cleanliness and professionalism to the market.

Keywords

Copper; Mining project; Feasibility study; Pre-feasibility study; CAPEX; Overruns; Contingency; Competent person.

1. INTRODUCTION

In general, investment in projects of any kind faces numerous risks. However, mining projects are unfortunately characterised by high-risk levels, especially those related to the length of the construction period and capital cost. Mining projects have severe cost overruns, higher than those of oil and gas (Iraj & Hamed, 2022), power generation (Saiful et al., 2019) and infrastructure projects (Al-Hazim et al., 2017). Moreover, it is expected to find warnings in the mining literature, much of which is referenced below, that capital cost and production costs can more than double from what was estimated in the feasibility studies, being an increasingly frequent phenomenon.

This paper analyses the economic risks related to capital cost presented by public investment offers in copper mining projects to provide capital markets and potential investors with a safer, more transparent and closer environment for investment decisions. According to Guo et al. (2021), capital cost is one of the essential criteria for assessing the feasibility of underground and open-pit mines, with a heavy influence on the projects' net present value (NPV).

Due to this criticality, there were many attempts to model the estimation of accurate mining capital cost. One of the most recognized models was developed by O'Hara (1980), using the exponential regression to estimate mining costs for feasibility studies. It was developed based on the data gathered in Canada, USA, Mexico, Australia, Peru, Bolivia, Ireland, France, Morocco and Iran. This mathematical model was updated by O'Hara & Suboleski (1992). It is still commonly practiced and widely used and allows mining engineers and other professionals involved in mining projects to introduce some parameters the model asks for estimating costs, being also possible to estimate the number of machines, personnel and space buildings and all infrastructure required for the mining project.

Although focused on coal mining, but applicable to the mining industry in general, Budeba (2015) highlights the shortcomings of the available cost estimation methods by not considering many variables that have a significant impact on the estimation of mining costs. He proposed a data envelopment analysis method to develop a frontier for effective surface mines, and the use of a parametric method to model cost and productivity with the aim of guaranteeing the competitiveness of the mine. Also, Shafiee & Topal (2012) state that accurate cost estimation is a critical component of mining project evaluation to determine whether a proposed project is clearly feasible, doubtfully feasible or clearly uneconomic. They introduce the concept of indices for different components of mining projects and a new econometric model for estimating the operating cost and capital cost of a coal mining project, calculated by using the proposed econometric model and verified by comparing the outputs with CostMine data and Sherpa software outputs for a surface coal mine.

Nourali & Osanloo (2020) developed a model based on Support Vector Regression (SVR) to estimate the capital cost of mining projects as an underestimation may postpone the construction. Accordingly, the production phases and an overestimation will decrease the value of the project. Zheng et al. (2021) forecasted mining capital cost through neural networks exploring the relation between production factors, ore grades and the life of mine (LOM). Previously, Zhang et al. (2020) also proposed neural networks to forecast the capital cost of open-pit mining projects, especially copper mining projects, considering annual mine production, annual production of the mill, stripping ratio and LOM as the most critical parameters. Nourali & Osanloo (2019) developed a model based on the regression tree method to estimate the mining capital cost in a wide range of mining capacities.

Alternative attempts to estimate the capex of mining projects can be found in Sterba et al. (2019). They estimated the capex of a generic lithium mining project by establishing a relation between the lithium carbonate production and the capital expense (CAPEX). The developed formula was used to estimate the capital expenses of the Cínovec lithium mining project in the Czech Republic (Sterba et al., 2020). Riesgo García et al. (2017) estimated the CAPEX for a generic rare earth mining project based on the solid relationship among the CAPEX, the amount of mineral entering the processing plant, and the total processing grade. This was later applied to Greenland's Sarfartoq Rare Earth Element Project (Riesgo García et al., 2019). Suárez Sánchez et al. (2015) made something similar for lithium mining projects. Previously, Auger & Guzmán (2010), regarding investment decisions made in copper mines, obtained a direct relation between investment and mine capacity.

Contrasting the severe concern about recurrent and notorious capital cost overruns is easy. Bertisen & Davis (2008) reviewed 63 international mining and smelting projects, confirming that as-built capital costs are, on average, 14% higher than the bankable feasibility study estimated. They also confirmed that roughly half of all projects' as-built capital costs fall outside the expected estimate of ±15% by the feasibility study, even after allowing for intentional estimation bias. Haubrich (2014) demonstrated after a detailed survey of mining projects over the last 50 years (1965 to 2014) that cost overruns have existed since the beginning of the industry and are long-standing and significant. He states that the average overruns of the projects analysed are between 20% and 60%.

Lwin & Lazo (2016) elaborate on the above, postulating the importance and endemism of capital cost overruns. Based on their experience and the analysis of 78 international mining projects with a capital investment of more than 50 M USD between 1995 and 2015, they conclude that (1) Owners and indirect costs tend to be significantly underestimated. The same is true for material and labour costs; (2) In feasibility studies, engineering, procurement, and construction management costs (EPCM) tend to match forecast costs to an accuracy of ±15%; (3) There is clear evidence that there is a correlation between capital cost overruns and raw material prices, although they are not proportional; (4) Newer projects have higher cost overruns; and (5) The estimation of capital cost is customarily done at the Association for the Advancement of Cost Engineering Class 3 feasibility level (AACE International, 2020a). However, reality shows that the errors are higher than the AACE guidelines.

One specific fact that emerges from this study is that the average cost overrun of projects is 37%, ranging from 0% to just over 250%, being higher in the last years of the study, where the average is over 40%. It is also evident that the larger the size of the project, the higher the relative weight of the cost overrun. By product type, nickel, copper, gold and zinc mines, in that order, are the most likely to incur this risk, with average cost overruns of 45%, 40%, 40%, and 34%, respectively. Notably, the most financially leveraged projects have the lowest cost overruns, explained by more outstanding professionalism and cost control.

The origin of cost overruns can be very diverse. However, it is noted that the main areas most frequently affected in feasibility studies are the design and programming of the LOM (32% of cases), the geological study together, with the estimation of mineral resources and reserves (17%) and metallurgical testing (15%) (McCarthy, 2013).

