The Role of Real Options Theory in Capital Budgeting for Energy Projects in the Mining Industry

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Acronyms and Abbreviations

$	US Dollar
B-S	Black-Scholes
CAPEX	Capital Expenditure
CAPM	Capital Asset Pricing Model
CO_2e	Carbon Dioxide Equivalent
CSRD	Corporate Sustainability Reporting Directive
DCF	Discounted Cash Flow
DTA	Decision Tree Analysis
ESG	Environment, Social and Governance
GDP	Gross Domestic Product
GHG	Greenhouse Gas
IPCC	Intergovernmental Panel on Climate Change
IRR	Internal Rate of Return
LCCC	Levelized Cost of Conversion Carbon Curve
MACC	Marginal Abatement Carbon Curve
MCS	Monte Carlo Simulation
NPV	Net Present Value
OPEX	Operational Expenditure
PaR	Profit at Rik
PPP	People, Planet and Profit (Social, Environment and Economy)
PV	Present Value
ROA	Real Options Analysis
ROT	Real Options Theory
RSA	Republic of South Africa
SDG	Sustainable Development Goal
US	United States of America
VaR	Value at Risk
WACC	Weighted Average Cost of Capital

Plagiarism Declaration

This is my own unaided work; where sources have been consulted, proper references have been cited as per the APA referencing style. I declare that no portion of this work has been submitted or accepted in another university or institution of higher learning for partial fulfillment of any degree.

Signed: ………………………

Date: 31 May 2024

Exemplary Ethical Standards Declaration

This research work was undertaken to address identified gaps in the literature and the application of the results thereof. Data collection commenced after necessary approvals and ethical clearance certificate had been issued. For ease of and future references, the ethical certificate with ethics protocol number WBS/BA818533/729 was attached to accompany the research submission. The possible unintended consequences as a result of this study were considered, and none were found. The research does not involve animal experimentation or the use of human subjects, human tissue or other material, or patient records

Signed: ………………………

Date: 31 May 2024

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Abstract

Global warming and the changing weather patterns have resulted in developing and developed economies (public and private) to invest in low-carbon solutions and greenhouse gas emission reduction initiatives. The mining sector is one of the notable contributors to environmental degradation owing to its mining and processing activities, with a reported 4% to 7% greenhouse gas emissions globally (Delevingne, Glazener, Grégoir, & Henderson, 2020). Implementation of energy projects shows commitments to address climate change and global warming issues. Under the 2015 Paris Agreement, 196 parties (governments) pledged to limit global average temperatures well below 2°C and to limit the temperature increase to 1.5°C above pre-industrial levels (UNCC, 2024) (Delevingne, Glazener, Grégoir, & Henderson, 2020) (Bloomberg, 2017). The commitments and drive have since seen energy investments being incorporated as key strategic pillars in private, public, and state-owned businesses. This research focuses on the use of real options theory in evaluating capital intensive energy projects in the mining sector. The energy use contributes about three-quarters of greenhouse gas emissions globally (Agency, www.iea.org, 2024). The mining houses are expected to set up clear targets and implementation plans to achieve net zero by 2050. The journey to 2050 is enabled and supported by different guidelines such as GHG Protocols, Corporate Sustainability Reporting Directives, 17 Sustainable Development Goals, Intergovernmental Panel on Climate Change, Paris Agreements, Task Force on Climate-Relates on Financial Disclosures etc. Each role player is expected to devise a comprehensive and inclusive strategy to be certified net-zero by 2050. This can be achieved by developing business cases on its energy and GHG maturity journey based on actionable plans implementation and incremental intervention on a yearly basis.

The energy projects portfolio scope is wide, constituting among other things, energy security, alternative energies, renewables, energy management etc. However, the research case study is limited to investment valuations of energy efficiency projects for the process plant in the mining sector. Energy efficiency projects provide significant reduction in energy cost and greenhouse reduction. These projects are characterized by high capital costs and significant level of uncertainty owing to the uncertainty in policy position, policy evolution timelines, commodity prices and availability of tried and tested technical solutions. These constraints can be addressed through a risk-based approach which enables management flexibility to minimise potential

business losses and improve on gains. The losses can be attributed to reputational damage affecting share prices, loss of key customers and results in high sunk costs, should projects prove to be unsuccessful. The real option theory analysis, an effective technique in resolving uncertainty and enabling managerial flexibility could be the ideal solution, given its applications in the energy domain (Fabianek, Glensk, & Madlener, 2021), (Liu, Zhang, & Zhao, 2019) to address drawbacks of traditional valuation techniques whilst meeting business objectives and climate change commitments.

The implementation of energy efficiency projects ought to be practical, economically viable, and offer sustainable and lasting solutions. The climate change ambitions and set targets require several resources, such as human capital and funding to successfully achieve targets within the set timeframe. The mining sector operates in volatile market conditions with commodity (raw material and final products) prices affecting the cashflow and strategic projects deliverables. This volatility further exposes the weaknesses of utilising traditional valuation techniques in evaluating capital intensive energy projects. To support the good cause of curbing negative environmental impacts, and integrate sustainable development goals provide sustainable solutions, the real options theory is sought to deliver long waited results when compared to static planning strategy (Nadarajah & Secomandi, 2023). The effectiveness of real options theory can be achieved by comparing it results with traditional discount cashflow techniques.

1. Introduction

The real options concept was first introduced by Myers in 1977 (Bastian-Pirlo, Eduardo, Brandao, Raphael, & Orozio), as an extension of the already existing financial options theory (Bogdan, Bartlomiej, & Iwona, 2017). (Myers, 1977) investigated the possibilities of applying the options theory in non-financial applications. A real option is defined by (Chi, lI, Trigeorgis, & Tsekrekos, 2019) as a right, not an obligation, to undertake a specific task in future at a cost to a tangible asset. The specific task could be to delay, defer, abandon etc. a project when market conditions become unfavourable (Ampofo, 2017).

The development of real options theory (ROT) was necessitated by the inadequacy of traditional valuation methods application in capital budgeting for projects under uncertainty (Gharib, Berrado, & Benabbou, 2018). The ROT analysis has since been used in different sectors, including information technology, natural resources, infrastructure projects, healthcare, renewable energies, and most recently in mainstream mining projects (mine valuations). The employment of the real options techniques is still lacking behind when evaluating energy projects in the mining sector. Real options theory creates and enhances value by enabling management flexibility. The flexibility built into the model assists decision makers to harness value from investments by capturing future uncertainties in a project. The trade-off between making long term investment decisions or holding off on investments in the face of uncertainty is the problem facing most mining companies.

Real options come in handy in addressing this dilemma through enabling interventions to compare profitability and risk of the energy projects. These energy projects aim to create shared value for stakeholders. Real options analysis was previously utilised for investments analysis in the information (IT) sector because of high uncertainty in future development of the products in this sector (Rutten, Steenverd, Lansik, & Hogeveen, 2018). In the same breath, given the uncertainty in the mining sector due to market fluctuations outside of the organization’s control, the ROT method is worth exploring. Thus, investing in energy projects can be seen to be analogues to IT investments because of the similarities in future uncertainties. The mining processes use different energy commodities, which are subject to price volatility, that depends on the movement of prices in the market and to a certain extent, on the regulatory bodies to determine the energy prices. These are concerning factors due to the uncertainty involved. Moreover, the mining commodities (final products) are also volatile, resulting in a more complex uncertainty. These fluctuations affect the energy projects because they are funded through the profits from the mine. The mine's poor performance can result in a direct impact on the optimal planning and implementation of energy projects in a capital constrained environment.

Given the nature of the uncertainty embedded in the mining sector, the ROT enables management to gather more information to make informed decisions. The ROT is often thought of as an alternative to the financial options. However, these two methods can be deployed as a combination depending on the nature of the investment and the uncertainty element thereof. Furthermore, this area of research has attracted different sectors because of its capability to develop unique and effective solutions. It is for this reason that (Smit & Trigeorgis, 2017) suggests the use of strategic net present value (NPV) which integrates real options and game theory to portray strategic decisions under management theory. The integration of game theory with strategic NPV is aimed at benefiting from trade-off between competing constraints, particularly on competitive uncertainties (Smit & Trigeorgis, 2017). This among other things suggests that application of ROT in real life applications becomes more relevant and necessary. Therefore, the mining sector can benefit hugely through the use of ROT techniques in investment valuations.

1.1 Background of the Study

The main issue faced by the mining sector is scarcity, where there are unlimited needs/wants and limited resources. This issue calls for an optimal allocation of resources to sustain the business performance and enables it to be an ongoing concern. The factors of production need to be deployed efficiently to afford the business a dynamic and adaptive approach to manoeuvre in the market during unfavourable conditions. The allocative efficiency can be achieved through understanding market conditions and the nature of possible outcomes. The mining (including concentrators and mineral processing plants) industry is complex and requires different inputs ranging from primary raw material, over-the-fence energy commodities and internally generated energies (bi-products). Raw material and over-the-fence energy purchases normally fall outside the company's control and bring about volatility and uncertainty in the business. The contributing factors to the uncertainties can be attributed to the nature of how the inputs are traded. (Bogdan, Bartlomiej, & Iwona, 2017) make an example of the price volatility which has a direct impact on the profitability of the organization, and the success of projects underway.

In order for the business to remain relevant to its customers and enhance its competitiveness in the sector, it ought to invest in the future. The future investments differ from the day-to-day operational requirements, on the nature and amount of capital expenditure (CAPEX) required, in line with the company's strategic objectives. The capital allocation needs to consider various competing projects, and prioritise them to maximise shareholder value and be cognisance of the impact it has on the society and the environment.

The traditional valuation techniques, discounted cash flow (DCF), such as net present value (NPV), internal rate of return (IRR) and payback techniques have been used in evaluating energy projects of capital nature. DCF methods consider the time value of money and are widely used in practice to determine the present value of the expected cashflow of investments (Sipila, 2022). The NPV of the project discounts the future cash flows using the risk-adjusted discount rate. The DCF techniques are characterised by high risk, irreversibility, uncertainty and non-flexible elements (Agaton & Karl, 2018). The author, (Trigeorgis, 1995), highlights that the DCF method is not adequate for capital budgeting for investment valuations under uncertainty because it lacks the management flexibility to revise investment decisions when the market conditions change. Traditional valuation techniques are used where cashflow is predictable and forecasts are certain and they have a tendency to ignore management flexibility. (Vintila, 2007) shows that the use of DCF does not consider all important aspects necessary in evaluating the investment. Considering the complexity of the mining sector, consisting of both operational and strategic projects. The real options theory can be used in conjunction with DCF techniques to address its drawbacks and enable management flexibility. This flexible approach is a necessity to address the issue of scarcity when allocating funds for capital projects, capture uncertainty and give management control throughout project phases.

The alternative approach by (Culik, 2016), suggests that ROT gives management flexibility to undertake activities in a fast-changing and unpredictable environment given that such activities are in the best interests of the organisation. Management is, however, required to undertake such actions taking into account the accuracy of information and making adjustments for changing market conditions. ROTs enable management to alter investment decisions in response to changing market conditions. (Trigeorgis, 1995) argues that in DCF, management involvement is more passive and lacks much needed intervention. Thus, the use of ROT empowers the managers to become more active role players in the investment process.

1.2 Context of the Study

The real options theory is looked at in the context of evaluating investments in the mining industry, paying specific attention to energy projects given limited resources (e.g., budget) and competing constraints (e.g., other projects) and the lack of technology readiness within the space. The role of real options in such applications is relevant since the hypothesis highlights that this approach will derive more value for the organisations when compared to the traditional valuation techniques.

1.3 Research Problem

The use of traditional investment valuation techniques is limiting the value that can be harnessed by the industry experiencing high volatility in final product prices and raw material inputs costs. The DCF techniques does not enable the management flexibility for investments under uncertainty, for example after the projects have already been launched, it deprives the business an opportunity to respond to market changes, thus losing an opportunity to capture value for the greater benefit of the organisation. This may result in high sunk costs should projects fail due to uncertainties. (Li, Zhang, & Wang, 2021) define sunk cost as the initial capital outlay associated with the investment project. In the context of real options exercise price is determined by the initial outlay, of which part of it is the sunk cost (Li, Zhang, & Wang, 2021). In addition, energy projects are susceptible to the energy commodity movement prices which make them more volatile. The lack of using ROT is detrimental to the organisation when evaluating projects because projects that matter the most are not given the much-needed priority and urgency. The literature (Barton, 2011) shows the slow adoption and application of ROT when compared to DCF in capital projects evaluation, and DCFs continue to dominate in real life application even though it has drawbacks.

1.4 Research Questions

The research questions below aim to expand on the following areas particularly in the context of energy projects valuation in the mining sector.

The research questions are divided into three themes, in the context of real options theory analysis.

Theme 1 (Main Objective)
<u>Real Options vs DCFs effectiveness.</u>

- Is the real options theory a suitable approach for evaluating energy projects?
- Can real options theory be used as a suitable and more effective replacement and/or in conjunction with DCF to capture full value of implementing capital intensive energy projects?

Theme 2 (Supplementary objective)
<u>Theoretical Frameworks and costs associated with real options analysis.</u>

- What theoretical frameworks are widely used and accepted (by the industry) to evaluate the energy projects?
- Are there software deployment, operations and maintenance costs associated with justifying the utilisation of real options theory?

Theme 3 (Supplementary objective)
<u>Real options effectiveness and Management viewpoint</u>

- What complexities and hindrances exist when applying ROT in practical applications?
- How effective is real options theory in addressing the market changes?
- What is management’s view on the real options theory analysis as an alternative to DCFs?

1.5 Hypothesis

H1: *The use of real options theory in capital budgeting enables the organisations to unlock the value entrenched in the energy projects.*

H2: *The lack of adoption of real options analysis by investors and managers is attributed to its valuation complexity.*

H3: *The few real-life application of real options analysis makes it difficult to feature and compete with traditional methods in evaluating investments.*

1.6 Research Objectives

The objectives of the study are:

1. To conduct a comprehensive literature review on real options theory, its application in capital budgeting, and to highlight gaps and areas for improvement.
2. To evaluate the applicability of real options theory in evaluating energy projects in the mining industry.
3. To empirically expose ROT value by comparing the results of real options theory with traditional valuation techniques. This can be achieved through evaluating specific project (on a predefined case study) using both techniques.
4. To establish if there exist a hybrid (combination of ROT and DCF techniques) approach that yields competitive valuation results. The analysis is concluded based on the literature review focusing on the energy domain.
5. Through conducting the literature review and result analysis (of this study), answer research questions and contribute to the academic body of work.

All the above research objectives are based on the main (and supplementary) research objectives. They are phrased in such a manner to assist the researcher to draw a correlation and interrelations between research question themes, hypotheses and research objectives. This shows that all three pillars cannot exist independent of each other.

1.7 Relevance of the Study

Mining companies are severely affected by market conditions outside of their control and end up operating within tight budget constraints, thus limiting their growth to invest in long term strategic projects necessary for their continued existence. The energy and GHG emissions reduction projects are now considered to be under a strategic portfolio owing to achieving sustainability goals and climate change targets. The underutilisation of real options theory at an industrial scale in favour of the traditional methods when evaluating projects potentially results in sub-optimal results, this impacts the investment decision making process. The significant improvements from real options approach give hope that investing in energy projects can be of value to the business. Energy investments in mining operations are crucial to ensure competitiveness, as well as positioning the organisation in a reputable position when it comes to decarbonisation and achieving net zero and carbon neutral emissions targets. The use of real options theory in investment analysis has proven to be valuable, thus the mining sector can also benefit from this approach in its energy projects.

In addition to remaining competitive in operational cost management, companies require that the organisation anticipates the potential global move into greener and environmentally friendly ways of mining and processing minerals to reduce GHG emissions. These expectations and commitments reside with all mining houses (both listed and non-listed in the stock exchange) that find themselves operating within sovereignties that are the Paris Agreement signatories (Nations, 2023). As part of the global community, the mining company will find itself in the middle of the global movement towards the European Green Deal of achieving climate-neutrality by 2050. Mining operations such as coal, iron ore and heavy mineral concentrate use different energy commodities giving rise to the climate change effects, and they have a role to play in improving their energy projects portfolio yielding to reduced emissions, whilst considering the CAPEX constraints.

