Final Report Project 2.8

Limitations and issues with using the DCF NPV method for valuations of mine closure and post mine closure

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Executive Summary

The activities associated with mine closure and post mine closure are integral parts of the mining life cycle and each phase constitutes an important operations process. Beyond the planning phase, mine closure describes the time frame during which a mine's operational phase is coming to an end, or has already ended, and the final decommissioning and rehabilitation activities are being carried out.

Mines close for many different reasons, with economic factors offering the primary reason, notably arising from a sustained drop in the commodity-of-interest's price or a diminishing remaining ore grade to below the economic cut-off. Alternatively, mine closure may be necessary due to a technical occurrence such as when an unplanned drop in grade occurs, or when geological conditions inhibit safe, economic ore extraction. However, usually most mines have not had sufficient financial assistance due to a number of problems, such as underestimating closure costs and lack of implementing new concepts.

To evaluate mine closure and post-closure activities and land-uses, the discounted cash flow (DCF) valuation method is commonly used, applying a net present value (NPV) technique, as it has been for many decades. However, there are shortcomings in this DCF NPV technique. In this study, the sole aim is to investigate and highlight the issues and limitations of reliance on using a DCF NPV technique for evaluating and valuing mine closure and post mine closure assets and functions.

1. Introduction

The final act of closing a mine eventuates for a variety of reasons and incorporates a long, pre-planned process, a process that commences almost immediately a mine starts operating. While the primary motivating factor supporting the closure of a mine is an economic one, other reasons include that the ore body may have experienced sustained lower, sub-economic grades or a specific geological inhibitor arose (faults, dykes, wash-outs, structural impediments, climate impacts, etc.). To evaluate mine closure, practitioners have relied on, and continue to rely on the use of the discounted cash flow (DCF) method applying the net present value (NPV) technique as the preferred valuation and evaluation tool. Despite other limitations discussed in this report, the DCF NPV methodology may also adversely drive closure-related behaviour at an early phase of the mine's life cycle.

This report aims to highlight the key reasons why the DCF NPV technique is not an appropriate tool for valuing assets undergoing closure or post-closure activities. This report does not offer any solutions to NPV's shortcomings, as this will be undertaken as a separate exercise.

Since mine closure and post-closure planning activities commence early in an operation's life, practitioners typically apply the same valuation method for these phases as they do to ongoing operations. That is, the DCF NPV technique is used to evaluate an operation's production-related cash flows as well as that operation's closure and post-closure activities. Since these two phases, operations and closure, are not specifically separated in the evaluation process, this report will review the methodology as it is applied to operational activities as well as to closure activities.

The premise supporting the DCF analysis is that a mining venture can commence or progress its operations all the way through to mine closure if the NPV of its future cash inflows and outflows, discounted to the present day at an appropriate discount rate, is positive. Unfortunately, due in part to its static structure and inability to include managerial flexibility, a DCF NPV analysis exhibits certain significant limitations. Some of the more obvious limitations include:

- the cyclical nature of the mining business, particularly relating to market and margin instability, is not taken into account in a DCF NPV analysis
- the long-term effect of sovereign risk is ignored in a DCF NPV (Gardner, 2015)
- it does not consider mine closure effects or certain costs such as comprehensive environmental, reclamation, climate, waste water drainage, social and other environmental, social and governance (ESG) and non-ESG factors
- it does not take into account geological uncertainty such as short-term ore grade variations or structural uncertainty, unless that is somehow incorporated as a sensitivity or other simulation analysis
- it seldom accommodates variability in the applied discount rate over time, as gearing levels vary, equity levels vary and specific non-cost-of-capital or project risks vary.

In some mining projects, it is strongly advised to employ alternative quantitative methodologies to gain an improved understanding of project risks, including risks and uncertainties associated with closure.

These methods can help project teams prioritise detected risks, assess how identified risks affect anticipated project outcomes overall, create reasonable project goals, confirm project timetables and budget projections, and quantify an adequate amount of project contingency.

The closure stage of a mining operation – which includes diminishing and ultimately discontinuing ore production, activities associated with decommissioning plant and infrastructure, rehabilitation of affected surficial and potentially subterranean areas, reclamation, and post-closure monitoring and maintenance – reflects the final stage of the mining life cycle before the land is finally relinquished. Economic, geological, geotechnical, environmental, social (community), governmental and other elements that contribute to a sustainable decommissioning process are also impacted by mine closure in addition to the residual mineral resource (Laurence, 2006; Nehring and Cheng, 2016).

Normal operations as a stage in a mine's life cycle is very different to the closure and post-closure stage. For normal operations, and for the derivation of a DCF NPV, the main considerations in the valuation of that mining project are:

- revenues, driven by ore production rates and grades, mineral quality (recoveries in processing) and local commodity prices
- pre-production capital expenditure (Capex) as well as ongoing Capex
- ongoing operating expenditures (Opex).

Naturally, depreciation and amortisation, taxation, royalties, duties, profit-sharing, participative or free carried interests etc., are factored into the DCF NPV calculations to arrive at a final value or value range of that project. Longer-term expenses that are more difficult to calculate, such as decommissioning, closure, reclamation and monitoring costs (including provisioning), typically receive less attention (Espinoza and Morris, 2017b), but are also factored into the same DCF NPV model. Ostensibly, some of these longer-term expenses may be intangible and/or uncertain (discussed later in this paper) during the various valuation exercises.

By convention, a DCF NPV applies a single discount rate over the life of the operation to arrive at a single value or a value range (NPV). However, a single discount rate in any DCF NPV model cannot address all, if indeed any, of the risk factors associated with mine closure or post-mine closure factors, in addition to many of the operational factors pre-closure.

A discount rate's inclusion of additional project risk is debatable anyway, because that additional risk is frequently not measurable or appropriately quantifiable. In fact, the numerical quantification of risk is somewhat elusive, let alone as a component of a single discount rate. It is also important to note the primary, well-documented purpose of using a discount rate. A discount rate is primarily a reflection of the real or nominal cost of funding for a specific project, being the weighted real or weighted nominal cost of debt, equity and preference shares (we will ignore preference shares because many countries do not offer preference shares as a funding instrument) (Lilford et al., 2018; Lilford, 2023).

Furthermore, even though for a very short-life operation there may be some motivation for using a single, all-inclusive risk-adjusted discount rate (RADR), since the impact of any discount rate over a short-life asset tends to be negligible, the question must still be asked as to whether a single discount rate can be justified and hence used throughout the lifetime of an operating asset, when the cost of capital is actually variable over time and the remaining risks remain numerically unquantifiable. Compounding this and for longer life operations, the question is then asked as to whether a single (static) discount rate can be justified equally for short-term, medium-term and long-term operations.

For any mining life duration, it is crucial to analyse how the risks and uncertainties connected with that mining project are reflected and captured in the valuation, and accept that the weighted average cost of capital (WACC) and therefore, the discount rate, changes over time. Logically, the WACC must change over time as the weightings of debt to capital and equity to capital change; not only because debt is repaid over time, but also because equity returns are received by the investor (including the mining operation and its non-shareholding stakeholders) through dividends and/or capital growth (reinvested capital). So should these components of a DCF NPV stay constant or should they reflect some dynamism that accommodates varying debt and equity ratios (weightings) over time, as well as varying risk and uncertainty over time (Lilford et al., 2018; Lilford, 2023)? These concepts will be discussed in greater detail later in this paper, including the idea of dynamic versus static discounting, which only partially or superficially addresses the problem.

The prosperity of a mining region does not only depend on the economic benefits derived directly from the mining activity, but also on that region's geological, environmental, social and cultural heritage and disposition before and after mining. In addition, and arising from the services and activities associated with mining, other sectors of the regional economy may also provide products or services into the mining activities, which may become self-sustaining (non-reliant on mining) over time. Over the course of the mine's life cycle, values and vulnerabilities develop and change, generating distinct territorial trajectories that are influenced by the starting circumstances as well as by political, economic and sociocultural factors (Marie and Magali, 2021).

Leading up to the closure phase, cash flows generated from mining projects tend to be highly volatile as a direct consequence of being influenced by a multitude of variables, including technical, economic, regulatory, environmental and social factors. In addition to this, mining projects are complex businesses and most of their executed investment decisions are irreversible. Commodity prices and exchange rates are continuously fluctuating and, at times, they exacerbate the risks associated with the mining industry. Collectively, mine management needs to address these potential risk exposures before making or acting on any investment decision (e.g., acquisition, expansion or recapitalisation). Hence, when there is a possibility of developing or acquiring either a new or operating mine, owners and stakeholders of the mining project need to know the value, as measured by cash flows, of the project that can be generated over the operating life of mine, and commensurately, whether that mine can generate sufficient cash flows and returns over its life to accommodate all closure-related costs and activities. Therefore, it demands appropriate evaluation methods that can consider real life circumstances, respond to global market dynamics, and provide managers and stakeholders with relevant information before the decision to invest in or develop the project is exercised. A DCF NPC fails to adequately address many of these factors.