In relation to compliance with the mining plan designed and programmed, with a correct exploitation and processing method, a study by the Center for Copper and Mining Studies of Chile (Cantallopts – Constanza Araya, J., 2023) remarks the high delays experienced by copper mining projects, especially medium-scale ones. Specifically, with an additional average duration of 6.3 years, which represents a duration slightly greater than 40%, with the corresponding additional costs incapable of being absorbed by the contingency levels.

On the other hand, it could be argued that the "Competent Person" or the "Qualified Person" responsible for the study may bear some responsibility (Krzemień et al., 2016).

The Committee for Mineral Reserves International Reporting Standards (CRIRSCO) defines a "Competent Person" as a professional in the mining industry who belongs to a professional organisation recognised by the corresponding international code (including those mutually recognised international professional organisations). These professional organisations must have enforceable disciplinary processes subject to a code of conduct whose failure to comply results in expulsion or suspension. In addition, the competent person should have at least five years of experience that can be considered "relevant" in the specific deposit or mineralisation type and in the kind of activity that it carries out (exploration, development or operation, or evaluation) (CRIRSCO Standard Definitions, 2012). The Canadian Institute of Mining, Metallurgy and Petroleum (CIM) uses the term "Qualified Person" (CIM Definition Standards, 2014), which is equivalent to a competent person.

The different international codes clarify the term "relevant" in the definition. For example, they are exempt from needing five years of prior experience in a specific type of deposit in cases with extensive experience in similar deposits. For the case at hand, copper, the JORC Code (2012) indicates that having five years of experience to estimate the Mineral Resources of a porphyry copper deposit is unnecessary if one has twenty years of experience in various ways metalliferous rock deposits. Something similar happens with international codes such as the PERC Reporting Standard (2017), the SAMVAL Code

(2016), the NAEN Code (2011), the CIMVAL Code (2019) and the VALMIN Code (2015), to mention some of the most representatives worldwide.

The final responsibility for the public information contained in the technical reports lies with the competent person, also called a qualified professional, with the experience and skills that are merited. Although the competent person relies on the information provided by the company itself, consultants, suppliers and other specialists, he must take reasonable measures to assess the risk, confirming the veracity and validity of this information (visits, participation in specific studies, etc.).

If the competent or qualified person signs a report for public disclosure stating that the maximum error could reach 25% (assuming the maximum recommended for pre-feasibility studies is used), and the project ends up with a 37% cost overrun (using the data reported above as an example), it would be logical for investors to disagree with the study and, in some cases, especially where there are gaps and significant impacts, they could hold the "qualified professional" accountable.

There are several recommendations to mitigate this critical issue (Dussud et al., 2019), such as standardising cost estimation criteria such as those of the AACE, promoting improvements in mining project processes that add value, stress testing feasibility studies based on cost benchmarks, being very careful with the use of contingency, detailing the basis for all relevant assumptions, reinforcing the procurement strategy from the outset and making a robust and rigorous construction and operation plan, detailing each development, avoiding delays.

One thing that has been pointed out throughout the previous literature is the consistency used for the different cost estimates. CRIRSCO even recommends the AACE Recommended Practice No. 47R-11 (AACE International, 2020b) to qualified professionals.

To detect the economic risks of copper mining projects presented to the public, the research pays parcticular attention to the existing methodologies for the valuation of mining assets, as well as for the preparation of technical reports with internationally recognised codes that aim to offer the expert in charge of the valuation a series of guidelines to carry out this work.

For this purpose, an in-depth study and analysis of four National Instrument 43-101 (2011) technical reports of current copper mining projects is carried out: Arctic Project (Northwest Alaska, United States), Kutcho Project (British Columbia, Canada), Josemaría Copper-Gold Project (San Juan, Argentina) and Eva Copper Project (Queensland, Australia).

The sample is based on the diversification criterion: geographical, by selecting some of the main copper mining regions; business, when selecting different mining companies; due to the type of exploitation, open sky, underground and mixed; and by size in terms of reserves and production capacity. However, all of them are current projects of junior mining companies, characterised by being in an early exploration phase (pre-feasibility or feasibility). Their common purpose is to locate new mineral deposits that are worth exploiting.

2. MATERIALS

2.1. Arctic Project

Trilogy Metals Inc., founded in 2004 and based in Vancouver (Canada), is a mining company producing copper, zinc, gold, silver and cobalt, listed on the New York Stock Exchange (NYSE: TMQ) and the Toronto Stock Exchange (TSX: TMQ), and is advancing exploration and development at the Upper Kobuk Mineral Projects in Alaska's Ambler Mining District, home to some of the world's richest known copper-dominant polymetallic deposits (Trilogy Metals Inc, 2024).

A NI 43-101 report for the Arctic project was delivered by Staples et al. (2018). The Arctic deposit is located in the Ambler Mining District in Arctic County, northwest Alaska.

All zones are part of an area of approximately 1 km^2, with mineralisation to a depth of 250 m below the surface. Mineralisation is predominantly coarse-grained sulphide composed mainly of chalcopyrite, sphalerite, galena, tetrahedrite-teenantite, pyrrhotite-arsenopyrite and pyrrhotite.

The Arctic project uses conventional open-cast mining methods. The mine is expected to operate 24 hours a day, 365 days a year. The maximum mining capacity is 32 Mt/a, and the processing capacity is 10 kt/d.

The processing plant is conventional for industrial use and will produce three concentrates: copper concentrate, zinc concentrate and lead concentrate. In addition, it is estimated that the gold and silver recovered from the copper and lead concentrates will be paid for at the smelter.

Mineral Reserves are calculated following the CIM Definition Standards (2014), according to the National Instrument 43-101 (2011). Only those Mineral Resources classified as Indicated are attributed to economic results for mine design. Mineral Reserves for the Arctic deposit have been estimated based on a mineral resource block model conducted on 25 April 2017, as well as information provided by Trilogy and information generated by independent consultant Amec Foster Wheeler based on a preliminary economic assessment. For a 0.50% Cu cut-off grade, ore reserves totalling 43,038 kt are estimated with average grades of 2,32 % Cu, 3,24% Zn, 0,57% Pb, 0,49 g Au/t and 36,00 g Ag/t.