The costs of not implementing energy value plans are high for diversified energy intensive users such as mining and processing plants. The cost of doing nothing can be translated into lost improvement opportunities and, the increase in penalties resulting from environmental non-compliances. Simply put, (Wesseler & Zhao, 2019) make a practical example in the "wait option" for the agricultural applications where the delay in approval of new technologies required to reduce the use of pesticides. This delay resulted in losing the opportunity to reduce GHG, and to increase crop yield which subsequently resulted in business profitability. (Agency, iea.org, 2020) highlighted that the steelmaking sector (direct impact of vertically integrated mines) is leading in CO_2 emissions and second in energy consumption in the world. Steel making works are energy intensive. However, over the years, the implementation of energy efficiency projects has seen a reduction of about 60% in the intensity measured against the tonne of crude steel since 1960 (Association, 2021). The same effort can be applied in the mining sector, given that the nature of loads are comparable in both sectors.

Moreover, these mining operations directly affect the green steel climate change requirements due to these commodities being an integral part of the steel value chain, as viewed to be upstream scope 3 by steelmakers. In the emission reduction context, scope 3 is defined by (CarbonTrust, 2024), (Barrow, et al., 2013) as indirect emissions that occur in upstream and downstream of the organisation, not covered by scope 1 and scope 2. The entire value chain of a typical organisation is depicted below to provide guidance on scope categorisation and reporting purposes.

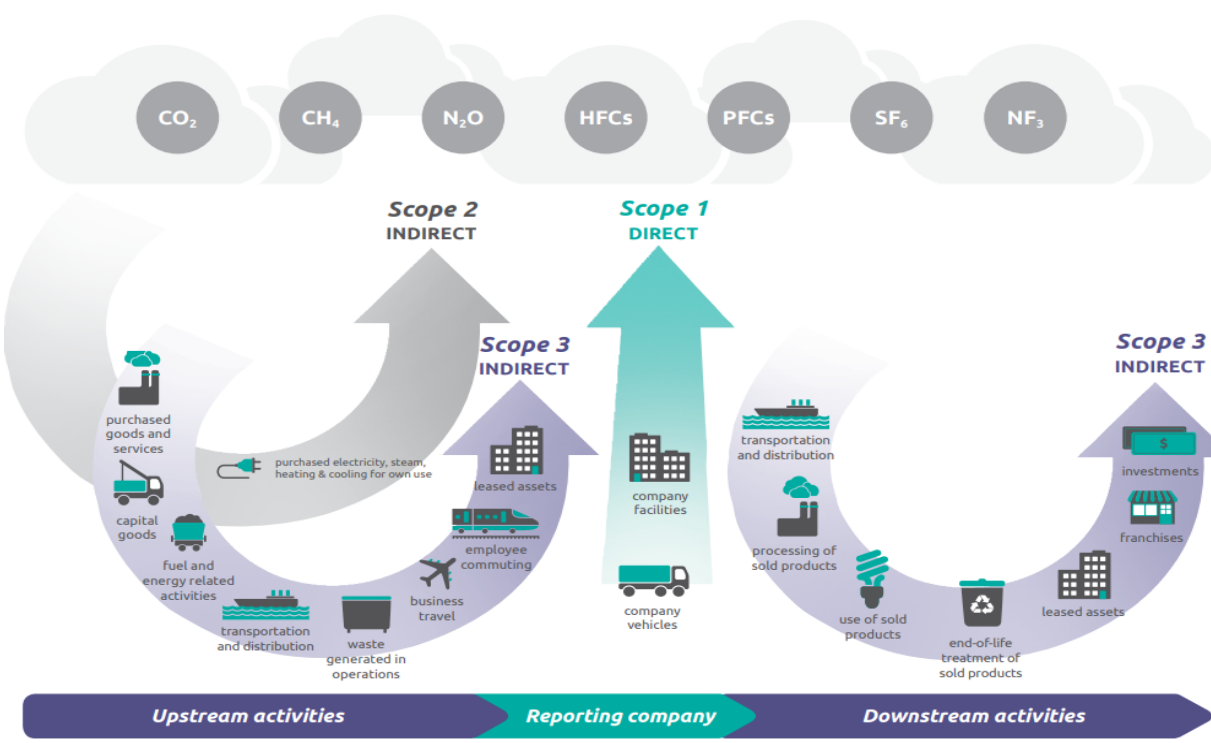


Figure 1 The GHG Protocol scopes of emission across the value chain (Barrow, et al., 2013).

Furthermore, the figure below is extracted from (CarbonTrust, 2024) where a summary is drawn to illustrate what ach scope mean, and how it can be categorised in the context of emission reduction.

Figure 2 The GHG Protocol's Corporate Value Chain (Scope 3) Standard identifies 15 categories (CarbonTrust, 2024).

Hence the mines will need to evaluate energy investments to support their upstream and downstream customers achieve their green commitments, to show their commitments in sustainable development goals and attainment of GHG emission emissions targets. There is sufficient value entrenched in efficiently implementing energy projects, at the right time using the right resources. Real option theory as a technique has proven to be useful in other sectors, it can thus be replicated in energy projects.

1.8 Delimitation of the Study

The study is limited to the application of real option theory in project valuation scenarios within the mining industry, focusing particularly on the energy projects. The energy projects valuation include energy efficiency improvements, electrification, cogeneration, alternative energies, renewable energies, and backup power projects. The study aims to highlight the application of real options theory in the mining operations – paying specific attention to energy efficiency and fuel switching projects. The application and testing thereof, is based on a single integrated mining company due to the nature of the sensitive project information. Other mining companies are unlikely to provide information which may be deemed to be exposing their competitive advantage and sensitive commercial information, this is because the author of this report is currently employed within the sector. The study further limits the application of real options theory to two models, namely, binomial lattice and Black-Scholes models. This should provide a richer and more in-depth analysis of the available data set.

The study also focuses on a quantitative analysis of real options in capital budgeting and utilise data from a business case of a mining company to evaluate energy projects using ROTs. The objective is to conduct result analysis and draw conclusion based on empirical evidence. The author is cognisant of possible glitches in obtaining approvals for data usage and the limitation this can have on the study. If time permits, Monte Carlo Simulations (MCS) will also be used to test the theory using generated random numbers and see the applicability of these analysis in real options theory. The use of MCS will be adopted, provided the author have time to conduct simulation. The reality suggests that studies and scenario testing are generally limited due to the time availability of the researcher, also this study is not an exception to the time constraints.

1.9 Structure of the Research

The structure begins by stating the introduction and background to the study, give the research hypothesis and synthesise the problem statement confronting the author. Thereafter, it continues to conduct a thorough literature review with the intention of identifying the gaps in the area of research. The literature review is followed by the research design which expands on the theoretical frameworks and the approach in solving the problem. The adopted approach is used to conduct quantitative analysis on the existing mining plants faced with energy projects with limited funding.

The empirical results, the case study outcomes is presented in the graphical form in order to compare the effectiveness of real options theory in capital budgeting against traditional investment valuation techniques. The recommendations on the future work are highlighted with the intention of expanding the study to cover areas that fall out of this study, as highlighted in the scope and limitation sections.

The structure can be summarised using the below flowchart.

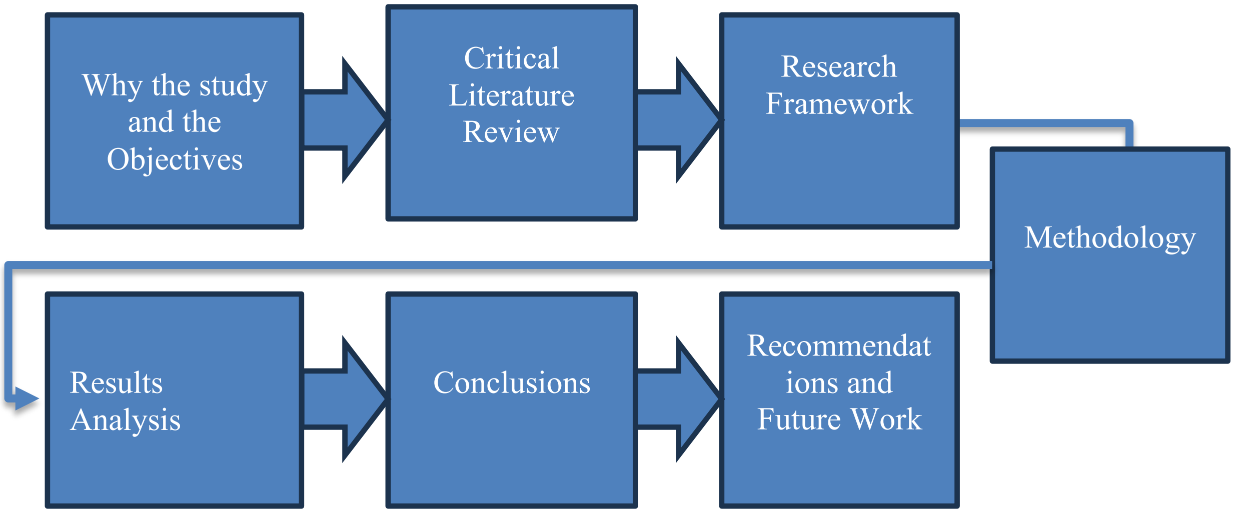


Figure 3 Research structure - flow chart.

2 Literature Review

2.1 Introduction

The literature review is conducted by focusing on theoretical concepts of real options highlighting the benefits and drawbacks in real life applications across different sectors of the economy. The introduction of real options as a theory emanating from financial theory is highlighted. Thereafter real options theory is contrasted and compared with traditional investment valuation techniques. The literature review enables the researcher to understand the body of work conducted in the area of study by other scholars and researchers, understand methods and theories utilised, and the research effort required to avoid reproducing the analysis already produced and published. Since the research focuses of the application of real options theory in capital projects found in the mining sector, a brief glance discusses the impact of a specific sub-cluster of minerals sands in the economy and a drive to protect the environment whilst maintaining its position to be a profitable company maximising shareholder wealth.

2.2 The Structure of Literature Review

The structure of this section covers the following contents:

- Review a specific sub-cluster of the mining sector, namely the mineral sands.
- Review uncertainty and managerial flexibility in the context of energy projects and highlight case studies without performing results analysis. This is achieved through conducting effective literature review and concluding based on the findings from the reputable literatures.
- Define and discuss capital budgeting in general
- Introduce and discuss discounted cashflow models – focusing on theoretical abstracts, applications and limitations.
- Cover the wider spectrum on the real options fundamentals, history and origins, then converges towards the application of real options theory in capital budgeting in the industry.
- Compare and contrast real options theory with finance options techniques.
- Summarize the section by combining ROT and DCF techniques for capital budgeting

Further to theoretical frameworks and concepts, the literature review is based on the papers that have already employed the real options theory in practical business cases. This assists the researcher to establish the practicality of the theory, focusing particularly on Black-Scholes and Binomial Lattice models.

Both conceptual and applied business science cases enable the researcher to establish the research gaps and potential areas of future work and recommendations.

2.3 Effective Literature Review

Effective literature review plays a significant role in shaping the output and quality of the research work. The below points suggested by (Umar Sekaran, 2016) aim to re-emphasise the position to be taken by any researcher conducting effective literature review, and what effective literature review presents.

- It helps to avoid a phenomenon termed "reinventing the wheel" from manifestation. The occurrences of such phenomenon results in the situation whereby the researcher falls for a trap of recovering what is already known about the subject.
- It assists the researcher to introduce relevant terminology and definitions applicable to the particular subject, constrain them within the context of study.
- It enables an environment to obtain useful insights on the research methods and techniques used to develop questions to similar research questions, to that of the researcher.
- It enables the researcher to relate findings to the findings of others in the similar topic or subject.

The above functions are very crucial to guide the researcher and optimise the use of time and effort.

2.4 The Mining Sector – At Glance

The mining sector plays a crucial role in the modern economy, creating jobs for different classes of the society spanning from unskilled workers to the executives. Mining activities date back from ancient times as the part of human civilisation, during the times when the mined commodities were used as a form of exchange in the economy. The mining sector has developed over time, taking advantage of technological advancements and developments through different phases of various industrialisation revolutions. The mining sector remains relevant across all numerous phases of human civilisation.

Mining activities are highly energy intensive in extracting, processing and converting raw material final into products. The energy use is directly proportion to the GHG emissions, and the quantity of emissions depends on the energy source and the location where energy is utilised. Furthermore, high energy consumption give rise to high costs and drives up overall mine operating costs. The high operating costs affect the mine's profitability. The lack shortage of capital availability affects future mine growth and puts pressure on spending, especially for strategic and enabling projects such as climate change initiatives.

The mining sector is also volatile due to the fluctuations in supply and demand of the products. Factors that affect the sector include geopolitics and economic stability. The literature attest to the volatility in (Bogdan, Bartlomiej, & Iwona, 2017), where the industry is highlighted to be prone to volatility in its product prices. Thus, the sector is sensitive to financial decisions relating to day-to-day operations and long-term strategy. The survival of the business among other things, depends on profitability of the business, execution of the strategy and investing in the future projects.

In addition, a common practice looks at diversifying the portfolio of products through the adoption of switch options (Bogdan, Bartlomiej, & Iwona, 2017). The concept of switch options in the context of (Bogdan, Bartlomiej, & Iwona, 2017) allude to changes in the input raw material, product offerings, product processes and other factors of production. The investment decisions lie with management, who are entrusted with the responsibilities to run the operations as per the strategic pillars agreed upon by stakeholders. This speaks to the management flexibility built into business operations, and can be expanded further with real options theory in this paper.

2.5 Capital Budgeting

Capital budgeting is the process of identifying and valuing medium to long term investments which require significant amount of funds (Barton, 2011). The projects categorised under this definition are referred to as capital projects. The business embarks on a capital budgeting process to identify and prioritise future projects and investments to be undertaken. A typical business may categorise project as capital projects based on a specific threshold on the project cost, implementation time and life of the asset. For example, in the mining sector the list could include mine expansion, research and development works, energy projects, safety initiatives etc.

The acceptable and auditable process is necessary to allow these projects to be valuated to establish its effectiveness (and prioritise thereof) in the business. Traditional investment valuation techniques (i.e., NPV) were primarily utilised to assess the attractiveness of the project. The traditional approach of capital budgeting contrasts projects regarding profitability and their impact on firm value. The same capital budgeting and analysis is applied energy projects. The energy projects normal falls a prey in this exercise given it does not give immediate benefits. The energy projects when evaluated using the same conventional approaches lacks the competitiveness due to the nature of the projects. The energy projects when compared to other projects such as production, metallurgical and/safety inclined initiatives, they do not provide a good business case as energy is perceived as an enabler in the process as opposed to direct production line.

Furthermore, the lack of strong business case such as shorter payback time, strong positive NPV and competitive internal rate of returns disadvantages energy projects. The contributing factor among other things is that energy projects return on investments is normally measured against factors that are not directly correlated to the nature of projects. For example, an investment in improving energy performance in a process plant is less compared to a project to improve metallurgical recovery, this is due to the magnitude of the savings harnessed from implementation of these two projects. Thus, the use of real options theory valuation techniques can enable managerial flexibility and position energy projects in a competitive edge. The ROT approach can further extract value entrenched in energy projects valuations when compared with DCFs techniques.

2.6 Traditional Valuation Techniques

Traditional investment valuation techniques and tools are widely used in real application because of the ease of implementation and reduced modelling and mathematical complexity. These techniques have since developed over time, allowing practitioners to create summarised templates, various sensitivity analysis tools, and computations. However, these techniques have not adequately addressed management flexibility to optimise the project value resulting from the uncertainty embedded in the project. Traditional valuation techniques are divided into payback, net present value (NPV) and internal rate of return (IRR). These techniques are normally computed to test the profitability of different projects. They further play a crucial role in prioritisation and ranking of projects in capital constrained environments.

2.6.1 Payback

Payback is the most basic traditional investment valuation technique, computed by counting number of years (or months) it takes for the cumulative cashflow to equal the initial investment of the project. The payback method ranks the projects' priority based on the shortest payback period and regard such projects as the most appropriate and attractive for investments decisions. (Brealey, Myers, & Allen, 2006) highlights the limitations of this technique, of which one of them is the inability to consider the investment cashflows after cut-off date. The investment could be the least appropriate for the effort and monies spent, but this is ignored owing to the nature of the technique used. The other basic limitation of this method is that it does not give a full investment view since it does not consider the time value of money (inflation pressures) especial if it extends over a year.