The above are the fundamental factors on which a final, irreversible decision is made regarding the natural resource project's investment, development, expansion or recapitalisation. The pending decision that is to be made based on the above investment factors, typically derived from the DCF NPV outcome, is referred to as an option. The estimation of a mining project's value is a complex task, as several risks and uncertainties are attached during the life of the project. This is because, in general, values of mining projects are influenced by many underlying economic and physical tangible and intangible risks and uncertainties over time. These include factors such as commodity prices, metal or ore grades, foreign exchange rates, operating costs, size of the deposit, environmental, social and political issues, closure and post-closure monitoring costs and numerous others. Consequently, mining projects face considerable challenges and risks, most notably due to the uncertainty surrounding commodity prices, exchange rates and operating costs, along with numerous technical and/or geological uncertainties. The valuation of the mining project is developed on the basis of the project itself. The traditional DCF valuation method incorporating an NPV fails to respond to these hard-to-predict economic risks and uncertainties, even while employing risk-mitigating insurance or hedging strategies, as the method relies on the generation of cash flows and simultaneously on a single or static discount rate.

While the DCF valuation method has been used in the mining industry over an extensive period of time, variations to this method have been introduced. Binomial Option Pricing is generally used as a methodology to evaluate a mining project using the real options valuation (ROV) method. However, previous research around DCF and ROV methods has typically encountered pitfalls. Other than through simple sensitivity analyses, the pitfalls include the fact that DCF valuation methods ignore integrating various types of uncertainties, such as those associated with the commodity price, costs, exchange rate, environmental and mine closure factors and costs, reserves/resources and others. These uncertainties are generally considered only by using a single parameter risk adjusted discounted rate. In general, in a DCF method, it is difficult to accurately determine an appropriate single risk-adjusted rate of return to apply.

2. Limitations of the DCF method

Due to its simplicity, the traditional DCF analysis is the most widely accepted method used for valuing potential economic outcomes of mining projects, on which investment and other economic decisions are made. To generalise, for resource projects with notable NPVs and stable cash flows, the DCF method of analysis is likely to remain the dominant investment decision-making tool for the mining industry over the foreseeable future. However, the validity of systematically using this methodology is undermined where there is a high degree of uncertainty in future cash flows and where management has the flexibility to respond to these uncertainties (Martinez and McKibben, 2010; Haque et al., 2014). Since various flexibility options are ignored, DCF NPV analyses tend to undervalue operating projects, and underestimate (due to discounting future outflows) the closure and post-closure economics of a project.

While conceptually very simple, the DCF method and its associated NPV outcomes, as applied to operating assets as well as to closure and post-closure aspects of operations, have some major shortcomings, including those highlighted below:

- **Dealing with uncertainty:** In a DCF analysis, the prediction of a cash flow outcome over a period of time in the future is necessary. Under this scenario, a disproportionate amount of time and effort is spent on assessing the likely impact of a cash flow and potential operational loss and how to alleviate or mitigate this potential outcome. A further limitation of the DCF method involves the use of a risk-adjusted discount rate, which is not able to capture many of the sources of uncertainty in the project, notably at or near closure. This means that this valuation method has the effect of ignoring the real sources of uncertainty, noting that there are many factors that can influence the value of a mining project including technical, financial, commodity price, exchange rate, geopolitical, geological and market elements (Martinez and McKibben, 2010). In a practical sense, it is also difficult, actually impossible, to determine an appropriate single (static) WACC risk-adjusted rate of return. Furthermore, the riskiness of the project may change over time as it heads towards closure, depending on how uncertainties unfold and management reacts to these uncertainties (Smith and McCardle, 1998, 1999), which are seldom or poorly captured in a DCF model.
- **Dealing with flexibility:** The traditional DCF method ignores the flexibility of management in valuing a project and, consequently, there may be hidden or unaccounted for possibilities of additional value associated with the mining project (McKnight, 2000; Shafiee and Topal, 2008a). In reality, if external or internal factors change in a mining project, mine managers exercise some level of flexibility, such as delaying operations, suspending or closing mine operations temporarily or permanently, or varying operating parameters, etc. These inappropriately-valued flexibility options will likely have an impact on the longer-term economics of the operation up to and beyond mine closure.

- **Dealing with intangibles:** DCF modelling can only incorporate what we know, being tangible parameters. Intangible parameters, often associated with social factors, climate change impacts, artificial intelligence innovations and IP, among others, are not modelled in a DCF, and varied likely outcomes arising from intangible risks (unknown knowns) and intangible uncertainties (unknown unknowns) (Maybee et al., 2023) are ignored.
- **Dealing with discounting (time value, risk and uncertainty):** There is still considerable dispute on the appropriate discount rate to apply when calculating the DCF NPV of a mining operation, let alone when an operation approaches economic ore-depletion and closure. The additional project risk that is typically captured in a discount rate is contentious, as it is generally not quantified and, in fact, may not be quantifiable at all. In addition, while there may be some argument to justify why a single, all-encompassing discount rate should be used, notably for a short-life (near-closure) operation, the assumption that a single discount rate applied over the life of an operating asset up to and beyond closure may not actually be reasonable under any circumstances (Lilford, 2023). Even a variable or dynamic discount rate to value closure and post-closure economics will fall far short of being appropriate due to the incorrect weighting applied to the cost of equity, the cost of debt (no debt remains at or near mine closure) and the fact that cash flows are replaced with outflows or expenses for closure, clean-up (including rehabilitation) and post-closure monitoring.
- **Driving behaviour:** The determinations of a DCF NPV often drive operational behaviour, since the modelled cash flows become the project's target outputs (key performane indicators, KPIs, are often based on these). Since closure and post-closure activities are modelled in the same DCF NPV model, closure-related behaviour may also be driven by the valuation tool itself, which tends to be a flawed approach to adequately addressing mine closure.

Closure provisions, including post-closure activities that incorporate monitoring activities, can have a significant effect on a company's balance sheet and hence value.

As stated, the NPV tool is the most widely used valuation technique in the mining sector. This technique involves a single component that, on a compounding basis, decreases future cash flows or future expenses (outflows) over time. When calculating the NPV of an investment, the main issue with combining time value of money – represented by the risk-free rate or after-tax yield on an appropriate government bond – and risk into one factor, is that it artificially reduces the value of cash flows, including cash outflows for closure and post-closure activities that occur far in the future, and exaggerates the value of earlier cash flows. Arising from this, it can be easily argued that such an analysis may be deceptive, causing businesses and governments to make incorrect or ill-advised design and operational decisions. This argument is compounded when we apply it to a mine closure and post-closure scenario, where income, costs and capex are nearing, or have attained zero values, meaning that the discounting is applied solely to rehabilitation, reclamation, monitoring, social and other closure and post-closure activities and their associated economic components.

Therefore, the results of such a DCF NPV analysis may be deceptive, leading businesses to make decisions about operations and design, including closure mapping, which may later prove to be harmful to stakeholders and notably to communities and shareholders alike. For mining investors, NPV techniques result in considerable valuation volatility for mines with long lives (>30 years), which is comparable to the volatility linked to spot prices for commodities. Additionally, and by way of example, the excessive reliance on the NPV technique makes it difficult to justify investments under the increasing threat of climate change impacts, and accommodating any adaptation to increase the mining operation's chances of withstanding the effects of future severe weather events linked to climate change (Javier and Espinoza, 2017a) become difficult to evaluate, especially with the DCF NPV tool.

Although many industry experts have pointed out the NPV tool's drawbacks and have suggested alternatives (e.g., Salahor, 1998; Laughton et al., 2000; Samis et al., 2006; Guj and Garzon, 2007; Haque et al., 2014; Hawas and Cifuentes, 2016), the NPV tool is still by far the most popular method used for valuing each and all phases of the life cycle in mining opportunities.

The value of long-term investments can now be estimated using a new valuation method (Espinoza and Morris, 2013; Espinoza, 2014), known as a decoupled net present value (DNPV). The DNPV purportedly addresses many of the flaws in the NPV method while maintaining the simplicity associated with a cash flow analysis. This DNPV technique is discussed further in section 3.4.

An additional problem with the use of DCF NPV is the timing of when shutdown or closure costs occur. These expenses have always been thought of as mine-ending or end-of-life expenses. They were not considered a necessary expenditure to take into account in the early phase of the life cycle of mining projects. Closure expenses were frequently insignificant to a project's NPV by including them at the end of a project (Mayne et al., 2022), and therefore discounting them over the remaining life of the project.