The Arctic project will produce 246,723 t/y of copper concentrate (30.3%, 169 g Ag/t), 29,493 t/y of lead concentrate (55.0%, 2383 g Ag/t, and 34 g Au/t) and 180,219 t/y of zinc concentrate (59.2%), which are estimated to be sold on the market.

The capital cost of the Arctic project has been estimated based on Ausenco's standard pre-feasibility studies with an accuracy of between -20 % and +30%. Most of the estimate is based on a turnkey project, which includes the cost of traditional engineering or project design, related procurement and construction management until the commissioning of the production facilities. Estimates are based on constant exchange rates, 1 USD = 1.25 CAD, and prices provided by individual suppliers based on current market conditions and expectations.

Two types of costs are defined: initial and sustaining costs. The initial capital cost, detailed in Table 1, includes all fees incurred during the pre-production phase: direct expenses related to equipment, materials, necessary infrastructure and labour associated with construction and indirect costs incurred in the commissioning of the facilities, such as design, acquisition, and construction.

Table 1. Initial CAPEX of the Arctic project (Staples et al., 2018)

Type	Item	Cost (M USD)
Direct	Mining	281.1
	Grinding	18.3
	Processing	113.8
	Residues	30.3
	Infrastructures	101.1
	Subtotal Direct	**543.8**
Indirect	Various	121.9
	Contingency	92.0
	Owners' costs	21.9
	Subtotal Indirect	**235.8**
Total initial CAPEX		**779.6**

Direct mining costs are broken down into operating costs for the 2-year pre-production period (158.6 M USD) and investment in equipment (115.7 M USD).

Sustaining costs amounts to 65,9 M USD and are those linked to the replacement of equipment according to the valuable life set by the manufacturers, the incorporation of a new fleet, the recurrent construction of new treatment plants and waste management.

In addition, the cost of closure and decommissioning is estimated at 65.3 M USD.

2.2. Kutcho Project

Kutcho Copper Corp., established in 1986 in Vancouver (Canadá), is a Canadian resource development company focused on expanding and developing the Kutcho high grade copper-zinc project in northern British Columbia (Canada), is listed on the TSX Venture Exchange (TSXV: KC), where approximately half of the companies are mining companies and on the OTCQX (OTCQX: KCCFF), where securities are traded among a network of brokers with specific characteristics and requirements (Kutcho Copper Corp., 2024).

A National Instrument 43-101 Technical Report was prepared for the Kutcho Project by Makarenko et al. (2017).

The property is approximately 100 km east of Dease Lake, in the north of British Columbia, Canada. It is at an elevation of roughly 1,500 m. The property can be accessed by air, with a gravel track 10 km away, or by a 100 km seasonal road from Dease Lake, which is only suitable for all-terrain vehicles during the summer months.

The project consists of 3 mineralised zones ("Main", "Esso", and "Sumac"). However, only the "Main" and "Esso" deposits are contemplated for production and economic planning, as the resources of the "Sumac" deposit are categorised as inferred. The mineable metals in the deposits are copper, zinc, silver and gold, in order of economic value.

Mining would be predominantly underground, with independent access to each deposit. The "Main" deposit extends from the surface to about 250 m depth, and the "Esso" deposit is about 420 m below the surface and extends vertically for about 200 m.

The underground mine is expected to produce at an average annual rate of about 2,500 t/d, operating every day of the year over the estimated mine life of 12 years, with a cut-off grade of 1.50% Cu in the "Main" deposit and 1.00% Cu in the "Esso" deposit. Ore reserves totalling 10.44 Mt are estimated for the total LOM, with average grades of 2,01% Cu, 3,19% Zn, 0,37 g Au/t and 34,60 g Ag/t, according to National Instrument 43-101 (2011). The cut-off grade of the "Esso" deposit is lower than that of the "Main" deposit to account for the significantly higher zinc, silver and gold grades of "Esso".

The CAPEX of the Kutcho project includes all costs necessary to develop, maintain, and complete operations over the expected LOM. The cost has been estimated based on (AACE International, 2020b) with an accuracy of +/-25% and applying a 15% contingency. They have been obtained from engineers, contractors and suppliers who have satisfactorily provided services on similar operations. All costs up to detailed engineering are considered sunk costs, including the asset's purchase price.

As usual, two types of costs are distinguished: initial capital costs, also known as pre-production costs, detailed in Table 2, and sustaining costs, which amounts to 45,4 M USD.

Table 2. Initial CAPEX of the Kutcho project (Makarenko et al., 2017)

Type	Item	Cost (M USD)
Direct	Mining	30.8
	Processing	47.1
	Residues/Water	7.7
	In-house infrastructures	14.4
	External facilities	11.8
	Subtotal Direct	**111.7**
Indirect	Various	25.7
	Contingency	21.7
	Owners' costs	6.9
	Subtotal Indirect	**54,2**
Total initial CAPEX		**165.9**

Concerning closure and decommissioning, a cost of 5.1 M USD is assumed.

2.3. Josemaría Copper-Gold Project

Josemaría Resources Inc, established in Vancouver (Canadá) in 1983, is part of the Lundin Group, founded more than 40 years ago, comprising a portfolio of companies in the minerals, metals, renewables and energy sector. Each project is managed independently and listed separately. Josemaría Resources Inc. is listed on the Toronto Stock Exchange (TSX: JOSE), the American OCTQX (OTCQX: JOSMF) and the Stockholm Stock Exchange (NASDAQ STOCKHOLM: JOSE) (Lundin Mining Corp., 2024).

The Josemaria Copper-Gold Project is a copper-gold mining project in the feasibility study stage in San Juan Province, Argentina. McCarthy et al. (2020) developed a NI 43-101 Technical Report for this project.

The deposit is about 4,000-4,900 metres above sea level, with a vertical depth from the surface between 600 m and 700 m. It is located 145 km southeast of Copiapó (Chile) and about 9 km east of the international border between Chile and Argentina, on the Argentinean side of the Andes Mountains.