(Al-Basha, 2023) discusses the alternative approach to the traditional payback period by introducing the provision for a possibility that the project may end prematurely, and underlying asset sold.

2.6.2 Net Present Value

NPV as the sum of discounted cashflow (DCF) of the investment over period minus the initial payment of the (same) investment (Rutten, Steenverd, Lansik, & Hogeveen, 2018). The discounting rate is normally denoted by the letter, i and NPV can be illustrated mathematically as (Gardner, 2015):

$$NPV(i) = -C_0 + \sum C_t V^t$$

where:

$V = \frac{1}{1+i}$

$i =$ discount rate,

$C_0 =$ initial capital investment at time, $t = 0$

$C_t =$ cashflow at time t: where t is the life of the project.

The NPV outcomes are simple to analyse because the commonly acceptable interpretation is such that if two (or more) projects are compared, the one with a higher positive NPV is more profitable and should be preferred than other projects. To compute the NPV, the initial investment and the projected future cashflows over time need to be known. The discount factor, V, reduces the future cashflow by the discount rate as shown in the formula above. The NPV works on the assumption that the value of money is more valuable today than anytime in future because the existing money can be invested immediately to start earning interest. The arguably downside of the NPV is the fact that its value is derived from the projected cashflow and the projected opportunity cost of capital, thus the manager's preference could affect the profitability of the project with little to no interference once the project has started.

The universal understood NPV analysis is to invest if the NPV > 0, that is when expected future cashflows exceeds the initial investments (Kyng, 2012). Any other outcome is deemed not attractive and is not worth considering, hence no investment is advised. A special case exists where NPV = 0, this outcome is normally considered indifferent to accept or reject the project.

NPV is normal employed where resource availability is not constrained. NPV method has been used in practical applications because, when compared to other DCF techniques, because of (ICSI):

- Easy interpretation of the results, making decision making process less complex
- Incorporation of the time value of money principle in calculations.
- The cash flow is considered throughout the project life.
- Drives the business objective to maximize shareholder wealth.

The drawbacks of NPV are (ICSI):

- Difficulty to compare projects with different durations.
- Difficulty to determine the appropriate discount rate.
- Requires special skills to perform mathematical calculations.

However, using ROT analysis, the projects with negative NPV could be considered because the company could abandon and modify if conditions are unfavourable. So, to say, the project can be implemented at phased approach even though the NPV is not as attractive, this can be in the case of prefeasibility studies. Should the studies show more value, and uncertainties improves, the managerial flexibility can be exercised. Furthermore, opportunities could be expanded and/or deferred with favourable outcomes. The real options approach provides the flexibility to start (early), stop and reconsider the investments decisions owing to available information at a specific point in time. In addition, the scalability of the projects once proven to be profitable and/or meeting the stakeholders' objectives is possible using ROTs, thus maintaining its competitive advantage as a first mover.

2.6.3 Internal Rate of Return

Internal Rate of Return (IRR) is also commonly used in evaluating the projects and investments. It is basically the effective rate of interest that equates NPV to zero, i.e., NPV(i) = 0. The analysis of IRR follows the same logic with the NPV, with the specific interpretation outlined below. The NPV is discussed in great lengthy below. For a simplified calculation, IRR can be determined by hand calculation setting, NPV = 0, and substituting discount rate with IRR, and solve the equation. However, in a more complex analysis, it is tedious and sometime impossible to compute IRR using the manual approach. The IRR is computed using sophisticated tools such as a financial calculator, Excel etc.

The output of the analysis is not enough without the interpretation of the IRR value. The guidelines below highlight how IRR is interpreted in practice.

- If IRR = 0, the investor received no return on investment.
- If IRR < 0, the investor lost money on the investment – a bad investment option.
- If IRR > 1, the investor received a positive return on the investment

Technically, IRR should at least be equals to or greater than weighted-average cost of capital (WACC) for the investment to be attractive. Since IRR is calculated from the NPV, it has the same advantages as NPV method. IRR is not immune to critics and drawbacks, (Gardner, 2015) briefly reports on the researchers' views on the pitfalls of using the IRR method. One of the crucial drawbacks applicable to a mining project is such, IRR does not have the ability to differentiate between projects of different sizes. Hence, if projects are competing for CAPEX on the bases of IRR, more valuable projects can be easily overshadowed by small projects with higher IRR. Furthermore, IRR assumes the compounding effect on the investments at the rate earned by the investment during the project's economic life. This assumption is misleading when the IRR is different from the average rate of return (ICSI).

2.6.4 Weighted Average Cost of Capital

The most acceptable and widely utilised techniques to calculate the discount rate use the weighted-average cost of capital (WACC). The mathematical formula and parameters are discussed in detail by (Martinez, Batistela, & Simões, 2019)

$$WACC = Ke \frac{Kp}{(Kp + Kt)} + Kd \frac{Kt}{(Kp + Kt)}(1 - t)$$

Ke is the cost of equity.

Kd is the cost of debt.

Kp is the market value of equity.

Kt is the market value of debt and T is the applicable corporate tax.

2.6.5 Capital Asset Pricing Model

Similar to the WACC, the capital asset pricing model (CAPM) is used in investments to assess the investment risks. It compares the risk-free market rate in the economic sector with the project-specific risk and adjust the equation with systematic risk and country premium risk where the project is undertaken. The mathematical formula and parameters are discussed in detail by (Martinez, Batistela, & Simões, 2019)

$$CAPM = R_F + \beta(R_M - R_F) - \alpha_{BR}$$

$$\beta = \frac{\rho(R_j, R_M)\sigma_j}{\sigma_M}$$

where

CAPM is the risk adjusted discount rate of capital asset.

R_F is the risk-free rate.

β is the beta risk of capital asset.

R_M is the expected market return.

$(R_M - R_F)$ is the market risk premium.

α_{BR} is the country premium risk.

σ_M is the standard deviation returns on market portfolio.

σ_j is the standard deviation returns on capital asset j.

$\rho(R_j, R_M)$ is the correlation coefficient of returns on capital asset j and market portfolio.

2.6.6 Discounted Cash Flow: General View

Discounted cash flow shares common features with the above valuation techniques, particularly the NPV, it works on the similar principle summing all future cashflows and discount them to the present time. The assumption built on DCF is such that project constraints (scope, schedule, costs etc.) is fixed for the duration of the project.

If the value of the DCF is higher than the investment cost, the business case may be considered as attractive.

2.6.7 Benefits of DCF techniques

It is by no coincide that DCF methods are leading the charts as the most used techniques in investments valuation analysis. (Gardner, 2015) highlights advantages of the DCF method:

- Simple and consistent valuation criteria across different projects
- Ease to explain to decision makers.
- Scalability
- Consider time value of money.
- Widely deployed and understood by investors and decision makers.
- Mathematically rigorous, less complex due to availability of computational capabilities

In addition, the other advantage that allows the DCF to remain relevant is the lack of simple alternative to evaluate the projects.

2.6.8 Limitations of DCF techniques

As much as DCF is deployed widely, it still does not offer the full value in project investments valuation. (Ampofo, 2017) attribute such limitation to the inability for the discount rate, i, to cater for multiple uncertainties found in the mining industry. The author, (Ampofo, 2017), argues this point because the discount rate is made up of three components, namely:

- Risk-free interest rate or government bond
- Market risk premium
- Country risk (outcomes of the rating agencies such as Moody's and Standard & Poor)

DCF assumes that the conditions remain the same throughout the project lifecycle, with a constant discount rate. The discount rate comprises of internal and external risks affecting the project, however due to the assumption built in the DCF methods, the technique fails to discriminate between these two types of risks (Ampofo, 2017). In cases where market conditions changes, DCF methods fail to intervene to improve project value or mitigate potential loss. Hence, the benefits of utilising real options theory analysis are paramount as it gives management flexibility to intervene with winning strategies.

DCF methods remain the most utilised techniques in the valuation analysis. The real options theory aims to complement these techniques as opposed to replacing them, where practically possible. The literature suggests that real options are an extension of DCF methods, which then differentiates itself by making provisions for future uncertainty and management flexibility. In order to use ROT as an alternative or combined with the DCF methods, the real options, its computation, and application thereof ought to be known to the practitioners performing the analysis. Prior utilising real options as a replacement of DCF, (Ampofo, 2017) highlights contributions by other scholars on suggestions to improve the DCF methods.

The methods that were suggested talks about affording managers options to:

- Create multiple discount rates for different projects.
- Create multiple discount rates for different risk factors.
- Use weighted cost of capital (WACC) to determine discount rate.

The traditional valuation techniques use discounted cash flow methods in capital budgeting, even though this method is limited to the fact that the risks identified during the course of the project remain part of the project. (He, 2007) and (Gardner, 2015) highlight further DCF drawbacks to be:

- Difficulty in estimating (with certainty) future cashflows of the project owing to non-deterministic factors affecting the cashflow.
- Capital costs (already invested) is irreversible.
- Limitation in the use of the discount rate in the DCF formula, the discount rate does contain estimation errors, which can lead to misleading results.
- DCF lacks the managerial flexibility element to intervene to ensure projects are profitable or losses are mitigated.
- Assumptions made on cashflow projections and manager's operating strategy are inflexible and remain the same for the duration of the project.

2.7 Options Theory

2.7.1 Financial Options

Financial markets divide financial options into two types namely, put and call options. (Hull, 2021) defines a call (put) option as an option that gives the holder the right, not the obligation, to buy (sell) a specified asset (with a stock price, S_T) on a set date in future for a specific price. The specified price is called strike or exercise price, K≥ 0. Options are further classified as American and European options. The clear distinction between these options is based on whether they can be exercised exactly at or any time before the expiry date, T. The American options can be exercised at any time up to the expiration date whereas the European option can only be exercised at the expiration date (Korn, Korn, & Kroisandt, 2010), (He, 2007), (Hull, 2021). By exercise it means the holder of the option can decide (free) to sell or buy the asset depending on the type of option held.

The option to buy or sell is only optional to the holder of the option. The writer of the option is obliged to deliver the option to the holder of the option, should the holder decide to exercise the option. In the context of real options, the investor can be thought of as the holder of the option with management flexibility to decide on the intervening strategy to minimise business risks and improve gains from the project.

The typical scenarios highlighting how financial options works can be demonstrated by examples. If the holder of the option exercises an option to buy when $S_T < K$, the holder therefore losses in this transaction because the holder would have already paid the premium which then becomes the sunk cost. The writer then keeps the premium from the option holder and makes the profit from the transaction. Conversely in the scenario whereby $S_T > K$, the option holder can exercise an option to buy at the strike price and make a profit of the difference between the asset price and strike price, $S_T - K.$ In conclusions, for a European call option to benefit the holder of the option, it ought to be exercised only when S_T exceeds K. The opposite scenario applies to a put option, the holder of the right to purchase hopes for the strike price to decrease, thus exercising and profits when $S_T < K$. In the above explanation, the transactional costs can be avoided to illustrate the point on how option pricing concept works.

The terminology in options theory is necessary to understand the differences between payouts and losses. (IFOA, 2024) defines a long position as a phenomenon in the contract when the contract has been purchased, and short position when a contract is sold.

Focusing on the European options, four types of options positions (Hull, 2021), namely:

- A long position in a call option – pays off when max $(S_T - K, 0)$, only exercised if $S_T > K$.
- A long position in a put option - pays off when max $(K - S_T, 0)$, only exercised if $S_T < K$.
- A short position in a call option – pays off when min $(K - S_T, 0)$.
- A short position in a put option – pays off when min $(S_T - K, 0)$,

The options are easily understood by the means of payoff diagrams, which shows the final gain derived from holding the option as a function of the underlying stock price S_T. (Korn, Korn, & Kroisandt, 2010). For illustrative purposes, the payoff diagrams only show for long position call and put options.

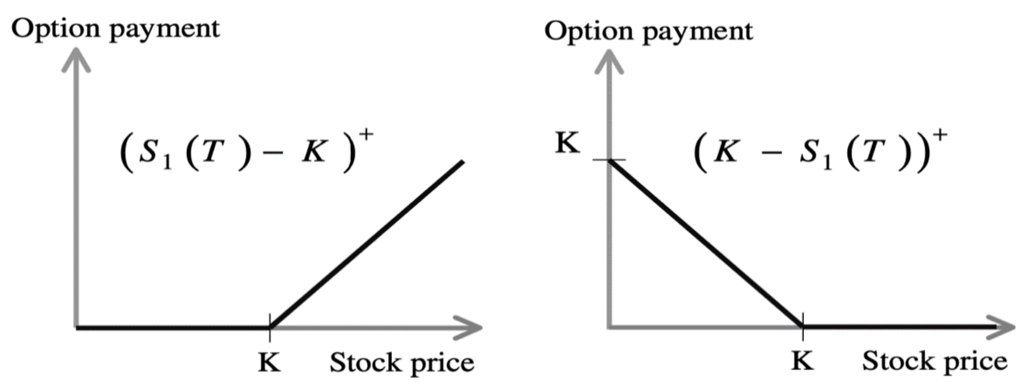


Figure 4 Payoffs diagrams of a call option (left) and put option (right) *(Korn, Korn, & Kroisandt, 2010)*

In summary, the European call option is always be exercised if the asset price if greater than the exercise price at the expiration date. The European put options are exercised if the asset price is smaller than the exercise piece at expiration date.

Table 1 The payoff table - put and call options. (Gui, 2011)

	Pay off when S > X	**Pay off at t when S < X**
Sell Call	$-(Se^{-\delta t} - X)$	0
Buy Put	0	$X - Se^{-\delta t}$
Buying Stock outright	$Se^{-\delta t}$	$Se^{-\delta t}$
Total	X	X

Furthermore, the concept of intrinsic value is important in understanding the value of the option assuming that the contract expire immediately rather than at time T in future. The intrinsic value of call option is equal to a long position in a call option, and that of a put option is equal to a long position in a put option.

The intrinsic value is further illustrated to mean the following (IFOA, 2024), (Aunan, 2022):

- It is positive, if it is in-the-money.
- It is equal to zero, if it is at-the-money.
- It is equal to zero, if it is out-the-money.

The key elements in defining an option discussed by (Markham, 2018) involves the following.

- Asset price at time t, S_t
- Exercise Price, K
- Expiration date, T
- Volatility of the asset price, σ
- The risk-free interest rate, r
- The dividends expected during the life of the option, D
- Establish whether an American or European option

The above determinants are common across different option pricing models. These are the input variables for pricing the options - depending on the specific model used, these may vary considering the assumptions relevant at the point and time. The literature (Selvaprabu & Nicola, 2023) shows that real options is rooted from financial options and has found its applications in which risks and uncertainty is predominant in decision making process. Thus, by no surprise to have similarities between the two options. The American call option is closely related to the real options when comparing its parameters, thus investment opportunities (projects) can be considered as if they were American call options, and use option pricing techniques to conduct analysis. The comparisons previously reported by scholars in the field is tabled by (Ampofo, 2017), this body of work was extracted in the research focusing in the mining sector.

2.7.2 Options Pricing Techniques

The real options theory expands from the financial options through adapting the traditional valuation techniques. The option pricing techniques that are further explored in the literature with the primary objective of applying them in real options analysis are the Binomial Tree model, the Black-Scholes model, and Monte Carlo Simulations.

2.7.2.1 Binomial Tree (Lattice) model

The binomial trees model was developed by Cox, Ross and Rubinstein in 1979, and is used to find the value at time 0 of the option that provides a payoff at a future date based on the value of a non-dividend-paying share (IFOA, 2024). The outcome of the analysis in the form of two or more outcomes. This method uses a discrete time framework (observing model outcomes at discrete times) to find the outcomes up to the maturity time. This sophisticated yet reliable approach can be used since the manager's intervention throughout the project life can be traceable. The model enables breaking down the complex problem into small and simple problems, focuses on the intervening points (at decision point nodes) to make decisions (Ampofo, 2017). This broken-down tree gives about the necessary visibility, transparency, and ability to respond to future changes (Gharib, Berrado, & Benabbou, 2018).

The lattice models, particularly binary, is mostly found in the literature because it is easier to calculate and analyse. Furthermore, it does possess the scalability element affording the model to use in other areas of applications (Oliveira, Couto, & Pimentel, 2021). However, as more uncertain variables manifest themselves in the problem, this approach's level of complexity increases exponentially with the number of uncertain variables (Ampofo, 2017).