Many industry experts (e.g., Salahor, 1998; Samis et al., 2006; Guj and Garzon, 2007) have acknowledged the inadequacies of the NPV method, notably with relation to the valuation of mining assets and liabilities (Davis, 2002). Alternative valuation techniques, such as real options valuation (ROV) or contemporary asset pricing techniques, have been proposed to address some of these flaws (Laughton et al., 2000; Haque et al. 2014; Haque et al, 2017; Lilford, 2023).

However, DCF NPV and internal rate of return (IRR) continue to be the preferred valuation techniques used in the mining industry. As a result, insufficient financing is frequently allocated for progressive rehabilitation and closure (PRC) and reclamation efforts (Boyd, 2001; Chambers, 2005). This encourages mines into selling precious commodities for prices that do not necessarily accommodate the true total cost of production, compounding issues around the project's economic expectations at the end-of-life or near-closure/post-closure phase.

3. Advantages and disadvantages of NPV

As stated, NPV is one of the DCF techniques used in capital budgeting to determine the viability of a project or an investment. Simplistically, NPV is the difference between the present value of cash inflows and the present value of cash outflows, over a specific time period that, when combined, are discounted to the present value using the required rate of return. A positive NPV denotes the achievability of an appropriate minimum rate of return on the investment (capex).A negative NPV indicates that the investment return does not achieve the minimum percentage return demanded from the investment.

3.1 Discounted Cash Flow Method

The present value (PV) or net present value (NPV) derived from a DCF is a value or range of values derived from a valuation technique used to estimate the project's or firm's net worth. The mathematical formula to calculate a DCF is typically as follows:

$$DCF = \frac{CF_1}{(1+r)} + \frac{CF_2}{(1+r)^2} + \cdots\cdots + \frac{CF_n}{(1+r)^n} = \sum_{t=1}^{n} \frac{CF_t}{(1+r)^t} \qquad (1)$$

where:

CF_1 = cash flow for year one

CF_2 = cash flow for year two

CF_n = cash flow for year n

r = the discount rate (adapted from the cost of capital, WACC).

3.2 Net Present Value tool

The NPV tool is used to determine the resulting value associated with a cash flow to ascertain whether or not an investment, project, or business will be profitable over a period of time, based on those projected future cash flows. Essentially, the NPV of an investment is the sum of all future cash flows over the investment's lifetime, discounted to the present value.

<u>NPV formula:</u>

Calculating an NPV involves calculating the cash flows for each period of the investment or project, discounting them to a present value, and subtracting the initial investment (capital expenditure, or capex) from the sum of the project's discounted cash flows.

According to the definition, an NPV is "the difference between the present value of cash inflows and outflows over time" (Park, 2007; Rami, 2023).

The formula for NPV is:

$$NPV = \frac{CF_1}{(1+r)} + \frac{CF_2}{(1+r)^2} + \cdots\cdots + \frac{CF_n}{(1+r)^n} - Initial\ Investment$$
$$= \sum_{t=1}^{n} \frac{CF_t}{(1+r)^t} - Initial\ Investment \quad (2)$$

where:

CF = the Cash Flow, being the net of money spent (outflow) and money earned (inflow) on the investment or project over a given period of time

n = the number of time periods (typically years)

r = the discount rate (%).

<u>The discount rate:</u>

The discount rate, r, in the above formula, provides the single, most contentious component of the valuation tool. In various studies associated with the technical and techno-economic parameters, including in feasibility studies, optimisation and expansion studies, or even forward mine planning studies, a significant amount of effort is put into refining the technical parameters of the project, as well as the economic inputs (commodity price, exchange rate, operating costs, capital expenditure, tax and royalty rates, etc) driving the project. However, very little time and effort is spent on determining the appropriate discount rate to be used in the ultimate NPV that will determine the go or no-go decision.

While significant research has been conducted on discount rates (Mullins, 1982; Smith, 1995; Sorentino 1993; Lilford et al. 2018), it is prudent to consider the key fundamentals of discounting in this paper.

3.2.1 WACC and discount rates

The discount rate used in a DCF NPV model is typically a single factor that incorporates the pre-tax or post-tax cost of debt, cost of equity and cost of preferential shares, if applicable (Belli et al, 2001). When these sources and associated costs of funds are pro-rated according to their weightings and then are summed, the result is a weighted average cost of capital (WACC) (Lilford et al., 2018).

The simple formula used to calculate the WACC follows (Smith, 1995):

$$WACC = r_e p_e + r_d p_d + r_p p_p \quad (3)$$

where:

$r_{e,\ d,\ p}$ = the cost of equity (%), debt (%) and preference shares (%), respectively,

and:

$p_{e,\ d,\ p}$ = the weighted proportions of each of equity funds, debt and funding from preference shares, respectively.

The sum of the attributable weightings equates to 1.00 (i.e. $p_e + p_d + p_p = 1.00$) (Brennan and Schwartz, 1985).

Since preference shares are specific to only some jurisdictions and not in Australia, they will be ignored.

The cost of equity can be calculated by using the capital asset pricing model (CAPM) and may be determined as follows (Mullins, 1982):

$$CAPM = r_e = f + R\beta \quad (4)$$

where:

r_e = expected cost of equity (%)

f = risk-free rate of interst, (return or yield on a government bond) (%)

R = the project's return in excess of the market's return, equating to the risk premium of market returns over the long term risk-free rate (%)

β = beta or volatility factor, being the coefficient of systematic risk (Hull, 1989).

The beta or systematic risk of a project reflects the volatility of that project's equity relative to the whole market's volatility (Van Horne, 1977).

In the mining sector, unsystematic risk, which can be diversified and diluted in a portfolio of investments (Mullins, 1982), will include varying production rates, grades, recoveries, operating costs and capital expenditure among other determinable inputs. The variation in these inputs can typically be mitigated or quantified using alternative tools to CAPM or WACC.

In the case of systematic risk, a project or company that has a beta coefficient greater than 1 means that the company has a non-diversifiable risk greater than the entire market's average risk (Dixit and Pindyck, 1994). So this particular project or company has more systematic risk, or greater share price volatility, than a portfolio of risky assets. Naturally, a beta of less than 1 means that the project or company has a non-diversifiable risk lower than the market average, which is interpreted as the project's volatility being less than the whole market's volatility.

The volatility of a company is a measure of the sensitivity of that company's value to the various economic inputs that influence all risky assets' values, incorporating interest payments and inflation rates, economic growth, exchange rate impacts and other influences (Lilford et al., 2018).

Betas derived from the market do reflect certain limitations (Lilford, 2010), including that betas:

- vary as the market varies and not independently of it
- are derived from historical variances, which tend to be inaccurate over the longer term
- indicate the volatility of a share price and not of a specific asset (a proxy can be used to determine the beta of an unlisted or subsidiary asset)
- vary over time, so that CAPM must also vary over
- cannot reflect a near-perfect or perfect market correlation (β cannot be 1).

On the broader cost of capital, WACC, there is a notable difference between the WACC and project risk and project uncertainty. Project risk and uncertainty is often collectively added to the WACC to give a final discount rate, being a rate higher than the WACC alone.

One of the major errors of which valuation practitioners are guilty is that they use a static or single discount rate over the life of the operation and, hence, over the projected cash flows. More accurately, a WACC must recognise the variability of its inputs over time. The 'W' in WACC is the weighting of debt and equity, and it cannot be denied that these weightings will vary over time as debt is repaid or redrawn, and further recapitalisation (through equity or retained income) of the project occurs. That is, as the principal amount of debt is fully repaid and equity levels change due to recapitalisation, the WACC will trend towards the risk-free rate over time (Lilford et al., 2018).

3.3 Issues with the Net Present Value tool

A closer look at the DCF method and NPV technique highlights a number of issues attributable to the technique. The following discussion provides a summary of the advantages and disadvantages associated with the DCF NPV technique.

Advantages:

<u>Time value of money:</u>

The primary benefit of using a DCF NPV is that the technique incorporates the principles of the time value of money (TVM). These pinciples state that money received in the present is of higher worth than money received in the future. This manifests because money received now can be invested and used to generate cash flows to the enterprise in the future, in the form of interest or from future investment appreciation and reinvestment. i.e., a dollar today is worth more than a dollar tomorrow owing to its earning capacity now. The computation under NPV analysis considers the discounted net cash flows of an investment to determine its viability.

<u>Decision-making:</u>

The DCF NPV method enables a decision-making process for companies. Not only does it help evaluate projects of the same or similar size, but it also helps in identifying whether a particular investment is profit-making or loss-making.