Due to its geological characteristics and location, the Josemaría deposit is classified as a copper-gold porphyry system. These porphyries can be found and are documented throughout the Andes Mountains. They represent a reasonably widespread deposit type in Chile and Argentina.

As this is a sizeable near-surface deposit, the Josemaría project will be developed as an open-cast mine.

Results obtained from a mine planning study completed before the 2018 pre-feasibility study established 150,000 t/d of tonalite at the 75% hardness percentile as the optimum processing rate. This rate is the basis for all subsequent mine planning, although softer ores can be processed at up to 160,000 t/d.

In terms of ore processing, only one method is considered: crushing-flotation, reaching a concentration grade of 25-27% Cu.

According to National Instrument 43-101 (2011), for a cut-off grade of 0.30% Cu and 0.22 g/t Au, just over 1 billion tonnes of ore are determined over the 19-year LOM of the project, with average grades of 0,30% Cu, 0,22 g Au/t and 0,94 g Ag/t.

The level of definition of the design, methodology and sources of information used to estimate the capital cost of the Josemaría project is based on the standards of the AACE International (2020b), Class 3, whose degree of precision in the global cost is ±15%.

The capital cost estimate is structured according to the work plan and its processes, grouped by significant items. Table 3 provides a breakdown of the initial capital cost.

Table 3. Initial CAPEX of the Josemaría Copper-Gold project (McCarthy et al., 2020)

Type	Item	Cost (M USD)
Direct	Mining	524
	Processing	666
	Residues	163
	In-house infrastructures	184
	External facilities	192
	Subtotal Direct	**1,729**
Indirect	Various	883
	Contingency	348
	Owners' costs	132
	Subtotal Indirect	**1,362**
Total initial CAPEX		**3,091**

The sustaining capital cost, which totals 940 M USD over the life of the mine, has been estimated because these are costs associated with sustaining and possible routine repairs for the whole production operation.

It considers replacing equipment, track improvements, fresh water wells, construction and extension of tailings dams, installation of new pipelines and necessary modifications to waste treatment facilities.

There are no costs associated with improvements undertaken to increase production capacity other than those already considered initial capital costs. Any improvement projects would be assessed based on their economic profitability in the future.

Finally, the cost of closure and decommissioning is estimated at some 277 M USD.

2.4. Eva Copper Project

Eva Copper is a project developed by Harmony Gold Mining Company, is a global, sustainable gold mining and exploration company with a copper footprint in the Wafi-Golpu and Eva Copper projects. It is a publicly listed company, with its primary listing on the Johannesburg Stock Exchange limited (JSE: HAR) and an American depositary receipt programme listed on the New York Stock Exchange (NYSE: HMY) (Harmony Gold Mining Company Ltd., 2024).

The project is an open-pit gold and copper mining operation whose feasibility study was conducted following National Instrument 43-101 (2011) by Staples et al. (2020).

This project asset, formally known as Altona, occupies an explorable area of mineralised ground of approximately 4,000 km^2. It is located in the northwest region of Queensland, Australia. The Eva Copper project is estimated to extract approximately 170 Mt of ore and 381 Mt of waste from 7 open-pit deposits, with an expected minimum mine life of 15 years.

The project area comprises volcanic rocks and metamorphic and poly-deformed marine sediments.

There are 12 deposits defined in the project, ranging in size from 0.7 Mt to over 100 Mt. Of the 12 deposits, seven are included in the current mine plan: four are copper-gold deposits ("Little Eva", "Lady Clayre", "Ivy Ann" and "Bedford", which is further divided into north and south), and three are copper-only deposits ("Turkey Creek", "Blackard" and "Scan-lan").

The Eva Copper project will employ conventional open-cast mining methods, including drilling, blasting, loading and hauling. A construction period of two years is envisaged, including one year of pre-production mining. Mining activities would be based on open pit mining of the Little Eva deposit at a rate of 31,200 t/d of ore. The Little Eva central pit will be complemented by the progressive mining of six satellite pits at Blackard, Scanlan, Turkey Creek, Bedford, Lady Clayre and Ivy Ann to achieve a minimum mill feed rate of 11.4 Mt/year.

Cut-off grades exceed 0.30% in all cases, and average grades correspond to 0,46% Cu and 0,05 g Au/t, the ore reserves suppose 171,05 Mt. Approximately 95% of the ore reserves are found in the Little Eva, Blackard, Scanlan and Turkey Creek deposits.

The capital cost estimate for the Eva Copper project has been prepared by Merit Consultants International, Inc., a Canadian mining consulting firm, with support from Copper Mountain Mining Corporation and several independent engineers and consultants. It is based on quotes solicited from equipment suppliers, vendor pricing, input from construction contractors and experience at similar-sized operations. The estimate has a degree of accuracy of ±15%, in line with AACE International (2020b) Class 3 for feasibility studies (Table 4).

Table 4. Initial CAPEX of the Eva Copper project (Staples et al., 2020)

Type	Item	Cost (M USD)
Direct	Mining	35.2
	Processing	150.8
	Infrastructures	67.6
	Ancillaries	25.6
	Subtotal Direct	**279.3**
Indirect	Various	57.0
	Contingency	41.5
	Owners' costs	15.3
	Subtotal Indirect	**113.8**
Total initial CAPEX		**393.1**

The sustaining CAPEX of the Eva Copper project is 95.4 M USD. Finally, the cost of closure and decommissioning is estimated at some 14.1 MUSD.

3. METHODS

The AACE International Recommended Practice No. 47R-11 (AACE International, 2020b) is an internationally recognised and accepted best practice guide for classifying cost estimating by phases and stages based on project definition and scope. It complements the generic cost estimating classification AACE International Recommended Practice No. 17R-97 (AACE International, 2020a) by providing a section that defines in more detail the classification concepts that apply in the mining industry and those of a geopolitical and regulatory nature that may affect cost estimating.

The RP no. 47R-11 establishes the cost classification for mining from class 5 to 1 according to the level of maturity, with class 5 being the lowest maturity (or conceptual phase) and class 1 being the highest maturity (implementation or review phase of an ongoing project). Table 12 shows the characteristics of the five estimation classes.