The binomial tree model is key in option pricing leading into more detailed and sophisticated models. In order to derive the model for option pricing, actuarial science highlight the following assumptions (Argimiro, 2014), (IFOA, 2024).

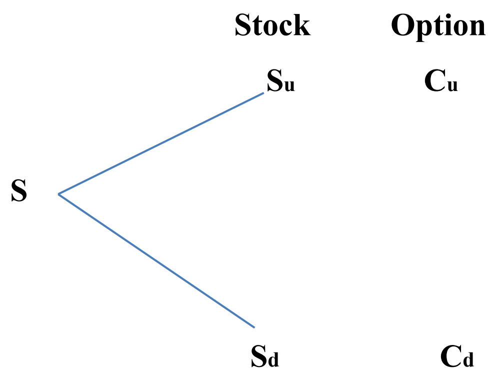
- No transaction costs
- No taxes
- No specified minimum or maximum units of trading
- Assumes a risk-neutral measure
- Assumed discrete time space for trading stock and bonds
- The no arbitrage principle applies.

The principle assumes that any two assets that behaves in exactly the same manner must have the same price. For example, any two options that give exactly the same payment must have the same price. Should the no arbitrage principle not assumed, the unlimited arbitrage profit are made through buying cheap assets and selling expensive assets continuously making the transaction more complex.

The inputs to the model are:

- The asset (stock) price, S
- The exercise price, K
- Height of the tree, n
- Expiration time (in years), T
- The stock volatility, σ
- Risk-free interest rate, r
- Time interval is, t=T/n - this is the time from one node to another.

The binomial option pricing model is also understood through mathematical derivations. The mathematics involved enables the method to be used even in more complex scenarios by assuming that at a specific time, a stock can return only two outcomes. The tree then grows from a single into multiple nodes as time progresses, say from t=0 to t=n. The derivation is highlighted by (Options), 2023). The value of the option price cannot be predicted with certainty in future, so the the payoffs are determined using the risk-free interest rate and stock price at different states probabilities are assigned for each outcome.



Assume the option with price, **S**, then it follows from the above one-step binomial tree diagram that the potion results in two outputs (either up or down) for the price option.

- Jump upward, **S_u**.
- Jump downward. **S_d**

Where u>1 and d<1 and the probability of up and down movements is denoted by p and 1-p respectively.

The resulting call option prices are:

$$C_u = S_u\Delta + (1 + r_f)B$$

$$C_d = S_d\Delta + (1 + r_f)B$$

Whereby B and Δ are unknow and are computed by manipulating the above equations and making them subjects of the formula.

$$\Delta = \frac{C_u - C_d}{S_u - S_d}$$

Delta (Δ) is the change in option price with the stock price.

$$B = \frac{C_d - S_d\Delta}{1 + r_f}$$

$$B = \frac{C_u - S_u\Delta}{1 + r_f}$$

Whereby B is the cash component in option pricing. Since B is as a function of risk-free interest rate, cash in future is always higher that the present cash components. i.e., $B(0) = 1$and $B(t) = e^{rt}$ and the option price is given by:

$$C = S\Delta + B$$

Table 2 Binomial lattice model parameters

Notation	Description
S	current stock price
r_f	risk-free interest rate
C	the value of the call option
S_u	the value at which the stock price can go up to
S_d	the value at which the stock price can down to
C_u	the value of the call option if stock goes up
C_d	the value of the call option if stock goes down

Thereafter the u and d parameters are estimated using the standard deviation, and the mathematical equations are tabulated below (Gharib, Berrado, & Benabbou, 2018) (Options), 2023).

Table 3 Binomial lattice up factor, down factor, and the risk neutral probability.

Description	Mathematical formula
The up factor	$u = e^{\sigma\sqrt{\delta t}}$
The down factor	$d = \frac{1}{u} = e^{-\sigma\sqrt{\delta t}}$
The risk neutral probability	$p = \frac{\left(e^{r\delta t} - d\right)}{u - d}$
The risk neutral probability	$1 - p = \frac{\left(u - e^{r\delta t}\right)}{u - d}$
Time to expiration in small intervals	$\delta t = t/n$

Using the above simplicity analysis, the call payoffs can be calculated as follows.

$C_u = \max(S_u - K, 0)$ and $C_u = S\Delta + B = \Delta uS + Be^{rt}$

$C_d = \max(S_d - K, 0)$ and $C_d = S\Delta + B = \Delta df\mathrm{S} + Be^{rt}$

The derivation is considered only for a one-period analysis; however, the same concepts can be extended to multi-period analysis. (IFOA, 2024) expanded the derivatisation using Binomial statistical distribution to determine the option price at time t.

The price at time *t* of the derivative is:

$$V_t = e^{-r(n-t)} \sum_{k=0}^{n-t} f\left(S_t u^k d^{n-t-k}\right) \frac{(n-t)!}{k!(n-t-k)!} q^k (1-q)^{n-t-k}$$

(IFOA, 2024)

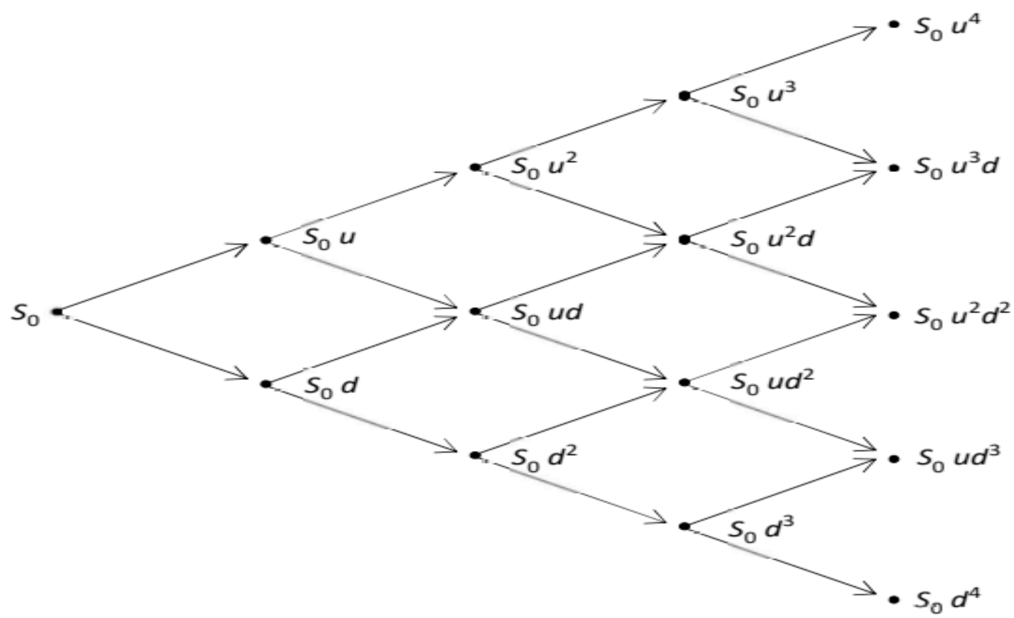


Figure 5 A 4-period binomial pricing tree model (IFOA, 2024)

The above figure shows stock price evolution from S_0 to the next two possible outcomes, be S_0u and S_0d after time T/n. The movement suggests that the stock price can either move (jump) up or down. Upward movement is denoted by u (u>1) and downward is denoted by d (0<d<1). So, the same process replicates itself from each current node moving from left to right of the tree diagram. The process ends when the expiration date has been reached.

The model is far from realistic given its assumptions. However mathematical derivations provided a pathway to the development of Black-Scholes model which eliminated the drawbacks presented by this model. The generic n-period can be determined following the same methodological approach for a single-period analysis illustrated above.

2.7.2.2 Black-Scholes Model

Following the discussion on the discrete time financial option pricing techniques - a continuous time approach is presented below. The continuous time process has an advantage over discrete time process of being able to continuously evolving over time and being independent of time intervals and non-recursive numerical procedures may be used. (Argimiro, 2014). The continuous time process, Wiener process, was very instrumental in the development of Black-Scholes model for pricing European options. The Black-Scholes formula for finance option pricing was compared by (Markham, 2018) (He, 2007) with the intention of extending its applications to real options. The parameters are equally applicable with customised outcomes relevant to real options. The interpretation of fundamental basis is the same. The application Black-Scholes is acceptable in the literature, with (Lander & Pinches, 1998) vouching for its application in real options analysis.

The assumptions considered by (IFOA, 2024), (Hull, 2021), (Black & Scholes, 1973). are:

- The stock price follows a geometric Brownian motion.
- There are no transaction costs and taxes.
- There are no risk-free arbitrage opportunities.
- The risk-free rate of interest is constant and is the same for all maturities.
- Unlimited short selling is possible and permitted.
- The underlying asset can be traded continuously
- All options are European - only exercisable in the expiration date.
- No dividends paid by the stock over the duration of the stock.
- Asset returns are normally distributed.

The above assumptions are not realistic, and the details therefore are summarised in (IFOA, 2024). The assumptions enable the scholars to derive the mathematical pricing models, so they can be looked at as the building block in building the option pricing theory.

The Black and Scholes option pricing model assumes that the asset price follows a Geometric Brownian motion (continuous space random walk), $S_t = e^{W_t}$ where W is the standard Brownian process $W_t = W_0 + \sigma B_t + \mu t$, and is lognormally distributed with parameters $W_0 + \mu t$ (mean) and $\sigma^2 t$ (variance). Statistically it means the asset price follows a lognormal distribution with the property of S is $S_t \geq 0$. for all t (Adrew, 2004).

Thus $dS = \mu S dt + \sigma S dz$ where μ is the growth rate of the price (drift rate), *dz* is the Wiener increment, σ is the volatility of S and {*Zt, t*>=0} is a standard Brownian process (Martinez, Batistela, & Simões, 2019) (Gardner, 2015), (Rebiasz, Gawel, & Skalna, 2017), (Hull, 2021).
The mathematical properties of the lognormal distribution shows that the assumption made by Black and Scholes in pricing European options makes sense, because the value of $S_t \geq 0$.

The call and put options models can be represented by mathematical formula developed by Black-Scholes. The above models take into account the above assumptions are given by (Benninga, 2008), The mathematical derivation of the option price from stochastic differential equation falls outside of the scope and can be found from (Hull, 2021), (Argimiro, 2014):

The European call and put options prices are denoted by C(S_t, t) and P(S_t, t) respectively (Argimiro, 2014).

$$C(S_t, t) = S_t N(d_1) - K e^{-r(T-t)} N(d_2)$$

$$P(S_t, t) = K e^{-r(T-t)} N(-d_2) - S_t N(-d_1)$$

whereby

$$d_1 = \frac{\ln\left(\frac{S_t}{K}\right) + \left(r + \frac{\sigma^2}{2}\right)(T-t)}{\sigma\sqrt{T-t}}$$

$$d_2 = \frac{\ln\left(\frac{S_t}{K}\right) + \left(r - \frac{\sigma^2}{2}\right)(T-t)}{\sigma\sqrt{T-t}}$$

$$d_2 = d_1 - \sigma\sqrt{T-t}$$

$$N(x) = \int_{-\infty}^{X} \frac{1}{\sqrt{2\pi}} e^{\frac{-t^2}{2}} dt$$

Table 4 Black-Scholes model parameters

Variable	**Description**
C(S_t, t	Call option value
P(S_t, t)	Put option value
$N(x)$	Standard normal cumulative distribution function
$N(d_1)$	Risk - adjusted probability that call stock won't expire in time
$N(d_2)$	Risk - adjusted probability that call stock will expire in time
$N(-d_1)$	Risk - adjusted probability that put stock won't expire in time
$N(-d_2)$	Risk - adjusted probability that put stock will expire in time
S_t	Asset value or Stock price at time t
K	Exercise price or Strike price
σ	Volatility of the asset price
r	Continuous Risk-Free Rate
T-t	Time to Expiration or time to maturity (in years)
d1	Standard Normal Stochastic Variable 1
d2	Standard Normal Stochastic Variable 2

The value of the option is influenced by the following factors/variables (Barton, 2011), assuming the asset does not pay dividends:

Table 5 Factors influencing the option value.

S_t	Asset value or Stock price at time t
K	Exercise price or Strike price
σ	Volatility of the asset price
r	Continuous Risk-Free Rate
T-t	Time to Expiration or time to maturity (in years)

Furthermore, (Barton, 2011) adapted a call and put option sensitivity analysis from (Hull, 2021). The table makes use of the Greeks to understand the option variable changes as a function of stock price, exercise price, time to expiration and volatility, holding all other factors constant.

Variable	Sensitivity	Call option value	Put option value
Underlying asset price	Delta, $\Delta = \frac{\partial c}{\partial S}$.	↑	↓
Volatility	Vega, $\nu = \frac{\partial c}{\partial \sigma}$.	↑	↑
Strike price	Xi $\Xi = \frac{\partial c}{\partial K}$.	↓	↑
Time to maturity	Theta, $\Theta = \frac{\partial c}{\partial (T-t)}$.	↑	↑
Risk-free rate	Rho, $\rho_t = \frac{\partial c_t}{\partial S_t}$.	↑	↓

2.7.2.3 Monte Carlo Simulation Model

Similar to Black-Scholes model, Monte Carlo Simulations (MCS) were also adopted from the financial option pricing models. MCS enables fast computation of different scenarios with less manual computations, which is time consuming. The simulation models take into account project interdependencies and serial correlations. MCS also provide an added advantage of enabling numerous scenarios to simulate cashflows using random values extracted from the statistical distributions that fit the project parameters. It also provides similar outcomes to the more mathematically elegant methods (Mun J. , 2006). MSC can be divided into parametric and nonparametric simulations. Using a parametric approach, a specific statistical distribution and its parameters is required before simulation commences. In a nonparametric approach, the historical statistical distribution data is used to model the scenario required to run the simulation (Mun J. , 2006). In cases where data is unavailable, the reliance on subjective data generation is paramount.

(Ampofo, 2017) highlights the importance of this approach given its analytical capabilities enabling generation of numerous scenarios, coupled with several uncertain variables. Given the nature of the approach with number uncertainties, it proves to be compatible with the real options theory.

The drawbacks (worth noting) of the MCS are such that it depends on (Toshev, 2016):

- End-user simulation experience – more experience and expertise is required to make the informed choices.
- Problem associated with subjectivity of assumptions
- Appropriate model design – model risks that relies on stochastic processes.
- Appropriate selection of applicable statistical distribution – incorrect assumptions could result in mistake on the Value at Risk values.
- MCS are complex and costly because it requires special skills and computational infrastructure with high speed

The observation from MCS, is that it is preferred for real options analysis, however, it has not been used thoroughly in the real-life applications particularly for the energy projects in the mining sector. This creates an important research gap that can be addressed by this study, to contribute to the research fraternity and proving its viability in mining energy projects applications.

2.7.2.4 Similarities and Differences on Pricing Models

The common theme of these pricing models – is that they all trace their roots back to financial option pricing models. The extension of the theory to the ROTs and its underlying pricing models suggests that real options can be treated as financial options in real life applications. Binomial trees and the Black-Scholes model assume that option price models follow a geometric Brownian motion, however the lattice technique is limited in its application because time steps approach zero. The fundamental difference between the Binomial tree and the Black-Scholes model is the nature of the stochastic process, being discrete and continuous time space respectively (IFOA, 2024). In addition, MCS differs from binomial trees and Black-Scholes model in a sense that data is simulated, using statistical distributions (both discrete and continuous, depending on the application). (Aarle, 2013) added that based on distribution functions, MCS generates a number of scenarios for the underlying project value. Then real option value is determined for each of the scenarios generated, then taking the average value is discounted to the present time. The common feature against the above option pricing models, is that they all assume a risk-neutral world.