Detailed: It is notably detailed, and incorporates most, if not all, of the fixed value drivers, both technical and economic, now and into the future.

Explicit: DCF NPVs determine the intrinsic value of an operation and do not require comparable companies (other than for proxies to determine WACC (Lilford, 2023)) to achieve a result. This makes decision-making, including mergers and acquisitions, a relatively simple process using basic Excel modelling tools.

<u>Simplicity:</u>

The DCF NPV method is very simple to use without any subscribed-for valuation software packages. Excel remains the preferred software for DCF NPV formulations.

Disadvantages:

Compliance:

Global accounting standards, including IFRS (International Financial Reporting Standards), do not identify or state what method(s) is appropriate to account for mine closure and post-closure activities and associated outflows. They also fail to consider associated consistencies in qualifying and quantifying these life cycle phases. While terminology and nomenclature continue to be updated and appropriately captured, the evaluation processes supporting them have not been identified or suggested. As policy typically lags activities and methodologies, the use of the DCF NPV tool faces numerous shortcomings because its use will not be applied consistently from one operation to another, by one practitioner to another, or according to a pre-set list of rules and guidelines. This applies equally to mine site provisioning for closure, where only rehabilitation and demobilisation activities are covered, without considering the wider ESG factors (e.g., heritage, future, in-kind or preferred land-use, etc.). Incorporating the mine closure and post-closure numerics (economics) in a DCF NPV analysis that drives operational behaviour, leads practitioners focusing on closure and post-closure activities and economics to be equally led or driven by that same tool.

Guidelines:

There are no set guidelines to calculate the required rate of return (discount rate), other than the WACC. The entire computation of a DCF NPV rests on discounting the future cash flows to its present value using the required rate of return, derived from the company’s cost of capital. However, there are no guidelines as to the determination of this rate, other than for the determination of the cost of funding (cost of debt and cost of equity, combined to generate the WACC). The determination of this percentage value, or discount rate, is left to the discretion of companies or valuation practitioners, and there known instances where the NPV has been inaccurately determined due to an erroneous rate of return calculation or personal / practitioner bias.

Hidden costs:

A DCF NPV only takes into account the cash inflows and outflows of a particular project. It does not consider any intangible costs, hidden costs, sunk costs, Intellectual Property (IP), social economics, or other preliminary costs incurred for the specific project. Therefore, the profitability and economics of the project may not be accurate, including for mine closure or post-mine closure activities where cash flows diminish to being costs and other outflows only.

Cannot be used for some comparisons:

Another disadvantage of NPV is that the technique cannot be used to compare projects of different sizes. NPV provides an absolute, single figure value (other than through incorporating sensitivity or scenario analyses to generate an NPV range) and not a percentage (excluding an IRR, which is also based on the DCF). Therefore, the NPV of larger projects would inevitably be higher than a project of a smaller size. This may present an inappropriate investment opportunity since an investment in the smaller project may provide greater returns than the returns attributed to the larger project, despite having a lower NPV. Hence the smaller project may be economically more attractive.

It is also logical that most larger projects have a longer mine life than a smaller project. A longer life means that its closure economics (mostly measured by cash outflows) will be discounted over a longer period of time than that for a shorter-life project, so that comparing closure-related economics of the two projects becomes unreasonable.

The following list provides additional reasons why the DCF NPV is a limited tool for operating assets as well as for closure and post-closure assets:

- Other than using simple sensitivity analyses, DCF evaluations include a large number of assumptions but ignore integrating uncertainties, and modelled outputs are very sensitive and hence potentially inaccurate to changes in:
  - commodity prices:

    The DCF method cannot appropriately address the fluctuation of commodity prices in project valuations, unless these changes are known ahead of time and are appropriately incorporated into the model. However, this is highly unlikely, and therefore any forecast around mean reversions, flat trajectories, contangos or backwardation commodity curves can only be based on best estimates and econometric measures.
  - the exchange rate:

    The forecast foreign exchange rate should be incorporated in the valuation model for a mining project (Haque et al., 2017). The exchange rate is an important issue not only for the valuation of an operating mining project value, but also in mine closure and post-mine closure. However, to accurately forecast whether one relevant currency depreciates or appreciates against another currency cannot be forecast with certainty, and especially so over longer periods of time.
  - reserves and resources (mining rates, grades, life of mine):

    Mine closure depends on the remaining tonnage and associated grades of a mining project. As long as the availability of economic grades in a mine exist, its operation will continue producing, and the closure of the mine may be deferred. Closure occurs when the available remaining blended mined grade falls below the economic cut-off grade. This may be unpredictable and hence cannot be modelled since the cut-off grade is determined by a number of interacting factors including commodity price, exchange rate, tonnage mined (rates), available grades, operating costs, royalty rates, capital expenditure and other lesser-impacting factors, which all fluctuate over an operation's life, largely driven by commodity markets.
  - operating costs:

    A change in the operating costs will impact the required cut-off grade that needs to be targeted to generate pre-determined returns at least equivalent to or above the required rate of return for the project. At mine closure and post-closure, the only operating costs are those associated with closing, reclaiming and cleaning up the site, as well as with ongoing monitoring. At these latter phases, since there is no income, no cut-off grade can be determined, hence a DCF NPV model will be focused on discounting a cash outflow alone (not net cash flows since there will be no sales or income at and beyond mine closure, excluding salvage sales and excluding the potential sale of part or all of the land previously held by the mining operator). The DCF NPV technique is a flawed modelling tool for discerning the value of cash outflow alone, and notably so when an arbitrary discount rate is used. In addition, it is incorrect to assume that closure provisions can be discounted at the same rate as operational cash flows, since provisions are not sourced or funded from equity and/or debt markets, but rather from retained (provisioned) earnings.Hence its assumed discount rate will need to be calculated separately – and it may actually not be a discount at all, but rather a positively compounding rate.

- capital expenditure (capex):

  While capex is considered during the operational life of the mine, it is not a consideration for closure and post-closure activities. The latter is funded through ongoing cash flows (provisioning) and ongoing rehabilitation (progressive rehabilitation). This means that allocating the appropriate amount of clean-up capital may or may not adequately address the clean-up required at that point in time, depending on available profits generated by operations. Despite this, if closure and post-closure activities are funded through capex, a DCF NPV may appropriately accommodate the time value of money, but will not address the need for an appropriate discount rate.

- environmental conditions and impacts:

  Tangible risks associated with environmental conditions can typically be appropriately addressed, whereas intangibles and uncertainties are likely to be inadequately accommodated using a DCF NPV technique. This comes back to the discussion around discount rates associated with risks versus uncertainties and tangibles versus intangibles. Uncertainties and intangibles cannot be accurately quantified, hence provisioning or evaluating them is near impossible, using any currently-applied technique.

- mine closure:

  The DCF NPV technique was designed to address the valuation of cash flows, not component parts of a cash flow (other than through Real Options or DNPV), and generally not those parts of a cash flow that reflect a variable (non-static) discount rate. Allocated costs or accumulated provisions for mine closure and post-closure activities cannot be discounted using the NPV technique, in addition to the fact that this stage of the mine life cycle is inherently uncertain (on final costs/expenditures), and on whether intangibles may become identifiable and therefore possible to mitigate.

Environmental and social conditions have a profound impact on a mining project as well as on mine closure. The category hosting environmental factors is generally considered non-market risk and includes the impact of climate change and/or significant earthquakes on mining operations and mine closure (Espinoza and Rojo, 2017a), amongt other events.

The DNPV method serves to address many of the factors listed above, but the method is not considered appropriate for mine closure and post-mine closure as there is minimal to no revenue during this end-of-life period, and these consequent cash flows (inflows and outflows) do not reflect normal mining operations. In addition, the DNPV technique also relies on a single risk-adjusted discount rate.