Table 5. Cost estimate classification matrix for the mining and mineral processing industries (AACE International, 2020b)

Estimate Class	**Primary Characteristic**	**Secondary Characteristic**		
	Maturity level of project definition deliverables	**End usage**	**Methodology**	**Expected accuracy range (80% confidence interval)**
Class 5	0% to 2%	Conceptual planning	Capacity factored, parametric models, judgment, or analogy	Low range: -20% to -50%; High range: +30% to +100%
Class 4	1% to 15%	Screening options	Equipment factored or parametric models	Low range: -15% to -30%; High range: +20% to +50%
Class 3	10% to 40%	Funding authorisation	Semi-detailed unit costs with assembly-level line items	Low range: -10% to -20%; High range: +10% to +30%
Class 2	30% to 75%	Project control	Detailed unit cost with forced detailed take-off	Low range: -5% to -15%; High range: +5% to +20%
Class 1	65% to 100%	Fixed price bid check estimate	Detailed unit cost with detailed take-off	Low range: -3% to -10%; High range: +3% to +15%

Recalling the National Instrument 43-101 (2011) terminology concerning economic studies is pertinent. They are often used de facto as categories of capital cost estimation rather than more specific classifications such as the ones in RP No. 47R-11.

National Instrument 43-101 (2011) clearly defines the typology of feasibility and pre-feasibility studies. A feasibility study is a comprehensive study of mineral deposits in which all relevant geological, engineering, legal, operational, economic, social, environmental and other factors are considered in sufficient detail to enable an investor to finance the project for mineral production. Pre-feasibility studies are those comprehensive studies of the feasibility of a mining project that has progressed to a stage where the method of extraction, in the case of underground mining, or pit configuration, in the case of open pit mining, as well as an effective method of ore processing, including a financial analysis based on reasonable assumptions of relevant technical, engineering, legal, operational, economic, social, environmental and other factors, have been established.

On the other hand, although National Instrument 43-101 (2011) does not strictly define another type of study, it does refer to studies carried out before pre-feasibility and feasibility studies without involving the status of mineral reserves. It calls them preliminary economic assessments, including a financial analysis of the potential viability of mineral resources.

The RP No. 47R-11 recommends that the mining industry better manage investment risk by equating capital cost estimates for a feasibility study to AACE Class 3 and pre-feasibility studies to AACE Class 4. The preliminary economic assessments could be understood to be comparable to AACE Class 5, although only sometimes, as they depend on other circumstances.

The methodology for estimating Class 5 costs, generally recommended for preliminary economic assessments, would be mainly based on capacity factors or orders of magnitude. This method calculates the project's capital cost from the cost of other projects of similar scope and size. For Class 4, appropriate for pre-feasibility studies, an equipment factor methodology would be used, whereby prices are estimated as a percentage of the capital cost of significant project equipment. Classes 4 and 5 are more conceptual than the others, although Class 3, recommended for feasibility studies, has a relevant detail component, the so-called semi-detailed. Semi-detailed estimates are those where capacity factor and equipment factor techniques are used to estimate the direct field costs of parts of the project, and the rest of the direct field costs are calculated in detail. Often, historical data and various factors are used to determine the quantities.

Finally, for Classes 1 and 2, a detailed estimate would already be made in which each component or set of components has been quantitatively inspected and valued using prices and budgets that are as realistic as possible.

4. RESULTS & DISCUSSION

4.1. Capital expense estimation

The capital expense estimation for the copper mining projects studied is analysed below. Table 6 shows the information for each of the projects concerning these practices.

Table 6. Data on the approach and cost estimation of the projects

Project	Type of Study	Does it follow the RP 47R-11?	Class	Declared accuracy range
Arctic Project	Pre-feasibility	NO	-	-20% to +30%
Kutcho Project	Pre-feasibility	YES	4	±25%

Josemaría Project	Feasibility	YES	3	±15%
Eva Project	Feasibility	YES	3	±15%

Thus, RP No. 47R-11 is generally used by the Competent Person when conducting mining project studies. Both the pre-feasibility study of the Kutcho Project and the feasibility studies of the Josemaría Copper-Gold Project and the Eva Copper Project are based on the standards of the guide above, which translates into greater comfort for the potential investor by being able to analyse the cost of capital of projects/investments within a standard, homogeneous and internationally recognised context.

More representative is the report of the Arctic Project, which, despite being a pre-feasibility study, is not aligned with the RP 47R-11. They report that the capital cost estimate follows the standards of Ausenco, a multinational company dedicated to conducting consultancy and project studies in the mining and metals, oil and gas and industrial sectors. However, its standards are private, so it cannot be determined that they are aligned with the AACE. Consequently, the economic risk is increased by not being able to compare this project in the same way as it could be reached using standard practices. They report the estimated accuracy range for the costs between -20 % and +30% to fit within the AACE Class 4, considering this is a pre-feasibility study.

Therefore, to mitigate the project's economic risk for potential investors, it should be recommended in the first place to use cost classification systems of recognised international prestige, such as RP No. 47R-11. CRIRSCO also recommends this practice.

Especially in junior mining companies, it is relevant to follow recommended practices applying the most prudent criteria in the estimation as well as superior safety buffers, while increasing contingency levels. These are aspects that are not fully applied in the reports to reduce economic risks, especially in a sector historically burdened by cost overruns.

The information in the reports is generally correct according to international codes and recommended practices, although in a risky sector, especially in junior mining companies, estimates should conform to the strictest criteria to minimize risk.

However, conformity to the strictest criteria should be accompanied by an adequate risk assessment, as many variables are used within the reports that must be estimated from available data. Risk assessment identifies and evaluates risks that may result in loss of investment or business operations, but it also includes the development of a plan or strategy for the mitigation of these risks. Its purpose is to implement reasonable control measures to remove or reduce risks, depending on the nature and scope of the mining project.

Risk assessment provides ming companies and investors with an adequate understanding of risks that could affect to achieve the pursued financial and operational objectives, as well as the convenience of the controls that were considered. Thus, risk assessment gives a basis for taking decisions on the best approach to treat risks. Its output representing an input for the decision-making process.