2.8 **Real Options**

2.8.1 Introduction

Real options theory is a useful tool in resolving projects with uncertainty and enables managerial flexibility when evaluating investment opportunities (Liu, Zhang, & Zhao, 2019). The increase in competition among resources (competing constraints) and uncertainties in dynamic global markets places managerial flexibility in a competitive position to enable firms to successfully take advantage of favourable (gains) investment opportunities (Lenos, 2002). The concept of real options was first introduced by Myers in 1977 (Bastian-Pirlo, Eduardo, Brandao, Raphael, & Orozio), as an extension of the already existing financial options theory (Bogdan, Bartlomiej, & Iwona, 2017). Myers investigated the possibilities of applying the options theory in non-financial applications. The development of real options was necessitated by the inadequacy of traditional methods to evaluate capital budgeting projects under uncertainty (Gharib, Berrado, & Benabbou, 2018). The literature shows that an enormous amount of work and progress has been conducted by scholars in developing areas of applications for real options theory. Understanding the origin and history of real options is not complete without its founding members. (Ampofo, 2017) did justice in his body of work by summarising and tabulating the real options contributors and founding founders dating back to 1970s.

2.8.2 Comparisons: DCF and ROT

The table by (Ampofo, 2017) aims to highlight the differences between the two methods in project valuation analysis. In the below comparisons, the table original format and content was borrowed from (Ampofo, 2017), and added additional column (pillars/theme) to further explain the differences between the two options.

Table 6 ROT vs DCF comparison

Pillars / theme	Discounted Cash Flow	Real Options Theory Analysis
Nature	Static	Dynamic
Flexibility	Now or never	Can intervene any time with necessary actions
Management	Passive management	Active Management
Discount rate	Constant discount rate for time and risk	Discounting for time and manage the risk
Risk adjustment	Blanket approach premium	Based on probabilities
Visibility	One view over the project life	Several views over the project life
Flexibility	Unchangeable across project life	Unchangeable across project life

The use of real options seemingly breaks the DCF rules that normally gives decision based on the analysis. i.e., making decision based on the NPV value. The concept of real options emanates from financial options, but it was extended for real assets and opposed to financial assets. Real options use project value whilst financial options use stock price, furthermore, exercise price on the financial options is a contractual value agreed upfront, however in real options it can be seen as cost to invest in the project. Thus it can be concluded given similarities between these types of options, and their history thereof, that real options is the special case of financial options (Ampofo, 2017), (Leary, 2013), (Markham, 2018), (Aunan, 2022).

The relationship between the real and finical options was alluded to by (Trigeorgis, 1995), by means of an example in the application of real options in pharmaceutical industry. The example showed an improved NPV after considering the optionality brought by real options. The improvement was presented as the shift of the distribution function, making the project more profitable when adding real options value in the equation. The expanded NPV considers both DCF and real options techniques. This was represented mathematically as follows:

Expanded NPV = static NPV+ real option value.

Furthermore (Aarle, 2013) refuted the unspoken assumption that DCF and ROT are mutual exclusive. The alternative assumption bought by (Aarle, 2013) is such that both DCF and ROT can be integrated to give a total value, combining two components, namely NPV and real options.

This is represented mathematically as follows (Aarle, 2013), (LenosTrigeorgis, 1993):

Total Project Value = Net Present value + Adjusted Option Value +Abandonment value

Expanded NPV = Passive NPV + Option premium + Strategic value

Expanded NPV = Passive NPV of expected cash flows + value of options from active management

This unique capability of the ROT suggests that investors can argue the use of the technique even though it appears the project is feasible using the DCF, provided there is a positive premium payable to the project. The premium is locked in the uncertainty that can contribute to the overall value of the project over time (Damodaran, 2023). The practical implementation of real options was shown by (Williams & Hammes, 2007) using a hypothetical scenario to illustrate the example of the ROT in real life application. The below figure shows that two options reached different conclusions.

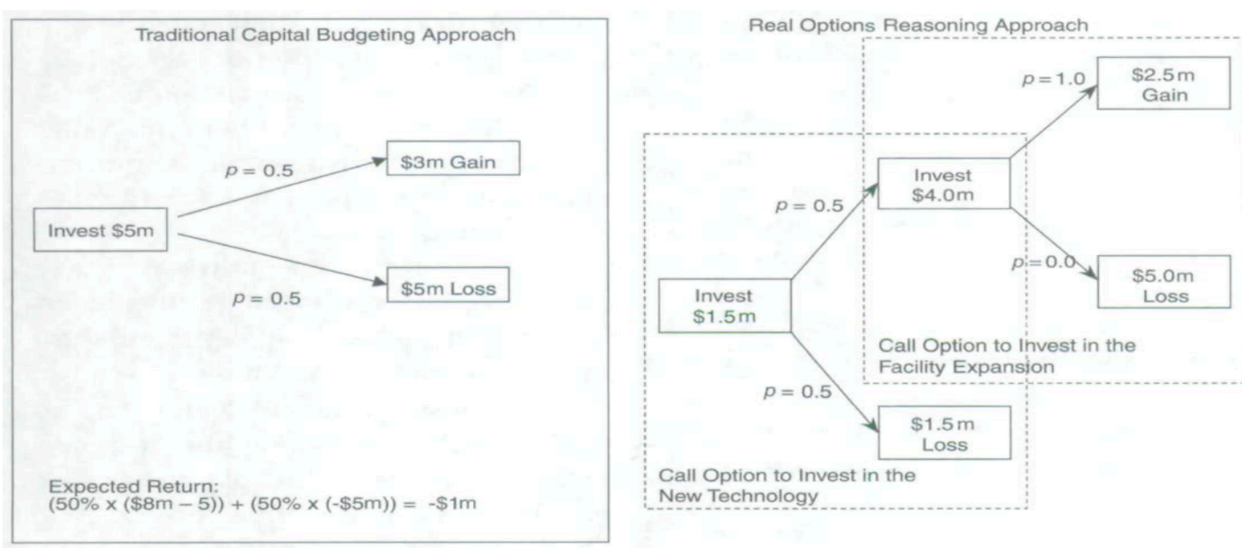


Figure 6 ROT vs DCF comparison - a Typical Example (Williams & Hammes, 2007)

The real options aim to complement the financial options. The characteristics used to determine the financial market prices, which are timing and uncertainty (Laughton, 2023), are applicable to real options. The taxonomy discussed (Laughton, 2023) illustrate that both methods are using the same characteristics, different with the location in the plane below.

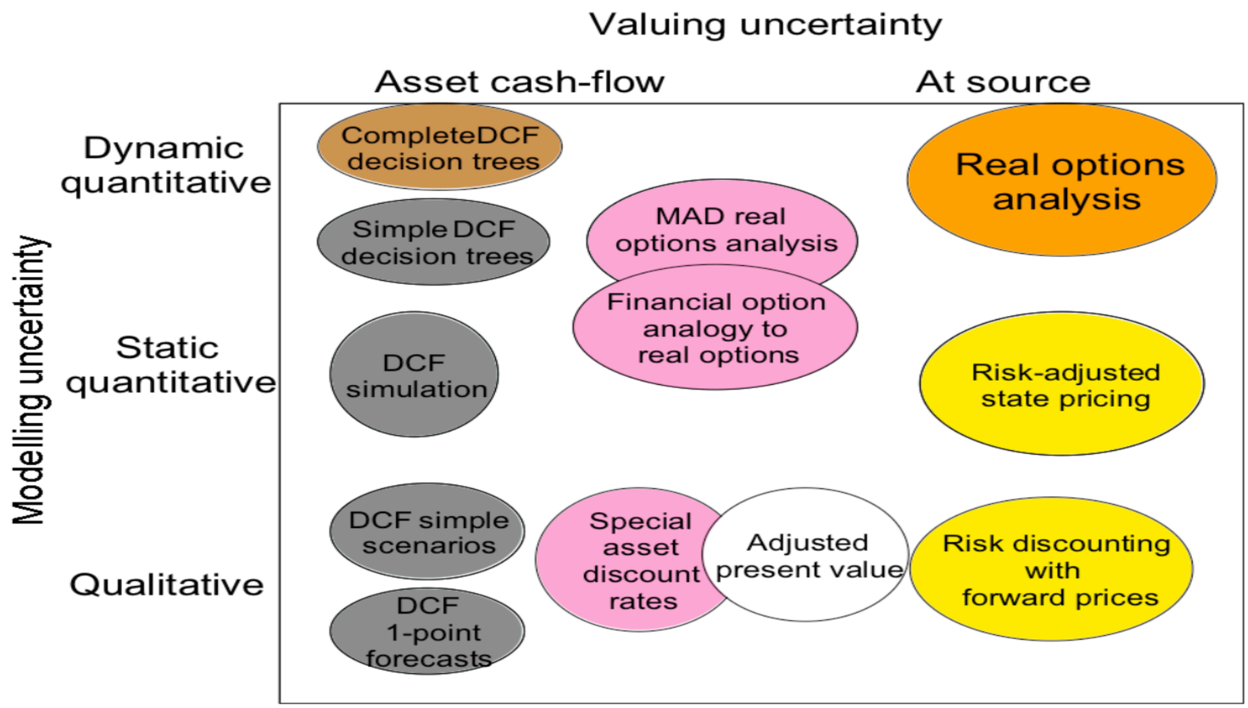


Figure 7 The taxonomy in investment valuation analysis (Laughton, 2023).

In comparing financial and real options, the table below shows the relationship among these two options. The underlying asset under financial option is the project under real options. The exercise/strike price uses K and X symbols interchangeable.

Table 7 Comparison between real options against the American call option (Ampofo, 2017), (Nicoleta, 2007)

Financial option (call or put)		**Real Option**
Stock price	**S**	Discounted cash flow for the project
Exercise price	**K**	Investment cost/ Capital expenditure
Risk free rate	**r**	Risk free rate
Expiration time	**T**	Maturity of opportunity
Price volatility	$\boldsymbol{\sigma}$	Project volatility

Table 8 Real options contributors and founding members (Ampofo, 2017)

Real options method	Founder
Analytical solutions for European-type claims	Black and Scholes (1973)
Lattice methods	Cox, Ross, and Rubinstein (1979)
Finite difference method	Brennan and Schwartz (1985)
Stochastic Monte Carlo Simulations	Boyle (1977)

2.8.3 Benefits of Real Options Theory

Real options theory brings about the much-needed flexibility to management that is necessary for decision making. The flexibility includes the opportunity to delay, abandon or switch the investments to harness more value when the future expectations change/unfold. (Brealey, Myers, & Allen, 2006) assume a directly proportional relationship between the project uncertainty and the flexibility of intervening in the project. In cases where there is a high level of uncertainty of the project, management can opt to delay and embark on a replacement with a more certain project, and vice versa, thus harnessing more value.

(Chi, lI, Trigeorgis, & Tsekrekos, 2019) emphasise the importance of the flexibility and commitment trade-offs. The author breakdown the trade-offs into:

- The exchange of the commitment with a more flexible option (i.e., delaying a booster maintenance projects when the new gas pricing methodology reduces the gas prices, rendering the booster project less attractive).
- Giving up an existing option (i.e., refocusing the available resources to low hanging fruits). The above trade-offs are crucial in a dynamic environment that requires a decision on the spot. Furthermore (Chi, lI, Trigeorgis, & Tsekrekos, 2019) highlight the benefits embedded in ROT under the below themes in the context of international businesses:
- The Timing effect.
- Irreversible decisions and exit strategy.

ROT can be instrumental in reducing the transaction costs by mitigating the opportunity costs of implementing fewer valuable projects and increasing the strategic returns by harnessing more valued projects considering the future under uncertainty (Hajdini & Windsperger, 2020). A similar approach adopted by (Hajdini & Windsperger, 2020) in franchise contracting can be used by the mining industry for profit sharing projects, such as variable speed drives and lighting efficiency improvement initiatives, funded by the third-party funders.

2.8.4 Managerial Flexibility

Managerial flexibility offers different types of options embedded in projects which are often overlooked, of which, if appropriately considered and evaluated, could result in deriving more value for the business. (Hull, 2021) and (Hilhorst, 2008) briefly discuss each option with the aid of an example. The contribution from other scholars is indicated accordingly in each option type description.

Option type	**Description**
Abandon	An option to abandon or close the project if market conditions are not favourable or the project proves to be unprofitable nor fit the business strategic plans. The authors in (Gharib, Berrado, & Benabbou, 2018) suggest that this option is equivalent to the financial market's American put option on the project value, thus affording the right, not the obligation, to sell the project as a set price before an expiration date. The project resource can then be deployed to other remaining projects. This option ensures that project losses are kept at minimum.
Expansion	If the conditions change and favours the project deliverables, more effort and investments are added to extract more value. (Leary, 2013) comments on the point that this is analogous to a call option with a positive payoff when $S - K > 0$. The pilot project deployed owing to lack of technologies can benefit from this option once it has proved to be successful. More investment can support this growth and take advantage of scalability element embedded in the project.

Contraction	An American put option used to scale down the project investments when the conditions are not favourable. (Leary, 2013) comments on the point that this is analogous to a long call option with a positive payoff when K – S > 0.
Stage	This option is closely related to the expansion option. It is concerned about breaking the project into a series of incremental outlays that enables management to terminate the project if conditions become unfavourable. The project value is derived from each stage of the project through minimising the risk and clearing out ambiguities.
Defer/delay	An American call option to defer the project to a future time when the conditions permit to extract higher value from the implementation of the project. This is analogous to a long call option with a positive payoff when S – K > 0 (Leary, 2013). The project is normally delayed avoiding spending investments with poor returns, whilst the potential exists that in future the returns may results in an attractive business case.
Extend	A European call option to extend life on ana asset deliverable value to the project or forms part of the project.
Switch use.	Management can exercise their discretion to switch the use of a project from its initial intended purpose to serve another purpose advancing current business objectives and priorities. The practical example is in the energy efficiency space, whereby the use of the carbonisation project to attract cost effective business cases that reduces energy costs and enable expedition of unlocking investments for lower-carbon technologies.

In addition, (Leary, 2013), discuss the option to shut down in the mining context. This option combines the option to abandon the project at salvage value when CAPEX and OPEX is higher than the expected project value. The second component discussed by the author is care and maintenance option, where temporary shutdown of production is because of, among other things, soft market for the mining products. This is arguably the same as option as “to delay/defer or wait” for the favourable time to ramp up production to access greater value.

The option to switch was not discussed by (Hull, 2021), which is surprising because this is more relevant in the works where competing projects surpassed each other by small margins. However, (Hilhorst, 2008) incorporated this option in the research work and clearly explained its importance in enabling management flexibility. The simple example is when two energy projects of different commodities compete, say electricity and diesel initiatives, since diesel price is linked to oil movement (assumed no hedging or long-term contracts). Whenever there's an oil price movement, it will affect the diesel price (either up or down), enabling the electricity projects to be competitive. The most valuable alternative can then be used to switch to and from diesel.

All the above options are relevant for evaluating the energy projects in the mining sector. The specific problem at hand plays a crucial role in enabling a researcher to choose the best option given the circumstances. Real options give management a practical and effective risk management approach to proactively manage strategic investments risks through intervening during the course of the project.

2.8.5 Uncertainty and Real Options

Risks exist in all projects. Energy projects are not immune to the potential failures or a project failing to deliver expected results. Thus, risks need to be identified, assessed and managed effectively using existing risk management tools. The use of real options theory can be seen as a valuable technique that can be used to monitor and create an environment to effectively manage project risks through management flexibility. This relationship between real options and risks is supported by (Nadarajah & Secomandi, 2023) whereby real options are viewed as models that optimise market value of operational assets that have been applied in a variety of settings in which risk plays a significant role in making decisions.

Energy projects are found in environments where different factors make them less competitive when compared with other production and safety projects. The common factors include project attractiveness when evaluated using traditional discounted cashflow techniques. In a scenario where by the organisation is expected to deliver on net-zero and carbon neutral commitments, to curb rising temperatures resulting from climate change. The challenge facing the organisation is that the technology is not readily available to implement some of capital-intensive projects in the mining sector. The unavailability of tried and tested technologies give rise to high project risks. (Hilhorst, 2008) alluded that where there is high risk, flexibility has value. This suggest that exploiting the value entrenched in real options theory through enabling management flexibility adds value to energy projects.

Flexibility can be enabled into two forms, namely the result and process dimensions. The result dimension is concerned about what do energy projects entail in the form of value, whereas the process dimension focuses more on how energy projects are delivered (Hilhorst, 2008). The two forms can be explained further by the means of an example, e.g., partial electrification of dryers and reheaters. In the case study that is analysed in this research work, the result dimension aspect aims to improve the intensity of dryers and reheaters. The measurable component is the amount of diesel consumed to dry a ton of heavy mineral concentrate. The sustainable approach in diesel consumption reduction is through a quantifiable intensive over a specific time interval, so that it can cater for changes in production volumes. The improvement in specific energy consumptions (and reduction in diesel consumption) results in reduced GHG emissions and reduction in energy costs.