- Furthermore, both for DCF NPV and for DNPV:
  - despite being simple and easy to use, they are prone to errors and to the introduction of over-complexity, potentially giving rise to the adage *garbage in = garbage out*. The DCF NPV and DNPV methods underestimate or inadequately estimate project values, especially when considering the end-of-life of a mine.
  - determining a single, risk-adjusted discount rate is challenging, and tends to be based on flawed input assumption governing sovereign risk (risk-free rate), volatility, the cost of debt, debt-gearing over time (zero debt at the end-of-life of a mine) and the ever-changing weighting (in the Weighted Average Cost of Capital, WACC) of the ratios of debt to capital and equity to capital.
  - the methods ignore other notable sources of uncertainty, including technical, commodity price, geopolitical, geological and market elements (Martinez and McKibben, 2010), as well as intangible factors that may also give rise to economic outcomes.
  - the methods rely on a single, static discount rate and, as a consequence, do not address any additional, significant sources of uncertainties and risks. By way of an example, commodity prices and exchange rates have notably large impacts on the valuation of mining projects (Haque et al., 2014; Haque et al., 2017) in operation, although less of an impact when the mine reaches closure. However, at mine closure, further risks and uncertainties arise which are not incorporated in the existing methods. Therefore, a single discount rate in a DCF NPV or DNPV model cannot address the risk and uncertainty factors associated with mine closure or post-mine closure.
  - each of the methods accommodate the incorporation of significant input detail. The high level of included detail is likely to induce over-confidence in the techniques' reliance.
    - We take for granted that, because a model is complex, it is reliable. However, the dependency and over-confidence associated with DCF NPV and DNPV methods provide over-estimated or under-estimated project values and cost estimations, arising from the many inaccuracies associated with these methods (discounting of costs and other outflows, time value, overall discounting, dealing with risks, uncertainties, tangibles and intangibles, and others).

- the methods consider operations explicitly, being in isolation, and not relative to other operations.
- using and applying the methods tends to drive or at least affect the project owner's behaviour when it comes to technical and economic planning and closure-related expenditure earlier in the operation's life. The discounting of future closure-related costs in a DCF NPV and DNPV to the present day suggests that the future closure costs are minimal or manageable (i.e., notably lower) and therefore need only be considered at some later point in the mine's life. Saving for or expensing closure-related costs, including appropriate provisioning, is therefore often deferred to a point in time closer to when the mine actually closes. This often leads to an underestimation of the future closure costs and hence an inadequate economic plan paralleling the technical closure plan, and ultimately insufficient funds being being set aside or made available to effect an appropriate, compliant closure plan.
- the terminal value of an operation at closure and post-closure is difficult to estimate, and can represent a large component of the value. However, this terminal value is typically and incorrectly discounted significantly over time by the applied discount rate.
    - The terminal value (TV) is the value of a project's or company's anticipated free cash flow after the end of life, as reflected in the financial model, and is a key part of the DCF. However, it is difficult to estimate the terminal value of a mine because projecting the company's financial accounts to indicate how it would change over a longer timeframe is difficult. The confidence associated with the financial statement prediction also declines exponentially over time. Additionally, structural changes in macroeconomic conditions that affect the nation and hence the company may occur (Dheeraj Vaidya, 2023). Therefore, in order to determine the company's or project's value beyond the forecast period, being the TV, the assumptions are typically simplified and rendered inaccurate due to applying broad rather than explicit assumptions, giving rise to incorrect or inaccurate end-of-life estimations and project values.
- it is impossible to accurately determine an appropriate single dynamic risk-adjusted discount rate to be applied in a DCF NPV or DNPV for numerous reasons (Lilford et al., 2018), as discussed above. Furthermore, beyond the weighted cost of debt and cost of equity constituting the discount rate, any additional project risk being captured in a discount rate is contentious and not recommended, as it generally cannot be quantified or even estimated (Lilford, 2023).
- the WACC, as a proxy for the discount rate, is a measure of the funding costs (the weighting of equity and debt over time) of an existing or projected operation's net cash flow. This measure is inappropriate for discounting closure-related costs and provisions, which are

estimated cash outflows with no recognised inflows to offset them at that point in time. Neither the debt nor equity market is approached to fund mine closure and post-closure activities.

- longer-term expenses that are more difficult to calculate, such as decommissioning, closure and reclamation, typically receive less attention (Espinoza and Morris, 2017b), hence they are more likely to be underestimated from the outset, and therefore even more significantly underestimated when discounted using DCF NPV or DNPV modelling.
- the risks and uncertainties of the mining project may change over time dependent on how uncertainties unfold and management reacts to those uncertainties (Smith and McCardle, 1998, 1999). The act of provisioning will alleviate or at least mitigate against some of these risks and uncertainties, but will never be able to address and accommodate them all, because uncertainties (unknowns) only become risks (knowns) over time and nearer to or during closure.
- these methods totally ignore intangible uncertainties (unknown unknowns) across the life cycle and potentially inadequately factors in tangible uncertainties (known unknowns) and intangible risks (unknown knowns), notably around ESG, mine closure and post-mine closure. Discount rates are used to address this, but this presents a bigger issue, as discussed previously.

3.4 Decoupled Net Present Value (DNPV) model

The cost to a project associated with risk, which is incorporated into the DNPV technique and used to determine the certainty equivalent cash flows at each time period, is viewed as an additional cost to the project above the WACC. The appropriate value and returns to compensate the risk takers, such as investors, for the individual uncertainties and hazards assumed by the project might be thought of as the cost of risk (Espinoza et al., 2022). The additional risk appears discretely in the cash flows as a project cost, and highlights the possible downside of an investment.

Risks associated with any mining project are divided into two categories:

- Revenue Risk, which is the possibility of receiving less income than anticipated
- Expenditure Risk, which is the possibility of spending more money than anticipated.

Depending on the project under consideration, each of these risks may have a number of contributing sources. Commercial hydropower plants, for instance, may experience temporary or permanent shutdown due to contingency risks (such as spillway overflow that could damage the dam as a result of extreme rainfall events), which could impact revenues due to lower energy output or increasing operating costs arising from necessary repairs. Another example to which mining projects are exposed relates to risks associated with climate change, which are sometimes divided into two categories:

- Acute: lower-probability event driven

- Chronic: resulting in a longer-term permanent alteration of the probability distribution.

No matter how the risks are categorised or named, the DNPV analysis needs to accurately account for the cost aligned to risk.

According to the DNPV technique, each risk has a cost, regardless of from where it comes. In order to lower the value of the anticipated cash flow to accommodate that risk (i.e., the certainty equivalents), these risk-expenses (costs) are taken into consideration throughout the valuation process. Risks cause certainty-equivalent revenues to diminish and certainty-equivalent expenditures to increase, representing an advantage to applying the cost of risk concept. As the project's risks are directly reflected in the cash flows, the net certainty equivalent, or riskless cash flows, can be discounted using term-appropriate risk-free discount rates. This is because the net certainty equivalent, being the riskless cash flows, is calculated as the certainty equivalent revenues minus the certainty equivalent expenditure.

From this, the DNPV formula is highlighted as:

$$DNPV = \sum_{t=0}^{T} \frac{\tilde{V}_t - \tilde{E}_t - R_t}{(1+r)^t} \tag{5}$$

where:

T = the asset life

$\tilde{V}_t$ and $\tilde{E}_t$ = the expected cash flows (revenues and expenditures, respectively) at time t

R_t = the sum of the costs of risks at each time period

r = the risk-free rate to account for TVM (time value of money).

Commodity prices and foreign exchange rates are examples of market risk. Non-market risk includes the impact of climate change and/or significant earthquakes on operations (Espinoza and Rojo, 2017a), as well as social and other ESG factors. More crucially, the DNPV tool enables a seamless integration of risk management strategies put in place by business leaders and technical specialists into the financial assessment of the project.

There is growing recognition that traditional techniques of valuing long-term investments in physical assets and infrastructure based on DCFs using constant risk-adjusted discount rates have difficulty taking climate-related risks into account (Espinoza et al., 2022). In addition, such methodologies classify these expenditures as sunk costs that lower investors' returns and fail to take into account the substantial financial advantages resulting from investments in resilience and adaptability. Such conventional techniques of valuation encourage investors to defer or completely avoid making investments in adaptability and resilience. In the paper by Espinoza et al. (2022), the authors describe systematically valuing resilient and adaptive investments to safeguard assets against climate change risk using the DNPV model.

Despite the DNPV being an improved tool for the calculation of a project's value, the issues surrounding the valuation of mine closure and post-closure events, activities, assets and outcomes remains unresolved using this technique when compared with the NPV technique.

4. Mine closure and post-closure mine management

This section highlights many of the issues surrounding closure and post-closure management and associated impacts. It is to be considered in the context of whether the application of either a DCF NPV or DNPV technique can be applied to guide the economic outcome of the points raised.

According to Bainton and Holcombe (2018), mine closure typically results in significant territorial destabilisation. The geological and economic values, which were strongly associated with those outcomes during the mine's operation, rapidly decrease when economic interest in the ore body discontinues. As a result, as the benefits cease and money is needed for mine closure and post-mining management, economic risks increase considerably.

Decommissioning of infrastructure, reclamation, and rehabilitation of land damaged or affected by mining operations are necessary for mine closure, which takes place when the mineral resource has been exhausted or is no longer economically feasible to continue being exploited (Laurence, 2006).