Risk assessment overall process consists on identifying, analysing and evaluating the risks, existing many methods and technics to carry it out: evidence based methods, systematic team approaches, inductive reasoning techniques, etc.

Addressing specifically financial risks, sensitivity analysis and uncertainty analysis should be develop to model, in the first place, the variables to which the solution (NPV, IRR or PP) is more sensitive, indicating exactly how much the financial ourtcomes will be modified according to variations of these variables, other things held constant. In the second place, a Monte Carlo simulation should be used to conduct an uncertainty analysis on previously detected key variables.

4.2. Contingency estimation

Within the estimation of capital costs, another aspect of parcticular relevance is the contingency used for their determination. The contingency is a cushion against cost overruns that may occur for various reasons, such as erroneous estimates or delays in the execution deadlines.

While it is true that the AACE classification system for cost estimation already takes into account a specific range of accuracy, it is noted that capital cost overruns in mining projects are historically recurrent, exceeding on average 40% of the initial estimate, a level that exceeds the maximum range of accuracy of the AACE system for Class 3, used for pre-feasibility studies and, in most cases, that of Class 4, used for feasibility studies.

Table 7 details the relative (and absolute) contingency levels reported in the technical reports of the four studied copper mining projects, separating the contingency applied on the initial and sustaining capital costs.

Table 7. Capital cost contingency estimations

Project	Over Initial Capital Cost	Over sustaining capital cost	Over total capital cost
Arctic Project (open-cast)	13.4% (92.0 M USD)	0% (0 M USD)	11.2% (92.0 M USD)
Kutcho Project (underground)	15.0% (21.7 M USD)	15.0% (5.9 M USD)	14.6% (27.6 M USD)
Josemaría Project (open-cast)	12.7% (348.0 M USD)	0% (0 M USD)	8.8% (348.0 M USD)
Eva Project (multi-open-cast)	11.8% (41.5 M USD)	0% (0 M USD)	9.5% (41.5 M USD)

It is expected to use higher contingencies in preliminary phases, such as pre-feasibility studies, than in later stages, such as feasibility studies, mainly because one would expect to find a more significant difference between the estimates and the final reality in the initial studies.

This logic can be confirmed by the information in Table 7, which shows that pre-feasibility studies have a higher contingency than feasibility studies.

Focusing on the pre-feasibility studies, it can be concluded that the Kutcho Project is the most conservative of those studied and, therefore, the one with the lowest economic risk for the potential investor from the point of view of the estimation of the cost of capital due to the use of a higher contingency than the Arctic Project, as well as being aligned with the practices recommended by the AACE, unlike the Arctic Project, which follows those of AUSENCO. Furthermore, it also assigns a contingency to the sustaining capital cost.

As for the feasibility studies, it is surprising that no contingency is considered for the sustaining capital cost. From an economic risk point of view, the Eva Copper Project is arguably more conservative than the Josemaría Copper-Gold Project because it considers a more significant contingency concerning its total capital cost and because it is a smaller project, a characteristic that, according to historical information, translates into lower cost overruns.

4.3. Initial, maintenance and closure/decommissioning capital costs

Table 8 compares the total capital cost with initial, sustaining and closure/decommissioning capital costs.

Table 8. Comparisons over total capital cost

Project	Initial capital cost	Sustaining capital cost	Closure and decommissioning capital cost
Arctic Project (open-cast)**Arctic**	85.6%	7.2%	7.17%
Kutcho Project (underground)	76.7%	21.0%	2.36%
Josemaría Project (open-cast)	71.53%	22.1%	6.41%
Eva Project (multi-open-cast)	82.3%	19.0%	2.81%

In general, and despite the characteristics of each project (geographical, type of exploitation, regulation, policies, etc.), the weights of each capital cost on the total are really similar for the four studied projects.

The high weight of the Arctic project's initial capital cost can be explained by including the operating and sustaining costs of the 3-year pre-production stage, thus simultaneously explaining the lower figure presented in the sustaining capital cost.

The low weight of the closure and decommissioning cost of the Kutcho project is because it is an underground exploitation. In the case of the Eva Copper project, it can be explained that instead of a huge open pit mine, the central open pit will be surrounded by satellite open pits, making the decommissioning process less expensive than in the case of having only one big open pit.

Regarding the initial capital cost of the projects, it is precisely in this phase (start-up) that the highest cost is accumulated in infrastructure, equipment, access, and engineering.

The sustaining capital costs are considerably less because they correspond to minor works and equipment replacement once it has reached its useful life.

Finally, addressing the cost of closure and decommissioning of the various projects, the weights are usually low.

4.4. Capital cost in open-pit mining and underground mining

The capital cost over the extracted volume is notably higher in underground mining projects such as the Kutcho Project than in the rest of the analysed projects, all of which are open-cast mining. Riesgo García et al. (2017) calculated that in the case of underground mining projects, the CAPEX could be sensibly bigger than the value that should be obtained for an open-cut project. Underground mining projects are capital-intensive, requiring greater drilling and more complex machinery. The data relating Kutcho project presented in Table 9 justify this conclusion.

Table 9. Capital cost indicators

Project	Total CAPEX (M USD)	Over gross income (%)	Over extracted volume (USD/t)	Over processed volume (USD/t)	Mining method
Arctic Project (open-cast)**Arctic**	910.8	9.13%	2.68	21.16	
Kutcho Project (underground)	216.4	12.68%	16.41	20.72	
Josemaría Project (open-cast)	4,321.0*	17.91%	2.16	4.27	
Eva Project (multi-open-cast)	491.4**	10.66%	0.90	2.88	

* Total CAPEX of Josemaría Copper-Gold Project includes an extraordinary working capital item of 13 M USD.

* * Eva Copper Project foresees a CAPEX reduction of 11.2 M USD due to pre-production incomes.

Furthermore, this higher capital cost in underground mining is also extendable regarding the volume processed, although the volume of waste obtained in the extraction process plays a relevant role.