The managerial decisions enable project implementation to take place amidst budget constraints and lack of technology readiness. This form of flexibility strives for a win-win strategy where decarbonisation plans are executed within committed timelines to minimise business reputational risks and potential penalties. Reality dictates that such project ought to be NPV neutral or positive when implemented using the DCF approach. The same approach can be adopted to avoid potential losses and preserve potential gains value that can be harnessed using real options techniques. Thus, a need for an alternative approach is inevitable, and this allows for a strategy to achieve climate change targets using a staged approach (phases to unlock incremental project benefits) coupled with development studies and pilot tests to minimise the project risks to the business.

The real option theory alongside with discounted cashflow techniques are applied in the real-life scenarios, compare results and highlight the readiness/ effectiveness of real options theory in energy projects of capital nature in the mining sector.

2.8.6 Real Options Theory for Projects

The scientific relationship with financial options, is such that projects viewed under ROT are considered as options on the underlying cashflow, and the intervening strategies are considered to be the optimal exercise rules of the projects. Considering that real options are derived from financial options – the management flexibility on the ROT does not oblige the managers to act; however, the discretion rests solely with the manager he has assessed the investment trends.

In comparing financial and real options, (Oliveira, Couto, & Pimentel, 2021) highlight those real options differ (though there exist significant differences) from financial options where call and put options are associated with expansion and abandon options respectively. The major difference noted by (Oliveira, Couto, & Pimentel, 2021) is arguably correct, because the literature shows an expansion of the financial options with necessary customisation to suit the real assets valuations agenda. The differences highlighted are rather cosmetic as opposed to being fundamental because the comparison made ignores the key real options characteristics which are distinct in each and very literature (i.e., flexibility, market dynamics, operational constraints, uncertainty etc.), hence the authors' view is different and is not aligned with the general view of the literature in this body of work.

The market volatility and uncertainty during the planning and implementation of the project requires the manager's intervention up until the project ends - hence the ROT is more similar to the American option when compared to financial options. The manager may choose to transact or intervene at any time during the project period (before the option expiries) or allow the project to proceed as along as the intervening strategies are favourable to the business. Thus, real options provide much needed benefits and overcome limitations presented by the DCF method.
The analysis by (He, 2007) shows that ROT can be used as a call option in practical applications. (He, 2007) also makes a representation that ROT is not competing with DCF, rather it complements the traditional techniques (through optimising the NPV) as an expansion of the concept with manager's given power to react to market conditions and operational constraints. Thus, the role of ROT in capital budgeting can assume similar hypotheses with call and put options - with the distinction to focus on the energy projects.

The below figure depicts the importance of real options given the market uncertainty and the requirement for manager's flexibility (Robinson & King, 2003). The common view depicted highlights the relevance and importance of ROT under these circumstances, and how the DCFs fails to compete in providing accurate and appropriate valuation outcomes.

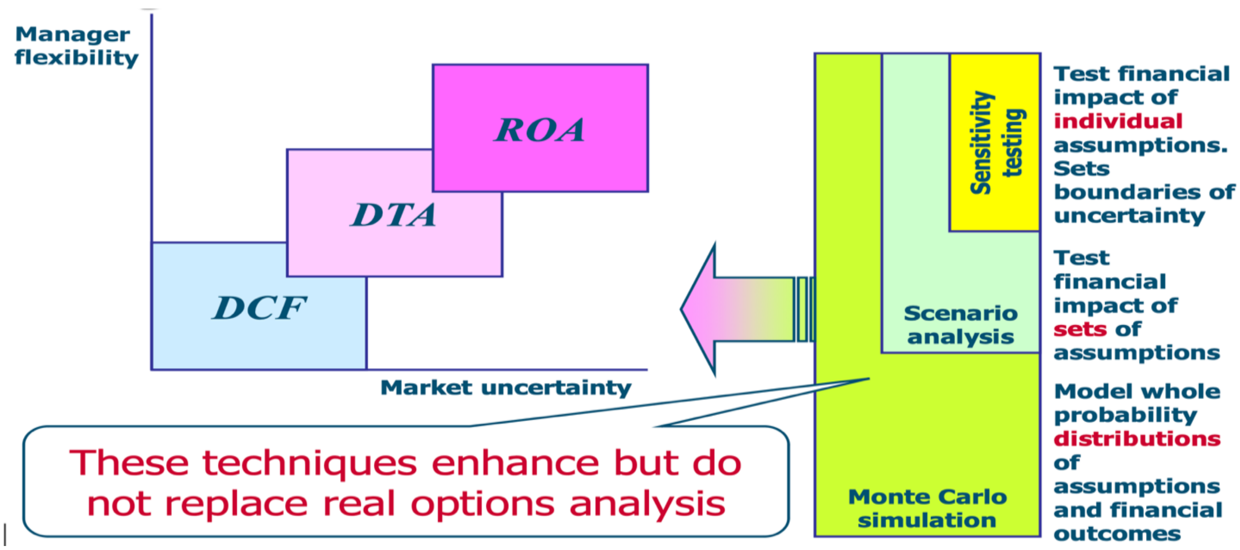


Figure 8 Investment valuation evolution (Robinson & King, 2003).

The link exists between financial options and real options. The widely accepted view is that real options are rooted from financial options and have been customised for tangible investments under uncertainty *(Barton, 2011)*. Real options have a distinct feature that gives management flexibility to intervene and minimise risks under unfavourable conditions while harnessing gains from the investments. *(Markham, 2018)* and *(Barton, 2011)* highlight comparison between variables influencing financial and real options value.

Table 9 Comparison between financial against real options (Barton, 2011), (Markham, 2018)

Description	Real Options	Financial Options
Exercise price or strike price	Investment expenditure	Price to purchase the stock
Underlying asset price	Present value of the future cash flow of the project	Stock price
Time to maturity	Length of time to amend the decision	Time to expiration
Risk free rate	Time Value of money	Risk free rate of return
Volatility	Riskiness of project's cashflow or volatility in the returns of the project	Variance of returns on stock

(Leary, 2013) Further give light to the comparison by highlighted few pointers not indicated by the above table.

Table 10 Additional comparison between financial against real options

Financial Option	Real Option
Underlying stock	Project
Stock return	Project return
Stock price volatility	Project value volatility
Stock dividend flow	Project net cashflow

2.8.7 Energy Projects and Real Options

The previous sections highlighted that energy projects cover a wider spectrum spanning from renewable, technology and energy efficiency initiatives. The logical approach is to focus on those projects found in heavy industrial application such as mining, steel manufacturing industries (for vertically integrated steel and mining companies) and the likes, which are very energy intensive in their processes.

The benefits and flexibility brought by real options makes it suitable for extending its application into the energy projects of capital nature. The real options are not new in academia and the real world, since it enjoyed application in numerous sectors ranging from natural resources to environmental compliance and conservation (Lander & Pinches, 1998).

Interestingly most scholars have used the real options for investment valuations particularly in renewable energy projects. The notable areas (gaps) where the application of real options in capital budgeting remains low is process optimisation and energy efficiency projects. However, there is value entrenched in these areas given the complexity and interdependencies that exist in different energy commodities.

2.8.8 Criticism of Real Options Theory – Drawbacks

Given the nature of real options theory, many managers consider them more complex and opt for simple valuation techniques which are not fit for purpose and more often resulting in ineffective outcomes. The computational complexity (mathematically rigorous when compared to standard DCF computation) makes it difficult to develop hypotheses without using formal modelling techniques (Chi, lI, Trigeorgis, & Tsekrekos, 2019) , (Ampofo, 2017), (Xavier, Peres, Almeida, & Carvalho, 2020), (Mun J. , 2006).

(Ampofo, 2017) further breaks down the difficulty and criticism of real options, into computation and implementation stages. (Ampofo, 2017), (Gharib, Berrado, & Benabbou, 2018) argues the points to be:

- Lack of numerical simulations to evaluate the projects – this makes it difficult to adopt the real option.
- Mathematically rigorous computational - higher order partial differential equations.
- Historically, it has been considered to be an academic exercise with less practical applications in real life.

2.9 Summary of the Research Gaps

- The inadequate application of the real options in the mining industry particularly where there are competing projects given that there are scarce resources.
- No consideration of mining commodity prices volatility and operational volatility caused by frequent changes to energy prices.
- The real-world application of ROT has been deployed elsewhere with minimal to no application evident in the South African market.
- No generally acceptable ROT applicable to the energy sector. Each process, configuration and works priorities will determine the applicable custom-made ROT solutions.
- No clear management and leadership role in adopting the real options theory as an alternative for capital valuations.
- No new research establishing the correlation between energy prices and the role of ROT in energy evaluating the projects.
- Very little evidence of previous quantitative research being undertaken in this area.
- Lack of regulatory support and ROT method approval by the industry to give the real options models much needed credibility.
- The lack of simplified and user-friendly application of real options theory has led to this method being perceived as less attractive to the real-life applications. The available software/s (e.g., MATLAB, R etc.) require/s special skills and normally come at a cost.
- The use of ROT as a mechanism to influence contractual agreements was introduced in the literature. However, the area of research is still in its infancy stage. This can be pursued further, particularly for projects that are funded by the third parties - ROT can be used as a tool to balance the risk for all parties to the contract.

2.10 Summary of the Literature Review

The literature review undertaken introduced the key concepts and the work conducted by the researchers in the field of study. The concepts assisted the researcher to understand the academic work and how it is relevant to the topic at hand. The gaps were identified through a critical analysis exercise and engaging with the body of work in the literature. The notable gaps that are in line with this topic were explicitly highlighted, of which they are used as a guideline to the researcher in crafting and responding to the research questions aligned with research objectives. The researcher continued, post the proposal stage, to conduct more work on the literature and presents narrative and critiquing (in nature) detailed analysis. The intention was to understand the similarities and differences (views that are supported by academic empirical evidence) held by peer reviewed and published work on the same topic and sub-topics. The author is of the view that relevant literature was conducted in line with the topic at hand and notable contributions from the scholars have been referenced accordingly with the intention of applying their theories in contributing to the work done on real options theory. The literature was undertaken through review of numerous papers, and it was guided among other researchers the work borrowed from (Umar Sekaran, 2016), (Ochara, 2016).

3 Research Framework and Design

The approach adopted for this study employs the use of deductive reasoning technique because the real options theory is well developed and accepted by academia as an innovative method for capital budgeting and investments valuations. The method enables companies to focus on the profitable side of the investment scenarios (He, 2007). This is achieved by using relevant options to curb the downside scenario using management flexibility interventions briefly described by (Hull, 2021). The real options theory as proposed by Myers in 1977, stems from the well-researched and widely accepted options theory on financial options. Therefore, deduction suggests that options theory can be extended to valuations of real and tangible assets.

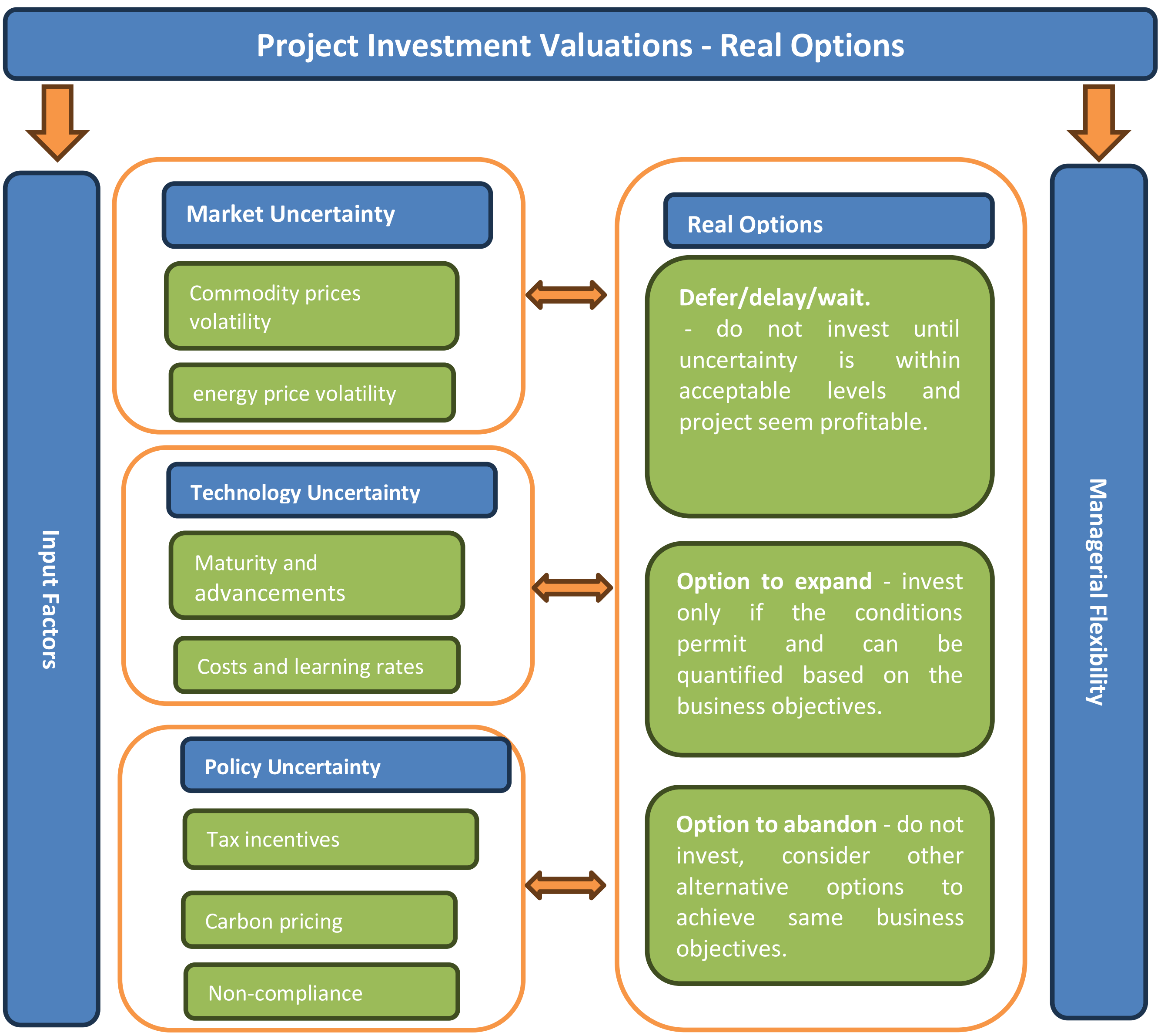


Figure 9 Research framework.

The framework shows relationship between factors that impact the investment. The factors have a significant influence in project success. These competing factors within the project need to be understood in the context of real options, to understand what impact to they present in investment valuations.

- Market uncertainty: commodity prices (mine output products), energy prices (diesel and electricity)
- Technology Uncertainty: maturity and equipment costs
- Policy Uncertainty: Tax incentives, Carbon Pricing and Non-Compliance Penalties

The deduction approach is used to solve a specific practical case study highlighting empirical evidence on the application of real options theory in capital budgeting. Given the time and scope limitations of the research, the research focuses only on quantitative approach to test the theory. The research works places emphases on utilising existing options pricing techniques and computational capabilities of modern computers to test the data retrieved from the specific mining company. The analytical tools adopted for modelling are Black-Scholes model, Binomial (Lattice) tree model and Monte Carlo Simulations. The overall objective of the research pertains to the use of real options theory (extension of financial options) to quantify the value contained in management flexibility, which could have not been achieved using discounted cashflow techniques. The case study affords the researcher an opportunity to have detailed understanding of the subject under study. This is shown my using different published approached in analysing the case study. The results obtained from case study data and simulated scenarios is interpreted to understand the alignment with the stated hypothesis, answer research questions and achieve research objectives.

The deduction principles are selected based on the following assumptions and alignment to the topic under study.

- The theory exists and can be used to test the hypothesis: For the purposes of this research, the application of real options theory is analogous to that of the financial options theory.
- The theory is then used to generate research objectives and hypotheses: The research questions are generated using the research topic and the literature review conducted to establish the applicability of ROT to the investments and gaps identified. Further research

questions were generated from each proposed hypothesis.