When a mine discontinues production and closes, the infrastructure must be dismantled and removed from site. Management of the socio-environmental consequences is thus necessary for the transition from mining to post-mining activities. According to Lima et al. (2016), post-mining strategies include to:

- remove trace metal contaminants from the site
- prevent contaminant transfer to the ecosystem
- remediate decontaminated areas
- restore the area, which aims to recover the ecosystem and its functions
- reclaim the area, being to reintroduce and regenerate the original ecosystem services and biogeochemical functions
- rehabilitate the area, which prioritises the ecosystem services to be reclaimed or caters for the construction of new infrastructure.

The environmental and social values, which were at their lowest point at mine closure, are aimed to be improved by these tactics. A lack of a post-mining strategy, however, results in slow and steady environmental degradation (in value) commensurate with significant environmental vulnerability.

Typically, teams of senior and specialised personnel at mining companies are responsible for ongoing and final closure planning as well as for post-mining land use options. External pressure from shareholders and other stakeholders, notably those with social inclinations and/or likely to be impacted, as well as regulatory (and internal) pressure from rehabilitation and closure standards and targets, have put mining companies under constructive pressure, even in the absence of regulatory requirements that would otherwise facilitate rehabilitation and relinquishment (Kragt and Manero, 2021).

Due to the loss of jobs, personal income and the discontinuance of normal project operations, there is a considerable social value decline and a high level of vulnerability associated with mine closure. Employing local personnel for post-mining monitoring and management may help prevent the social value's decline and lessen its potential impact to some extent. Conversely, hiring outsiders for the tasks typically results in societal conflict. None of this can be accurately evaluated using the DCF NPV technique.

Post-mining monitoring and management may be constrained by local or national policies. Mining sites may be abandoned if these restrictions are weak or nonexistent, which would culminate in low social and environmental benefits. The greater the environmental and social values and the lower the socio-environmental vulnerabilities become, the more restrictive the policies are. Post-mining monitoring and management enable the territorial stakeholders to prepare future post-mining trajectories, which reduces localised and regional economic vulnerabilities.

Over the past few decades, mine closure planning and procedures have improved, but industry-wide rehabilitation results have not kept up with public expectations. Although there are very few instances of successful rehabilitation, there are still instances of mines closing and switching out the property to another land use. Australia's overall mine closure policy has changed dramatically over the recent past. Amendments in some states have strengthened rules for progressive rehabilitation and financial assurance procedures in an effort to further enhance mine closure outcomes (Tiemann et al., 2022). At fulfillment of one mine life cycle, four broad geographical pathways have been identified (Kivinen, 2017):

- a new mining project may eventuate
- reprocessing of mine wastes may occur
- promoting mining heritage may ensue
- an alternative economic activity may be enacted.

There are several instances of inadequate or unsuccessful environmental and mine closure results, despite evidence of some successful closure planning and rehabilitation having occurred (Western Australian Department of Mines, Industry Regulation and Safety's Abandoned Mines Program; DMIRS, 2021). Government and industry are hindered from taking the necessary steps to achieve the best potential transitional land use outcomes after mine closure as a result of regulatory gaps, delayed closure, and inadequate relinquishment planning.

From the above discussion highlighting a number of the challenges associated with mine closure and post-closure activities and commensurate value, and in conjunction with the previous discussion noting the shortcomings associated with DCF NPV and DNPV techniques, it becomes intuitive that the DCF NPV technique demonstrates significant shortfalls and limitations when attempting to capture the value or any other economic parameter associated with mine closure.

5. Integrated mine closure planning

To minimise poor or underfunded closure outcomes, integrated mine closure incorporates reclamation knowledge with strategic mine planning. In order to maximise project value throughout the course of the mine life cycle, integrated mine closure planning involves merging closure and returning land use objectives. It would be helpful to incorporate closure best practices and ESG principles into the full mine life cycle valuation and ensure a project has the resilience and capacity for adaptation over a long time frame, by incorporating additional disclosure requirements related to post-closure liability and returning land-use planning (Okane, 2023). Unfortunately, DCF NPV techniques are not adequate to accommodate integrated mine closure planning.

6. Closure guidelines and cost estimates

Many mine sites around the world have been abandoned over time without an adequate closure process, giving rise to unsecuritised environmental liabilities that cannot be attributed, and hence addressed, by any specific party (Lopez et al., 2018). In Lopez et al. (2018), the authors offer a comparative analysis of some state-specific regulations to assist in calculating mine closure costs.

Cost estimations are produced for mining operations at various points over their lifespans, starting with preliminary prefeasibility studies and ending with the definitive decommissioning cost projections. The estimates for capital and operational costs created at different points in the mine's life are expenditures offset against operating income, and they are easily evaluated using a NPV technique. At the end of the life of an operation, closure costs are then determined as expenditures in isolation, and not covered by any form of operating income, hence are difficult to include in an NPV model, unless an interest-bearing closure fund (sinking fund) is established (Jones, 2019) many years prior to closure. Due in part to this, many mining operations have typically underestimated the necessary expenditures associated with closure and post-closure activities.

Estimates of the costs of closure vary. They are typically driven by:

- the purpose for which they are prepared
- the organisation preparing the estimate
- the stage of the mining operation.

Estimating closure costs serves a variety of objectives, including:

- adhering to regulations set forth by the government (such as those of the Department of Mines and Petroleum and Environmental Protection Agency, 2011: Western Australian (WA) Mining Rehabilitation Fund). Elsewhere, potential liabilities are established by the government (e.g., New South Wales Department of Primary Industries, 2006)
- adhering to accounting standards (including AASB 137's undated provisions, contingent liabilities, and contingent assets)
- fulfilling the conditions for a stock market listing (KPMG, 2004)
- a financial analysis of the project (such as feasibility studies and due diligence).

Different organisations, including financial institutions, operational firms, state governments and third parties (consultants), can also create cost estimates to accommodate closure objectives.

In estimating the closure of a mine, different organisations typically arrive at different cost estimates. This is due to the fact that the organisations' reasons for quoting cost estimates and, consequently, their viewpoints on how the estimates are managed, differ from one another. The most recent Western Australia Act demands estimates for present disturbance, whereas Financial Provisioning to fulfill AASB requires estimates for 'future obligations' (Government of Western Australia, 2012).

The varying forecasting methodologies of closure costs employed by various estimators is another factor contributing to cost estimate differences for the same site. For instance, the closure cost estimate may, in some situations, include all of the progressive rehabilitation work done to date as part of the mine's regular production operations (and hence periodic operating costs), whereas in other cases, these activities are not included in the closure cost estimate.

Plessis and Brent (2006) developed a risk-based South African mine closure cost calculation model during the life cycle of a mine. The model is an extension of previous closure cost calculation methods that simulate risk using the Monte Carlo method, in order to simulate the effects of both internal and external changes associated with closure costs and post-closure monitoring and activities. It is demonstrated that the suggested risk-based model offers a means of improved understanding around the effects of uncertainty on closure costs.

According to a report by Deloitte (2007), a review of 27 mining businesses between the years 2000 and 2005 revealed a cumulative rise in physical assets of those companies of 75%, yet total closure provisioning climbed by 173% (to $11.6 B) during the same time. This again provides evidence that forecasting the closure and post-closure costs is somewhat inaccurate.

From the above, the fact that forecasting closure costs and post-closure remediation and monitoring is inaccurate at best, supports the view that applying a DCF NPV tool to determine closure and post-closure economics is flawed and inappropriate.

7. Tangible and intangible risks and uncertainties

Specifically relating to mine closure and post-closure activities, costs, benefits and outcomes, and providing additional support as to why DCF NPV will fail to adequately accommodate the evaluation of the end-of-life activities for a mine, it is necessary to consider the listed definitions below of risk and uncertainty prevalent throughout the mining life cycle. These definitions have been taken from Maybee et al. (2023) discussing ESG, and have been slightly reworded to account for the mine closure and post-closure timeframes, which also incorporate aspects of ESG.

Risks and uncertainties may either be tangible in nature, or intangible. Specifically defined, they reflect:

- **Tangible Risk** – Known Known: Risks that are known to exist, and if they eventuate, the varied outcome can be predicted with confidence (examples include under-/over-estimation of closure costs and associated post-closure monitoring activities and associated costs, over-/under-provisioning for closure costs, etc.).
- **Intangible Risk** – Unknown Known: Risks that are currently unknown, but if they eventuate will give rise to a varied outcome that can be predicted with confidence (examples include post-closure mild or severe flooding (environmental impact), ground instability inhibiting closure or post-closure activities or land use, predetermined land-use after mining impeded, etc.).
- **Tangible Uncertainty** – Known Unknown: Uncertainties that are known to exist but the varied outcome should they eventuate cannot be predicted with any level of confidence (examples include sovereign risk (degrees of nationalism affecting post-closure activities or land-use), and climate change and associated impacts and costs).
- **Intangible Uncertainty** – Unknown Unknown: Uncertainties that are not currently known, but may arise and be identified in the future. Due to their unknown nature, neither their occurrence nor the varied outcome should they eventuate can be predicted with any level of confidence (examples may include localised increase in concentration of a deleterious element contained in post-mining waste/rehabilitated piles, local, regional or global instability (such as sanctions, embargos, war, strategic imposition, etc.)).