In the Arctic Project, the reduced exploitation ratio due to the high amount of gangue extracted causes a significant increase in the capital cost of the volume processed.

The data in the table also demonstrate that the weight of capital cost over gross income has similar levels in all projects, around 10%, except in the case of the Josemaría Copper-Gold Project. This outlier is explained by extraordinary costs in this project linked to the complicated access to the deposit.

4.5. Progress on the technical studies of the analysed projects

Since the start of the research, two of the studied projects have advanced their technical studies until the end of 2022.

The Arctic Project has advanced its development from the pre-feasibility phase, documented in the 2018 technical report, towards a feasibility study with the publication of a new report in October 2020. There are no relevant differences in terms of the volume extracted and processed. The increase is practically residual (less than 1%).

However, it represents the estimated net present value (NPV) after tax, which is reduced by around 20%, even more, if the estimated metal prices did not change concerning the previous study.

Table 10 shows the comparison of CAPEX between the pre-feasibility study and the feasibility study, the latter following, this time, the AACE Class 3 standards.

Table 10. Comparison pre-feasibility vs feasibility CAPEX of Arctic Project

Item	Study	Cost (M USD)
CAPEX Initial	Pre-feasibility	779.6
	Feasibility	905.6
CAPEX Sustaining	Pre-feasibility	65.9
	Feasibility	113.8
CAPEX closure and decommissioning	Pre-feasibility	65.3
	Feasibility	205.4
CAPEX Total	Pre-feasibility	910.8
	Feasibility	1224.7

The total cost of capital has increased significantly in all items, especially sustaining and closure/decommissioning. It is common for prices to rise as technical studies approach the implementation phase. This increase, therefore, explains to a large extent the significant reduction in the NPV of the project.

In the pre-feasibility study, a contingency of 13.4% was envisaged for the initial capital cost, a level that has been reduced to 11.65% in the feasibility study. However, no contingency was envisaged for sustaining capital, closure, or decommissioning costs.

Table 11 shows the effect of the increase in the cost of capital on gross revenues and operating volumes, both at the volume extracted and processed levels.

Table 11. Comparison indicators pre-feasibility vs feasibility CAPEX of Kutcho Project

Indicator	Pre-feasibility (2018)	Feasibility (2020)	Variation
Total CAPEX / Gross Revenues (%)	9.13%	12.56%	+3.43 %
Total CAPEX / t extracted (USD/t)	2.68	3.58	+33.58%
Total CAPEX / t processed (USD/t)	21.16	28.19	+33.23%

On the other hand, the Kutcho project has also evolved from a pre-feasibility study, detailed in the 2017 technical report, to a feasibility study, the report of which was published in December 2021. With this new publication, the progress has been notable in giving more weight to open-pit mining, which now accounts for 96.4% of the volume mined compared to 24.2% in the pre-feasibility study and 83.8% of the volume processed compared to 3.8% previously. As a result, the total volume mined increases exponentially to 99.8 Mt, an increase of 6.56 times, and the volume processed grows to 17.3 Mt, an increase of 66.3%.

Regarding NPV after tax, the increase is 84%, supported by a higher volume processed and an increase in the estimated selling price of copper of approximately 27%, considering market developments.

Table 12 shows the CAPEX comparison between the pre-feasibility study and the feasibility study, the latter now following AACE Class 3 standards.

Table 12. Comparison indicators pre-feasibility vs feasibility CAPEX of Arctic Project

Item	Study	Cost (M USD)
CAPEX Initial	Pre-feasibility	165.9
	Feasibility	366.9
CAPEX Sustaining	Pre-feasibility	45.4
	Feasibility	68.0
CAPES closure and decommissioning	Pre-feasibility	5.1
	Feasibility	26.2
CAPEX Total	Pre-feasibility	216.4
	Feasibility	447.6

The pre-feasibility study envisaged a 15% contingency for initial and sustaining CAPEX, a level that has been reduced in the feasibility study to 10.7% and 10.1%, respectively. No contingency was or is contemplated for closure and decommissioning costs.

In the same way, as for the Arctic project, Table 13 shows the higher weight of the cost of capital on gross revenue and operating volumes of the feasibility compared to the pre-feasibility study.

Table 13. Comparison indicators pre-feasibility vs feasibility CAPEX of Kutcho Project

Indicator	Pre-feasibility (2017)	Feasibility (2021)	Variation
Total CAPEX / Gross Revenues (%)	12.68	16.69	+4.01 %
Total CAPEX / t extracted (USD/t)	16.41	4.48	-72.70%
Total CAPEX / t processed (USD/t)	20.72	25.86	+24.81%

The opposite behaviour of the capital cost on the volume extracted is striking. The explanation for this variation contrary to what was demonstrated before is the evolution of the project towards open-pit mining as opposed to underground mining that was contemplated in the pre-feasibility study, which causes an exponential growth in the extracted volume. However, the data is normalized at the level of capital cost over processed volume as the growth ratio of extracted volume over processed volume is practically 4 times.

The results reflected from the progress of the technical studies, which advance from a pre-feasibility to a feasibility phase, demonstrate the notable increase in the capital cost, in terms of revenues, and above all on processed volumes.

Regarding revenues, the growth is not too significant, 3%-4%, although the increasing trend in the price of mineral in the markets must be considered. But regarding processed volumes, the growth is high, with an extra cost of 25%-33%, levels that, even without reaching an execution phase, demonstrate how the overruns emerge as the study phase progresses, consistent with what is stated in the reviewed literature.

5. CONCLUSIONS

Mining projects are characterised by assuming high levels of risk, among which those linked to (i) the long duration of the construction and exploitation period, (ii) the complexity of the geological study and metallurgical testing, (iii) external factors such as environmental and social regulations, and (iv) high construction costs.

The most relevant problem in the mining sector is linked to significant capital and production cost overruns in projects, as estimations are usually made with the most advantageous levels of precision for the company according to recommended practices and without a sound risk assessment of these factors.

It is a major weakness for the industry, translating into high risk for investors and creditors. It has historically generated mistrust due to recurrent and notorious profitability losses, reflecting the undervaluation of costs.