- Each hypothesis must be testable in a mathematical format. Formulate the hypothesis to test it in the specific context.
- The theory in general is well researched and it has been applied in numerous sectors as presented by (Lander & Pinches, 1998). However, the application in the energy space limited in the energy efficiency domain.
- The researcher is required to check the results of the analysis or responses whether they are correlated to the existing theory, and thereafter explain the deviations, if any.
- The potential limitation to adopt deduction approach is insufficient data to test the hypotheses with the intention of confirming that the theory holds.

4 Methodology

4.1 Methodological Approach

The approach adopted in this study uses Black-Scholes and Binomial (lattice) model to evaluate energy projects in the mining sector. The output of the real options techniques is then compared with the DCFs (NPV and IRR techniques) to identify the empirically evidence of the value entrenched in the ROA approach. The main part of the study focuses on the quantitative approach, applying the data (case study model inputs and simulated results) on the existing theory. The specific managerial flexibility options chosen for the analysis are option to scale down, option to defer, option to abandon and option to expand. The starting point of the analysis already assumes option to scale down, because the phased approach is opted to minimise investment risks. This approach is adopted to clearly expose the value of real options in investments valuations.

For each real option type (defer, expand and abandon), the analysis is conducted, and value is determined. Thereafter, results from DCF techniques are compared with each real option type and the business case that proves to be worthy is chosen with comments. The detailed analysis and results interpretation are discussed in the "*Results Analysis*" section.

The methodology steps are as follows:

1. Perform investment valuations and analysis using DCF techniques.
2. Perform investment valuations and analysis using real options pricing techniques in the following order.
    a. Black-Scholes Model
        i. Option to Defer.
        ii. Option to Expand.
    b. Binominal Lattice Model
        i. Option to Defer.
        ii. Option to Expand.
    c. Option to Abandon
    The scenario is a stand-alone option because through the use of DCF techniques, it is quite evident that the project value is positive.

3. Volatility assumptions

The volatility is assumed, since this information is not given. The method of calculating the volatility is discussed, however for ease of reference the author chose to assume a flat value across all scenarios.

4. System real options technique

In addition, we reviewed the system real options (SRO) developed by (Ampofo, 2017) with the intention of testing the model using real data. The SRO model was developed for evaluating the traditional mining projects excluding energy projects. In this framework, the author approached the problem statement by highlighting risks into economic, recovery, geological and mining risks. This is in addition to market and private risks. The SRO model focuses on a four-state model that drives mine reserves, these were prices of underlying commodity, reserves quantity, reserve grade and time. The price of the underlying commodity was assumed to follow a geometric Brownian motion. Due to scope limitation on Monte Carlo Simulations, the diesel prices modelling falls outside of this research, however, the framework is used to analyse the results. This similar to the assumption made on the price of diesel due to volatility of the prices driven by oil movements. This framework can be extended to the energy domain focusing on the specific energy risks and uncertainties such as market, technology and policy risks, to test its scalability. The SRO algorithm was borrowed from (Ampofo, 2017) approach, and adapted to suit the context of the study with minor customised changes as shown in figure 9.

4.2 **Data Source**

The data is extracted from a mining company with various energy projects competing for limited resources. During the project selection and prioritization process, energy projects compete with other projects from different streams i.e., safety, production, business improvement. This makes it difficult for energy projects to feature in the prioritized projects short-listed for implementation, owing to the nature of them being less attractive when evaluated on DFCs. In most cases are seen as enablers as opposed to strategic pillars core to the business.

4.3 Capital Expenditure Process

The existing project prioritization focuses on the investment / business case attractiveness using the clear stated key performance indicators that drive the returns on investments. The parameters at hand include among other things, the NPV, IRR, ease of implementation and payback period. The notable issue with this method, is that it uses the same weight to measure attractiveness of each project.

The existing specific process utilised by the company under study uses the following criteria to classify whether projects are capital or non-capital in nature. The details are be explained in detail to maintain confidentiality and anonymity.

- Expenditure of capital nature minimum threshold in US Dollars, and
- Have a useful life more than 12 months.
- The projects may be of tangible and/or intangible nature. i.e., new assets (fixed, joint-venture, critical spares, refurbishments etc.

In line with the company specific classification of projects, the energy project under review falls under this category.

4.4 Implications of non-compliance

The inability of the company to meet its climate change and emission reduction targets, due to lack of competitive edge on the energy projects when assessed with other project in the business may jeopardize the business reputation, give rise to environmental penalties and to a certain extent may even dent the share price. The climate-change related risks are significant to the economy and industry, however addressing climate change presents significant opportunities to organisations focused on climate change mitigation and adaptation solutions (Bloomberg, 2017). The value at risk (VaR), on climate-related risks, as viewed from the total manageable global stock was estimated to be ranging between $4 to $43 trillion from 2015 to the end of the century (Bloomberg, 2017). The VaR losses are attributed to potential weaker growth and low returns on assets due to climate change related risks.

4.5 **Proposed Project Ranking and Prioritization Process**

The proposed project prioritisation matrix require energy and decarbonization projects to be measured against additional factors such as Levelized Cost of Conversion Carbon Curve (LCCC), Marginal Abatement Carbon Curve (MACC) to highlight the effectiveness of the project. Thus, the combination of real options theory with the project ranking methodology can yield to positive results emanating from managerial flexibility and assessing projects within the correct context. Since energy is found in all phases of mining activities, the risks affecting these specific activities can be easily mirrored to the energy projects.

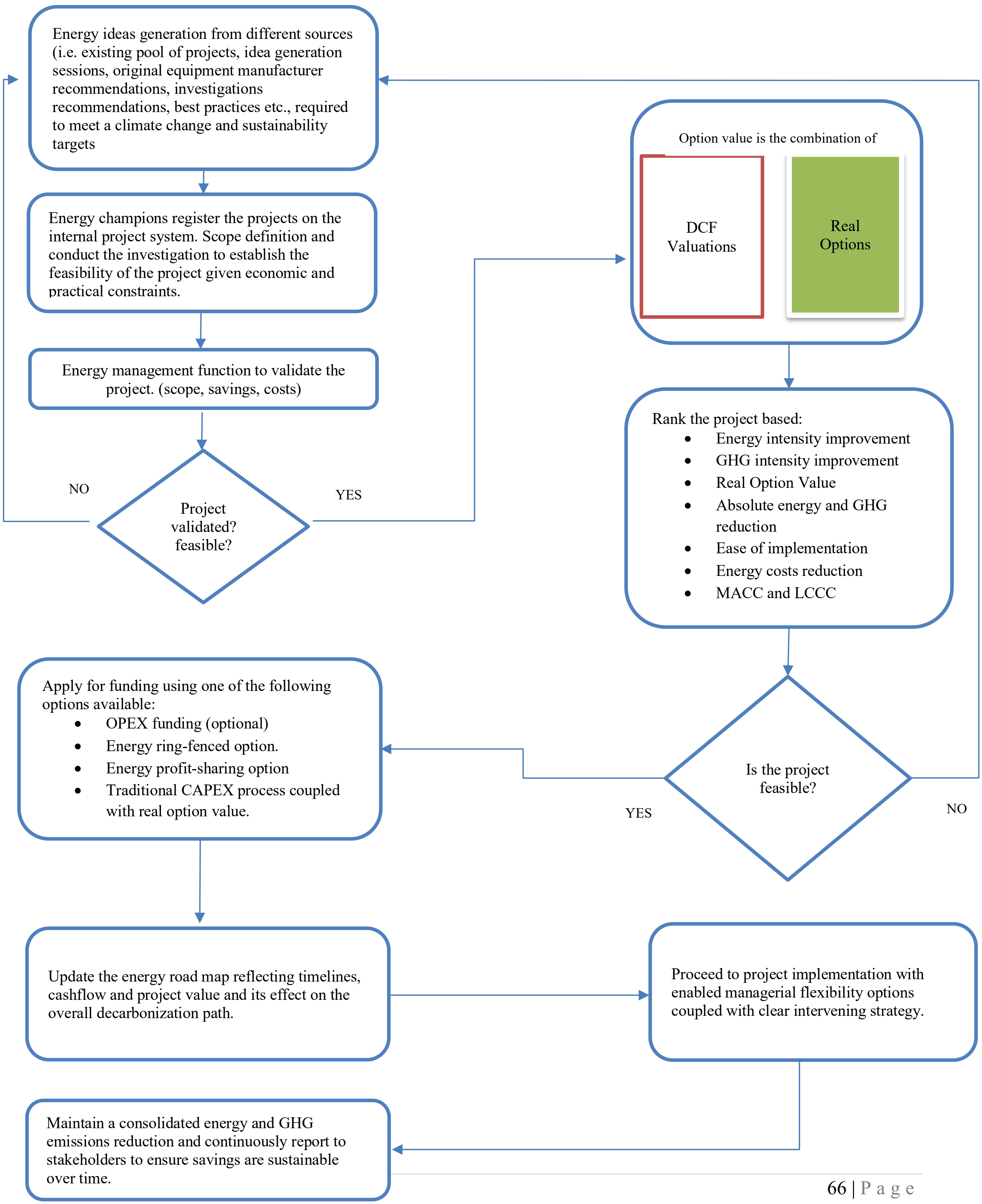


Figure 10 Ranking and prioritisation process.

Management can put managerial flexibility into practice through the development of a real time project risk register and the checklist with intervention points on clearly defined key performance indicators, e.g., the learning rates, minerals commodity prices, macroeconomic indicators, energy commodity prices, climate change policies evolution, taxation and rebates on climate change, funding options etc. This is termed intervening strategy in the proposed prioritisation and raking process in figure 10. The perfect example of a high risk yet valuable project when implemented correctly, is the partial electrification of dryers at the process plant (see Shepherd's Minerals case study). This project is chosen because of its high level of uncertainty due to operational & technological complexity.

5 Case Study: Shepherd’s Minerals

5.1 Introduction

The concept of real options theory has been applied in numerous sectors since its inception, including the energy space focusing mostly in evaluating renewable energy projects. In this research project, the focus is more on the application of real options in energy efficiency (including fuel switching) in the mining sector with the objective of enabling projects implementation amidst budget and technology constraints. The implementation of these projects will result in reduced emissions and energy costs resulting in a more profitable business and ensures sustainable growth. Real options tools give managers a right but not an obligation to intervene (defer, abandon, expand) in the project to improve gains through exploiting future growth opportunities.

5.2 The Real options in Context

Energy efficiency projects in the process plant require huge initial investments costs. The costs are associated with detailed engineering studies, upfront equipment procurement, installation and commissioning works. Such exorbitant costs can be curbed through investing resources in developing technical solutions, research & development, and in conducting pilot studies. However, the proposed interventions come at a cost and are high risk considering the technology readiness and market confidence in proposed solutions. Thus, managerial flexibility is necessary to enable dynamic strategies that will add additional value to projects given uncertainties.

The concept of upfront studies has been conducted by scholars in the energy filed focusing on renewable energies (Davis & Owens, 2003), (Kim, Lee, & Park, 2014). Real options analysis is applied in the context of optimising the use of R & D for high risk and high costs projects. The application of real options analysis is scalable and can be utilised to analyse the economic value of energy efficiency projects.

The case study presented, aims to understand whether to continue to use diesel or invest in partial electrification projects for the drying processes in the process plant. The main factors driving the decisions are the diesel costs, policy uncertainty evolution on GHG and the readiness of electrification technologies. The detailed constraints are presented in the research framework in figure 9. The research focuses the attention on the specific case and uses available techniques within the real options theory to establish if the investment is economically viable, identify key performance indicators to partial electrify dryers and analyse the costs impact of enabling different options of managerial flexibility.

5.3 Anonymity

Due to the nature of sensitive commercial information, the research shares high level inputs to the project. The name of the company remains anonymous to protect its commercial and financial information. The adopted approach is to use fictional name, Shepherd's Minerals. The detailed analysis are found under result analysis section. The agreement with the owner of the data stipulates that the report will be reviewed by the company to ascertain that no commercial information (that is deemed confidential) is shared with the public. Thus, there exist a possibility to see some minor changes in the commercial data (data inputs may be hidden to maintain anonymity or prevent the possibility of giving away the company identity) or use asterisk instead of actual data on the input. However, the analysis that shows the outputs will remain unchanged. The results may not be affected because the project values can be scaled up or down to project the confidentiality of the company.

5.4 Overview

The case study is based on the mining and processing company based in the continent of Africa. As a listed firm on reputable stock exchange, it publishes the energy performance, energy performance and sustainability information to relevant stakeholders.

Permission was given to the researcher to use the data on an anonymity basis, meaning the real name and details thereof of the company is not published to protect its identity and the confidential commercial information.

5.5 Site Diesel Consumption

The case study is based on the partial electrification of mineral processing dryers used for moisture removal from the mineral concentrates. The mineral concentrates comprise of minerals deposits normally found in the coastal areas along the ocean, and in some cases in inland areas. The project under review is very instrumental in enabling the business to achieve its short, medium and long-term climate-change commitments. The emissions are divided into three scopes, namely scope 1, 2 and 3. For the purposes of this study, the focus is on scope 1 where the business utilises fuel fired dryers for moisture removal to improve separability and efficiency for the downstream processes.

The mineral processing portion of the plant accounts approximately 50% of sitewide fuel consumptions. This is depicted by 2022 and 2023 actual consumption in figure 11 and 12 below. The fuel consumption at processing plant is solely utilised for drying processes. Hence, the electrification of drying processes will result in significant reduction in energy costs and scope 1 emissions. However, the existing technology is not ready to fully electrify the process owing to the unavailability of fully tried and tested solutions. Furthermore, the uncertainty exist on how the electric fired dryers will impact the process stability and product quality.

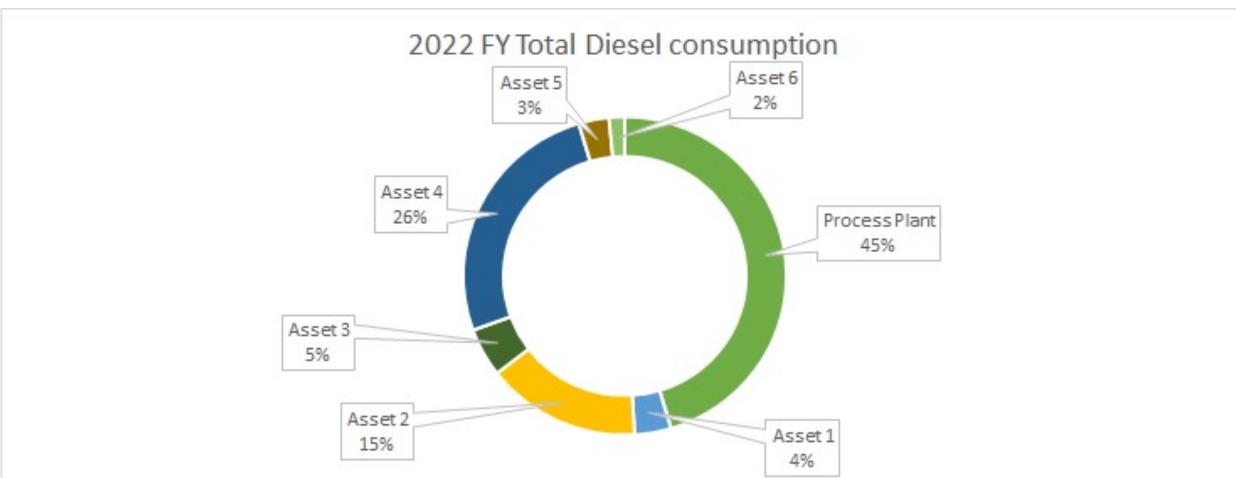


Figure 11 2022 Sitewide Total Diesel Consumption

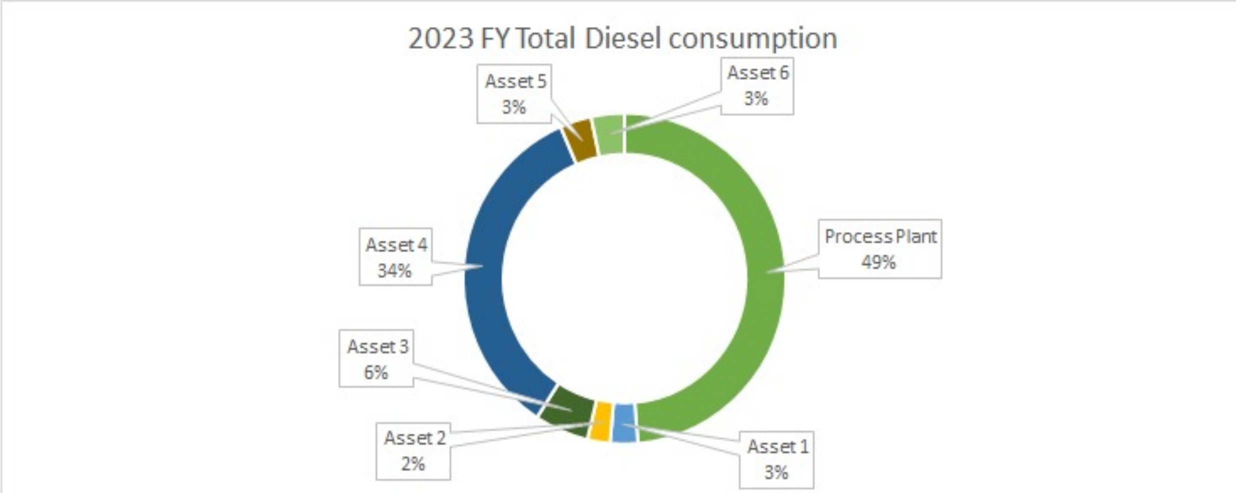


Figure 12 2023 Sitewide Total Diesel Consumption

5.6 Process Plant Diesel Consumption

Out of the process plant consumption, the *asset under study* consumes 50-55% of the total demand, this was a key criterion in selecting this circuit as the first one to run a pilot study to partially electrify its drying processes.