Over the life cycle of an operating mine, there may be some justification for applying the DCF methodology of valuation, using the NPV tool to determine cash flows and values of the operating asset. The cash flow analysis may be informative when tangible risks (known knowns) are considered, because operational outcomes can be confidently predicted. Naturally, this supportive stance becomes a tougher argument as we move into tangible uncertainties and intangible risks associated with mining operations.

If we exclude the operating phase of mining and only consider the closure and post-closure phases (including provisioning for closure and post-closure activities), we can readily list the reasons why a DCF analysis is fatally flawed and that an NPV analysis is inappropriate. Many of the reasons have already been mentioned, but those associated with risk, uncertainty, tangibles and intangibles include:

- minimal to zero cash inflows, merely cash outflows (provisions and amounts above provisioning), at mine closure and post-closure, so discounting a 'cash flow' in this instance is actually merely discounting cash outflows (rehabilitation, reparation and post-monitoring costs). Discounting a forecast cost is a flawed concept
- including but also thinking beyond ESG, where a number of the closure and post-closure costs and associated activities may evolve into something other than what was originally planned, costed and possibly provisioned. At the costing and provisioning stage, these activities would have included a few unknowns (uncertainties and intangibles). Conducting a DCF and/or NPV on unknowns is intrinsically inaccurate (finding an appropriate valuation methodology for this provides scope for further work/research)
- the notion that, since discounting future cash flows relies on an appropriate discount rate, the discussion around the cost of capital (equity and debt), variable discounting, and the application of discounting to cash outflows alone comes to the fore. There is no methodology of determining an accurate and appropriate discount rate to apply
- the notion that, since closure and post-closure forecasting is a moving undertaking, being updated regularly over the life of the operation prior to closure, it is unlikely that the predetermined closure and post-closure costs and associated activities can be accurately predicted at any one point in time. It is expected that as the operation nears closure, many of the unknowns will be 'converted' or proven-up to be knowns, meaning that they can be more accurately predicted and hence provisioned. A DCF will not assist this process, and a NPV analysis will assist even less.

8. Conclusions and Recommendations

8.1 Conclusions

In the mining industry, reliance on traditional valuation techniques including the net present value (NPV) has frequently led to contentious asset values not only in mining operations, but also in mine closure, reclamations and post-closure activities. The mining industry is facing new problems, thus mining companies need to alter the way they view operations, particularly closure. The cost estimations of mine closure or post-mine closure is an important issue for a mining company. A greater emphasis on closure during the planning process is also required by a number of legal frameworks. Historically, the majority of mines have not had adequate financial support due to a variety of factors, including underestimating closure costs and adopting new ideas. The estimates for capital and operational costs created at different points in the mine's life are expenditures meant to produce income, and they are generally evaluated using a NPV technique. This supports the fact that applying DCF NPV and/or DNPV techniques to mine closure activities actually influences and drives the project owner's mine-closure-related behaviour, and not necessarily in a good way, especially around the under-estimation of ultimate closure and post-closure expenditures.

Intuitively, closure costs are expenditures that result in no income, other than potentially through land sales, and are difficult to include in an NPV model unless an interest-bearing closure fund is established.

To determine the anticipated closing costs, it is advised that a risk-based model be used along with the appropriate master rates, quantities, and escalation factors applicable to the particular project. Given it will provide an improved understanding of the project costs before the project is implemented, the risk-based model will be valuable to the mine's life cycle management. More case studies and discontinued projects should also be tested to see if the cost could have been forecast using this suggested approach. The impact of the indices and the percentage contribution that each index makes to each cost component should also be the subject of further study.

The DCF NPV method could not address or quantify the mine closure cost precisely. Therefore, a new risk-based model needs to be developed, e.g., an adapted Monte Carlo Risk Simulation technique that can incorporate risk within the model and generate a distribution of likely closure costs. This enables the mining business to decide how much risk they are ready to accept and then only make preparations for that risk.

DCF NPV valuation techniques usually overlook and are not able to integrate market risks such as commodity price, foreign exchange rates, geological and technical risks as well as non-systematic risk, such as the effect of climate change, heavy rainfall, floods, earthquake, ESG economics and others. The value of future obligations is heavily discounted by current valuation techniques, the DCF NPV in particular, obfuscating the actual costs of mineral extraction, mine closure and post-mine closure activities and economics. Since long-term obligations have been forcefully reduced, mining closure and investor behaviour may be misleading because the mining asset may be valued at an unreasonably high level, creating a potential financial burden for future generations and other stakeholders. Due to the project size, deference of state regulations, impact of worsening weather and environmental conditions, the cost estimation of mine closure and post-mine closure are also varied and need to be addressed depending on project-specific scenarios.

From the above, and the previous discussion in this paper, the DCF NPV technique is not a suitable method for mine closure analysis or for cost estimations of post-mine closure. There are many flaws in this technique that have been discussed in detail and, therefore, in conclusion, the DCF NVP method is not an appropriate technique for the evaluation and cost estimation of mine closure or post-mine closure economics. Although the DNPV method may address a few of the DCF NPV shortcomings, it is also not suitable for mine closure and post-mine closure economics because during mine closure, there is no revenue or income (other than through potential land sales), rather just expenditures and other outflows.

In conclusion, it can be put forward that a risk-based model such as the Monte Carlo Risk Simulation technique may be a better option for the economic estimation of mine closure or post-mine closure, but there remains issues around quantifying those risks and uncertainties. Furthermore, real options may provide an improved technique for the valuation of mine closure or post-mine closure, which can address real life scenarios of mining project risks and non-systematic risks for mine closure and post mine closure activities and outcomes.

8.2 Recommendations

Since the DCF NPV and the DNPV techniques are both unsuitable and fall significantly short in qualifying and quantifying mine closure and post-closure economics, activities and behaviours, the following recommendations can be proposed:

a. Research and further effort is required to determine an alternative and improved technique(s) to measure and quantify the mine closure and post-closure phases of a mining operation
b. The issues surrounding driving poor internal company behaviour as it relates to spending on mine closure throughout the mine life and the reliance on the DCF NPV technique must be addressed. Since the DCF NPV technique is inappropriate anyway, any recommended alternative technique(s) must also be assessed against the criteria of driving improved behaviour, notably internal company bahaviour, ensuring appropriate ongoing spend on closure. This improved behaviour will ideally deliver notably better mine closure planning integration into overall mine planning, and give rise to lesser end-of-life uncertainties and under-provisioned cash outflows
c. Associated with an alternative technique(s), the issues surrounding the cost of capital (WACC and discount rates) must be appropriately addressed, if discounting is recommended in that alternative
d. To assist in guiding the development of an alternative technique(s), greater industry consultation is recommended since industry practitioners will ultimately be the end-users of the alternative technique(s).

9. References

Bainton, N., Holcombe, S. (2018). *A critical review of the social aspects of mine closure*. Resources Policy, 59, 468–478. https://doi.org/10.1016/j.resourpol.2018.08.020

Belli, P., Anderson, J. R., Barnum, H. N., Dixon, J. A. , Tan, J. P. (2001). *Economic Analysis of Investment Operations: Analytical Tools and Practical Applications*. World Bank Institute Development Series, Washington, D. C.

Brennan, M. J.,Schwartz, E. S. (1985). *Evaluating natural resource investments*. Journal of Business, 58(2), 135-157.

Boyd, J. (2001). *Financial responsibility for environmental obligations: are bonding and assurance rules fulfilling their promise?* Resour. Future, 71.

CFI. 2023. *DCF Model Training Free Guide*. Updated March 13, 2023. https://corporatefinanceinstitute.com/resources/financial-modeling/dcf-model-training-free-guide/

Chambers, D. (2005). *The cost of mining: underwriting mine closure risk.* Corp. Ethics Monit. 17 (1).

Espinoza, R. D., Morris, J. W. F. (2013). *Decoupled NPV: a simple, improved method to value infrastructure investments.* Construction Management and Economics. 31 (5), 471–496.

Espinoza, R. D., Rojo, J. (2017a). *Towards sustainable mining (Part I): Valuing investment opportunities in the mining sector*. Resources Policy, 52, June 2017. s 7-18.