In parcticular, capital cost overruns in mining have become an endemic and significant problem, with average deviations of about 37% over the last decades. In relative terms, more considerable projects have more extensive cost overruns, and projects with more external financing tend to have fewer variances due to greater control and professionalism.

It should not be forgotten that, in general, investors in this type of project assume a noteworthy risk by advancing significant capital to develop a project that starts from scratch and with an expected long-term return based on estimates and data that, in most cases, are unreliable. All of this is based on an intangible base, the technical reports. As we have seen, the initial capital is the most representative, representing practically 80% of the total cost of capital in the projects analysed.

Therefore, transparency in the calculation methodology and the information used to make the estimates should be maximised and adapted to internationally recognised industry standards.

This research aims to demonstrate this reality with objective data and underline the importance of using methods that allow the confidence of those involved in the financing of mining projects to be regained, as without them, the sector's future looks more than complicated.

As seen and as recommended by CRIRSCO, one way for mining companies to provide greater confidence and transparency to the market is for competent persons to use the AACE Recommended Practice No. 47R-11 for general principles of cost estimation. RP No. 47R-11 is an internationally recognised and accepted best practice guide that applies general principles for estimating mining project costs based on the maturity level of the project. Especially for junior mining companies, it is advisable to apply the most prudent criteria of the recommended practice in the estimations.

It is also relevant for investor security that studies include contingencies or "capital buffers" to absorb unexpected cost overruns. There are many external factors of great impact, such as environmental and social, difficult to predict, that must be able to be absorbed. In line with AACE standards, a correct contingency estimation would allow most projects to absorb cost overruns without impacting profitability.

Three of the four projects analysed follow PR 47R-11 of the AACE, although with a diverse range of precision in their estimates and, all of them, with a potential improvement in this aspect to reduce the economic risk.

However, conformity to the strictest criteria is not enough. Most projects lack an adequate risk assessment, and thus, no reasonable control measures are implemented to remove or reduce risks according to the nature and scope of the mining project. This may be the twofold explanation for why CAPEX overruns are worse in the mining sector than in other sectors that must also estimate CAPEX on complex projects, something that leads again to the responsibility of the qualified professionals or competent persons who must take reasonable measures to assess the risk, confirming the veracity and validity of the information they use.

In pre-feasibility studies (AACE Class 4), such as the Arctic and Kutcho projects, they declare an accuracy range of -20%/+30% and -25%/+25%, respectively, which exceeds the lower limit of the expected high accuracy range (+20%/+50%). The feasibility studies (AACE Class 3) of the Josemaría Copper-Gold and Eva Copper projects declare an accuracy range of -15%/+15% in both cases, which also exceeds the lower limit of the expected high accuracy range (+10%/+30%). Would it only be desirable, especially in preliminary studies, if these limits were reached?

Moreover, the contingency considered in all the projects studied is at most 15%, and the feasibility studies show levels below 10%, which makes such an underestimation incongruous given the expected accuracy ranges.

Cost overruns and delays, both correlated, are critical factors in the mining industry and have relevant implications regarding the success or failure of projects. Therefore, it is advisable not to forget to focus on the capacity to comply with the mining plan and that the exploitation and processing method is the one that best adapts to the deposit, since otherwise significant extra costs will almost certainly be incurred.

Finally, as the technical studies approach the implementation phase, the "reality", the estimated capital costs increase and, consequently, the expected profitability decreases, something that can be considered acceptable, as it is reasonable that investments are relatively contained in the early stages of a technical study. What is striking, however, is the significant increase in costs between the two study phases (pre-feasibility and feasibility), with variations as substantial as those of the Arctic Project and inconsistent with those of the Kutcho Project.

It would therefore be advisable that mining companies and, especially, competent persons responsible for preparing technical reports, starting from the historical distrust of mining projects due to the high-cost overruns incurred, apply the practices recommended by the AACE and prescribed by CRIRSCO, being extremely conservative with the ranges of precision and contingencies that are contemplated in each phase. It should be a significant turning point for the sector, which, to prosper, must leverage transmitting trust, transparency, cleanliness and professionalism to the market.

In addition to suggesting using AACE PR 43-101 recommended practice, applying the most restrictive criteria, considering a higher level of contingency according to the risk assessment, and making sure to work with a responsible and prudent competent person, it is also necessary to focus on:

(i) Compliance with the mining plan, with the consequent operational performance. Although it is more linked to operating costs, the delay of the plan and certain circumstances linked to lower performance cause considerable CAPEX increases.

(ii) Adaptation of the exploitation and processing method to the geographical and geological characteristics of the deposit. Many times, an incorrect study of the deposit causes additional engineering costs and new infrastructure, especially in this type of long-term project.

Credit authorship contribution statement

Luis Suárez Nieto: Conceptualization, Data curation, Writing – original draft, Writing – review & editing. Gregorio Fidalgo Valverde & Francisco Javier Iglesias Rodríguez: Conceptualization, Data curation, Writing – initial draft, Writing – review & editing. Alicja Krzemień & Pedro Riesgo Fernández: Conceptualization, Data curation, Writing – original draft, Writing – review & editing.

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Table Caption:

Table 1. Initial CAPEX of the Arctic project (Staples et al., 2018)

Table 2. Initial CAPEX of the Kutcho project (Makarenko et al., 2017)

Table 3. Initial CAPEX of the Josemaría Copper-Gold project (McCarthy et al., 2020)

Table 4. Initial CAPEX of the Eva Copper project (Staples et al., 2020)

Table 5. Cost estimate classification matrix for the mining and mineral processing industries (AACE International, 2020b)

Table 6. Data on the approach and cost estimation of the projects

Table 7. Capital cost contingency estimations

Table 8. Comparisons over total capital cost

Table 9. Capital cost indicators

Table 10 Comparison pre-feasibility vs feasibility CAPEX of Arctic Project

Table 11. Comparison indicators pre-feasibility vs feasibility CAPEX of Arctic Project

Table 12. Comparison indicators pre-feasibility vs feasibility CAPEX of Arctic Project

Table 13. Comparison indicators pre-feasibility vs feasibility CAPEX of Kutcho Project