Espinoza, R. D.,. Morris, J. W. F. (2017b). *Towards sustainable mining (part II): Accounting for mine reclamation and post reclamation care liabilities*. Resources Policy, 52, June 2017, 29-38.

Espinoza, D., Rojo, J., Phillips, W. , Eil, A. (2022). *Decoupled net present value: protecting assets against climate change risk by consistently capturing the value of resilient and adaptable investment*. Sustainable and Resilient Infrastructure. 2023, 8, 323–336.

Davis, G. A (2002). *Economic Methods of Valuing Mineral Assets.* For presentation at the ASA/CICBV 5th Joint Business Valuation Conference, Orlando, Florida, October 24-26, 2002.

Deloitte (2007). *A Deeper Level of Detail-Improving the Reporting of Mine Closure Liabilities*. Deloitte, 14.

Dixit, A., Pindyck, R. (1994). *Investment Under Uncertainty.* Princeton, NJ: Princeton University Press.

DMIRS (2021). *Mining rehabilitation fund: yearly report 2020–2021.* Department of Mines, Industry Regulation and Safety. https://www.dmp.wa.gov.au/

Forget, M., Rossi, M. (2021). *Mining region value and vulnerabilities: Evolutions over the mine life cycle*. The Extractive Industries and Society. 8 (1), March 2021, 176-187. https://doi.org/10.1016/j.exis.2020.07.010

Gardner, N. A. (2015). *A discounted Cash Flow and Real Option valuation approach for Iron Ore Minining Company*. Master's Thesis. Department of Mining and Materials Engineering McGill University, Montreal, Canada.

Haque, M. A., Topal, E., Lilford, E. (2014). *A numerical study for a mining project using real options valuation under commodity price uncertainty*. Resources Policy, 39, 115-123.

Guj, P., Garzon, R. (2007). *Modern Asset Pricing — A Valuable Real Option Complement to Discounted Cash Flow Modelling of Mining Projects*. In Project Evaluation Conference. Melbourne, Vic, : The Australian Institute of Mining and Metallurgy (AusIMM).

Haque, M. A., Topal, E., Lilford, E. (2017). *Evaluation of a mining project under the joint effect of commodity price and exchange rate uncertainties using real option valuation*. Journal the Engineering Economist, 62(3),231-253.

Hawas, F., Cifuentes, A. (2016). *Valuation of projects with minimum revenue guarantees: A Gaussian copula–based simulation approach*. The Engineering Economist, 62(1), 90-102.

Jones, H .Chapter-19: Rehabilitation and closure. Cost Estimation Hand book. https://www.google.com/search?q=Chapter+19%3ARehabilitation+and+closure&oq=Chapter+19%3ARehabilitation+and+closure&aqs=chrome..69i57.16638j0j7&sourceid=chrome&ie=UTF-8

Hull, J.C., (1989). *Options, Futures, and Other Derivatives*. 3rd ed. Prentice Hall, Phipe.

Kivinen, S. (2017). *Sustainable Post-Mining Land Use: Are Closed Metal Mines Abandoned or Re-Used Space?* Sustainability 2017, 9, 1705; doi: 10.3390/su9101705.

Kragt, M. E., Manero, A. (2021). *Identifying industry best practice, barriers, and opportunities for mine rehabilitation completion criteria in Western Australia.* Journal of Environmental Management 287:112258. https://doi.org/10.1016/ j.jenvman.2021.11225

Laurence, D. (2006). *Optimisation of the mine closure process*. Journal of Cleaner Production. Vol 14, Issues 3 – 4, pages 285 – 298. https://doi.org/10.1016/j.jclepro.2004.04.011

Laughton, D. G., Sagi, J. S. Samis, M. R. (2000). *Modern Asset Pricing and Project Evaluation In the Energy Industry.* Western Centre for Economic Research Bulletin 56, September 2000.

Lilford, E. (2023). *Cost of capital and discounting – Risk and uncertainty.* Volume 14, Issues 3–4, 2006, Pages 285-298. Natural resources. Resources Policy, 80, January 2023, 103242.

Lilford, E., Maybee, B., Packey, D. (2018). *Cost of capital and discount rates in cash flow valuations for resources projects*. Resources Policy. 59, 525 – 531. https://doi.org/10.1016/j.resourpol.2018.09.008.

Lilford, E. (2023). *Natural resources: Cost of capital and discounting – Risk and uncertainty.* Resources Policy, 80. January 2023. https://doi.org/10.1016/j.resourpol.2022.103242

Lilford, E., Williams, D., Mackay, W., Garcia-Flores, R., Green, N., Kragt, M. (2022). *Current Tools, Techniques and Gaps in Evaluating Mine Closure*. CRC TiME Limited, Perth, Australia. https://crctime.com.au/macwp/wp-content/uploads/2022/03/Project-2.3-Final-Report_18-Mar-2022_approved-v2.pdf

Lima, A. T., Mitchell, K., O'Connell, D. W., Verhoeven, J., Cappellen, P. V. (2016). *The legacy of surface mining: Remediation, restoration, reclamation and rehabilitation*. Environmental Science & Policy , 66, 227–233.

Lopez, A., Toro, R., Paredes, A. (2018). *State of Practice of closure costs calculation:comparative analysis between guidelines*. 2nd international conference on planning for closure of mining operations.

McKnight, R. T. (2000). *Valuing Mineral Opportunities as Options*. Mining Millennium. Toronto, Canada: Content Management Corp.

Martinez, L., McKibben, J. (2010). *Understanding Real Options in Mine Project Valuation: A Simple Perspective*, Xstract Mining Consultants, Australia.

Maybee, B., Lilford, E., Hitch, M. (2023). *ESG Risk, uncertainty and the mining life cycle*.. The Extractive Industries and Society. Vol 14. https://doi.org/ 10.1016/j.exis.2023.101244

Mullins, D. W. (1982). *Does the Capital Asset Pricing Model Work?* Harvard Business Review. The Magazine, January 1982. https://hbr.org/1982/01/does-the-capital-asset-pricing-model-work

Nehring, M. ,Cheng, X. (2016). *An investigation into the impact of mine closure and its associated cost on life of mine planning and resource recovery*. Journal of Cleaner Production Volume 127, 20 July 2016, 228-239.

Okane. (2023). *Mine Closure and Reclamation*. https://www.okc-sk.com/2023/04/ (Accessed on 8 May 2023).

Plessis, A. D., Brent, A. C. (2006). *Development of a risk-based mine closure cost calculation model.* The Journal of The South African Institute of Mining and Metallurgy. Volume 106, Refereed paper June 2006.

Rawashdeh, R. A. I. (2023). *Feasibility of copper mines in Jorda*n. Arabian Journal of Geosciences (2023). 16:50. DOI:10.1007/s12517-022-11063-9.

CFI. 2023. *Mining Asset Valuation Techniques - Key valuation metrics used to value mining assets.* https://corporatefinanceinstitute.com/resources/valuation/mining-asset-valuation-techniques/ (accessed on 28 April 2023).

Salahor, G. (1998). *Implications of output price risk and operating leverage for the evaluation of petroleum development projects*. The Energy Journal 19(1), 13- 46.

Shafiee, S., Topal, E. (2008a). *Applied Real Option Valuation (ROV) in a Conceptual Mining Project*. In Proceeding of the 2008 Australian Mining Technology Conference. Queensland: CRC Mining, 173-187.

Samis, M. R., Davis, G. A., Laughton, D. G. Poulin, R. (2006*). Valuing uncertain asset cash flows when there are no options A real options approach*. Resources Policy, 30, 285–298.

Smith, J., McCardle, K. (1998). *Valuing oil properties: integrating option pricing and decision analysis approaches.* Operations Research, 46(2), 198-217.

Smith, J. E., McCardle, K. F. (1999). *Options in the real world: Lessons learned in evaluating oil and gas investments*. Operations Research, 47(1), 1–15.

Smith, L. D. (1995). *Discount rates and risk assessment in mineral project evaluations*. CIM Bull. 88 (989).

Sorentino, C. (1993). *Mine and property evaluation: risk analysis.* Notes for a graduate course. Master of Minerals and Energy Economics. Macquarie University.

Tiemann, C., MacDonald, V., Young, R.Dixon, K. (2022). *Rehabilitation and mine closure policies creating a pathway to relinquishment: an Australian perspective*. Restoration Ecology October 2022.

Vaidya, D. Investment Banking Resources - Terminal Value. https://www.wallstreetmojo.com/terminal-value/#understanding-terminal-value (Accessed on 25 May 2023).

Van Horne, J. (1977). *Financial Management and Policy*. Fourth Edition, Prentice/Hall International editions, 84–95, 197–225.