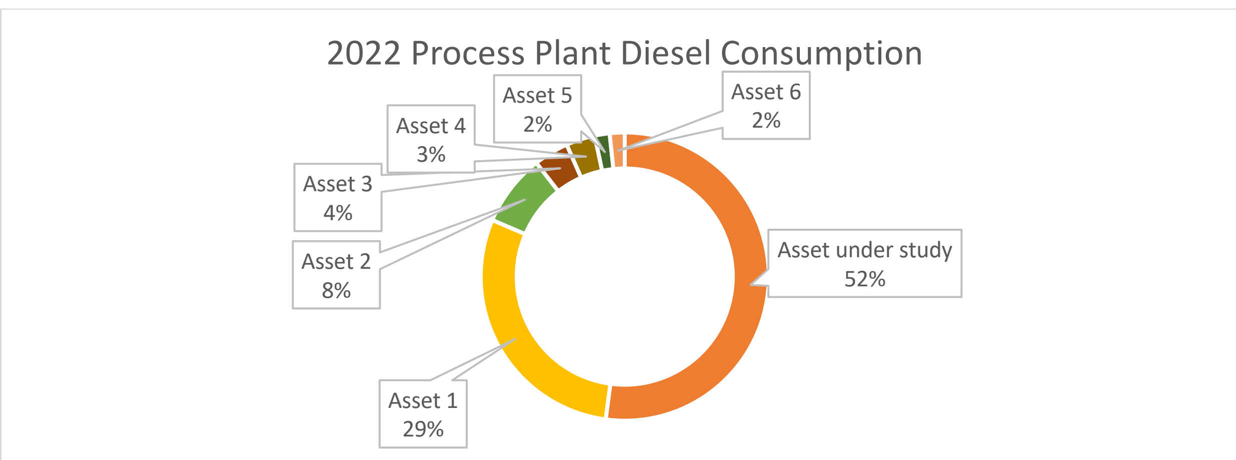


Figure 13 2022 Process Plant Total Diesel Consumption

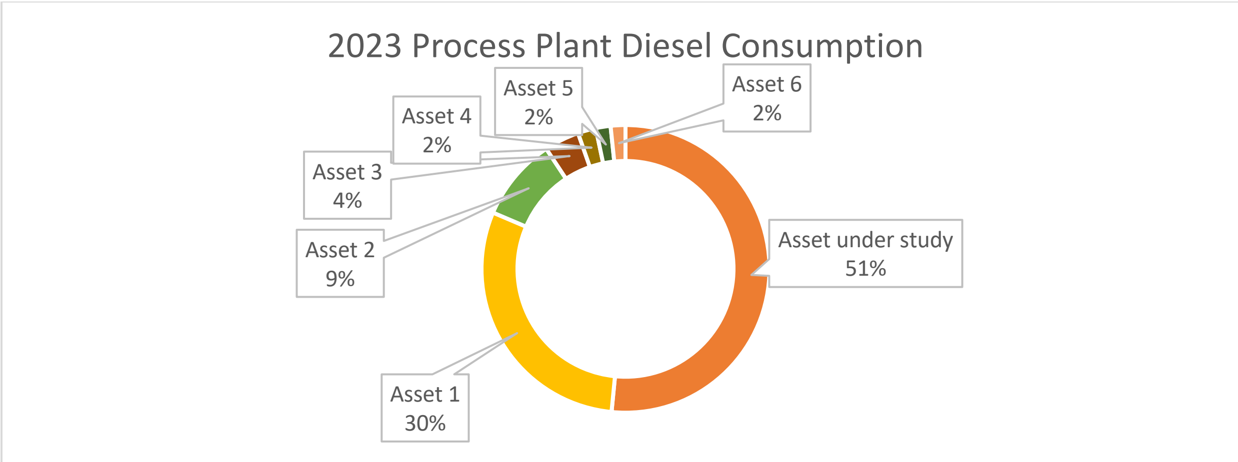


Figure 14 2023 Process Plant Total Diesel Consumption

The mineral concentrates from the wet high speed magnetic separation circuits consist of 60% solids and 40% water content. The high moisture consent is required upstream to create a slurry which is easy to pump over long distances and different geographical layouts. Furthermore, the Wet High Intensity Magnetic Separation is more effective on high moisture content. The mineral concentrates from Wet High Intensity Magnetic Separation are then separated into magnetic and non-magnetic products which goes through a continuous belt filer which reduced moisture further to 5-6%.

Thereafter, the remaining moisture is removed through the drying process for each product line. The drying process requires high energy input (mostly diesel, and a negligible quantities of liquefied petroleum gas for burners) due to the latent heat of evaporation to remove water or other solvents. The high energy requirements are evident from the literature, where (Kemp, 2012) highlighted that this process accounts for 10-20% of total industrial use in developed countries. This case study is from a developing economy, and the energy distribution is slightly above the one mentioned in (Kemp, 2012), however the data distribution is affected by the fact that the country under review is not fully industrialised.

5.7 Project Specifics

The drive behind partial electrification of the drying process is to reduce carbon footprint through utilising an alternative energy source with reduced carbon equivalent emissions per energy source, conserve finite fossil-based fuels, reduce energy costs and play a leading role in combating negative impacts of climate change.

The plan of action leading to climate change commitments and ultimately net-zero ambitions for the process plant are based on the large diesel users, starting with the pilot test on the *asset under study* at a small scale of 12% displacement of diesel consumption with an equivalent of 1MWp heater-based solution. Should the technology prove to be successful, it will then be scalable to full partial electrification of the *asset under study* with a potential further 40% reduction in diesel consumption with 3.4MWp electrical load requirements. Figure 15 shows the output of detailed analysis conducted on the *asset under study* circuits to quantify the trade-off between electricity and diesel-powered drying process, keeping thermodynamic parameters intact. The diesel displacement is limited to 40% reduction due to space constraints. More studies can still be conducted and through the use of real options management flexibility can play a crucial role in adaptive the scope of the project to increase gains.

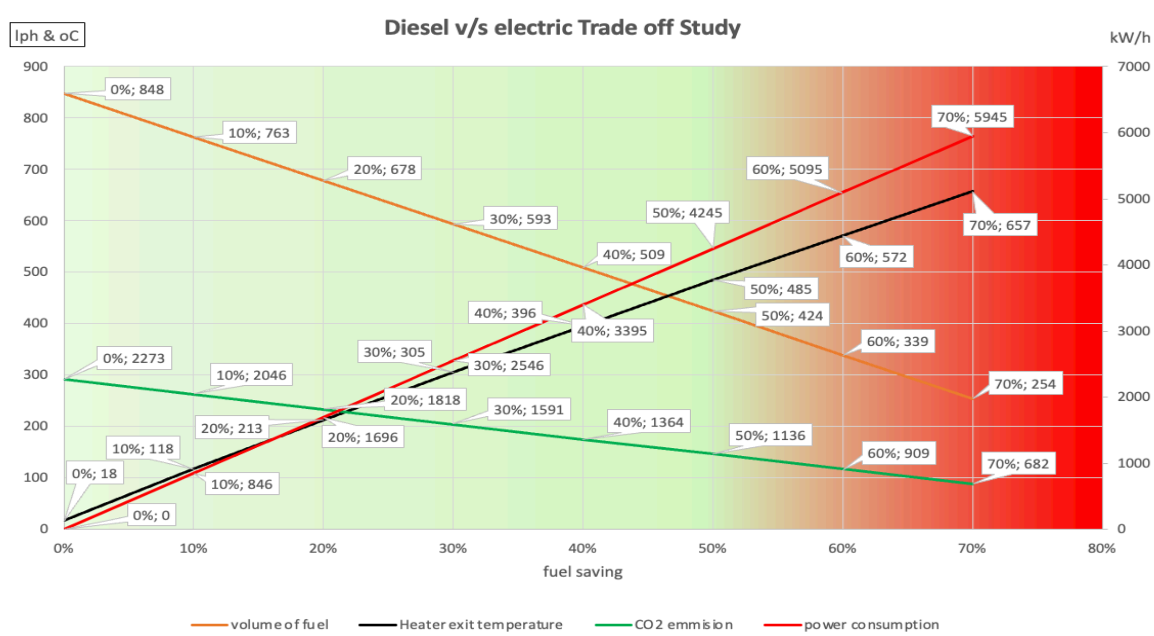


Figure 15 Trade-off studies for dryer partial electrification. (Minerals, 2023)

Thereafter all other dryers will benefit from the scalability of this solution using a phased approach owing to CAPEX availability, cashflow management, resource availability and decarbonisation strategy. The application of real options theory in this case will enable managerial flexibility and employ a phased or staged approach. The fair assumptions are such that should real options theory and management flexibility be used effectively; value will be harnessed through risk management mechanisms and necessary timely interventions.

5.8 Competing Constraints and Unknowns

The business is clear on its commitments to decarbonise its operations and contribute meaningfully in addressing global warming and climate change issues arising from industrial activities. The decarbonisation journey needs to be realistic and be completed in a cost effective and economic viable approach. The competing projects within the business make it challenging to motivate and implement energy projects, since the capital allocation process uses focuses on DCFs (NPV, IRR and payback) approach as a measure of the business case failure or success.

The key competing constraints affecting the implementation of this solution can be classified as follows:

5.5.1 Technology Readiness

The technology to fully electrify the drying process is not currently available at the commercial and industrial scale. Furthermore, the use of electrical heaters to increase the temperature of ambient air from the inlet duct has not been proven (with certainty and based on empirical evidence on similar installations at the sizeable process plant) to work effectively without compromising thermodynamic cycles within the process. Hence, this calls for a pilot project to test and prove this under the proof of concept for a specific application.

5.5.2 Process Stability and Thermodynamic Barriers

The drying process is very crucial and considered a bottleneck in the process plants similar to the one under study, particularly because of the interdependence between downstream processes and product grades specifications and quality. The multidisciplinary team (cross-functional team including electrical, process, chemical, energy and metallurgical disciplines) will assess the progress and liaise on technical feasibility taking into account all constraints, this approach will reduce any possible risks of failure.

5.5.3 Electrical Power

The electrification of the process requires additional capacity to supply new electrical loads. The constraints on power availability, if not considered during the due diligence and feasibility studies may jeopardise this initiative. These constraints ought to be assessed throughout the trial session and devise strategies to curb the potential loss of power supply (and power quality thereof). In addition, cost of electricity and electricity supply contract complexity will also be assessed during the course of the project.

5.5.4 Volatility in Energy (diesel and electricity) Prices

The energy price falls outside of the business control, due to volatility in the input factors driving energy prices such as geopolitics, climatic conditions and crude oil price movements. The electrification (partial) of the drying process needs to be economical viable to enable the business to maximise shareholder wealth whilst meeting its climate change commitments. The literature makes clear assumption on the energy price movements and how they can be aligned with geometric Brownian Motion.

5.5.5 Volatility in Commodity Prices

The source of funding required to develop and execute the energy projects is dependent mostly on the business profitability. The profitability of the business, among other factors, is depended on the revenues generated by the business. The biggest contributor to the business revenue is sales of mined and processed products, commodities. In cases where commodity prices fall or remain unpredictable, the business may take a position to halt its expenditure until such time uncertainty risks is acceptable.

5.5.6 Policy Certainty (carbon trading, incentives and taxation)

The climate change projects, particularly the ones dependent on energy performance, requires extensive amount of Capital Expenditure (CAPEX) and in some cases Operational Expenditure (OPEX) to implement and run in a sustainable manner. The lack of clarity on available tax incentives and policies on carbon tax hinders the business to have effective funding model for decarbonising operations. The amount of energy reduction and switching to alternative sources require background work on research and development, hence the policy certainty is of paramount importance to understand the impact on the business and enable optimal capital allocation. Furthermore, incentives could be pivotal in expediting the rollout of climate change solutions. The typical example would be, should the policy be clear on carbon tax rate and penalties, businesses would conduct sensitivity, cost-benefit and trade-off analysis on business cases to determine the viable options to invest now, delay, defer, abandon etc.

5.5.7 Environmental Regulations

In line with commitments to address climate change problems, environmental policies have been formulated to stop these problems. The promulgated policies and regulations play a crucial role in assisting businesses to conduct detailed analyses on the impact of uncertain factors and how to choose an optimal investment strategy. The uncertain factors include fuel price, electricity price, tax policies, carbon price, environmental regulations, commodity prices, solution equipment costs, power availability, market volatility and technology readiness.

The common factor on the aforementioned constraints is the lack of managerial flexibility, when projects are evaluated under DCF techniques. The use of real options will enable such flexibility to make each factor adaptative in a cost effective and sustainable manner during the life of the project.

5.9 Model Inputs

The set of assumptions are based on the case study commercial information and the assumed project volatility. The estimated CAPEX information is based on a 12% diesel displacement with an equivalent 1MWp electrical heater circuit (including auxiliaries) load requirements. The confidence level on the estimates is low due to the fact that the figures were scaled down from a 3.4MWp solution, assuming linear extrapolation. The volatility is assumed to be 30%.

Table 11 Case study model inputs

	Units of Measure	*Quantity*
Investment costs	$	1 849 205
WACC	%	14
CPI	%	2
Tax rate (VAT)	%	16
Asset Life Expectancy (Pilot)	years	2
Diesel price (estimated)	USD/litre	1.0
Electricity Tariff	$/kWh	0.08

Table 12 Case study binomial model inputs

Binomial model inputs	
volatility	0,3
u: up factor	1,063151
d: down factor	0,9406
PV: project present value	1,836309
K: Exercise price (project investment)	1,849205
r: risk-free interest rate	0,05
p: probability for u	0,892689
1-p: probability for d	0,107311
δt	0,041667

5.10 Volatility Assumptions

The volatility therefore depends on the market risks and other macroeconomic indicators. The volatility is measured as the standard deviation of the logarithmic returns on the free cash flow stream (Mun J. , 2006). This method is widely used for highly tradeable assets such as diesel and electricity prices, however this approach is less accurate for real options volatility estimations (Mun J. , 2006). Since electricity and diesel prices are significant in this analysis, the below formal can be applicable

The project volatility σ is estimated using a volatility of energy prices (i.e., fuel and electricity) or MCS from the expected cashflow of the project. The estimated σ assumes that the project is highly sensitive to the energy prices. The historical energy prices can be used to determine the volatility over a given period of time. However, for the purposes of this research, project volatility is assumed to be 30% throughput the analysis. This assumption is based on the movement of crude oil price ($/bbl.) for the period Feb 2019 to Dec 2023, and the price volatility was 32% (Adminstration, 2024).

$$Volatility = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}\left(x_i - \bar{x}\right)^2} :$$

Since the diesel prices depends on crude oil price movement, the changes in the crude oil are thought to have the same volatility effect on the energy price. Given the nature of regulated electricity market, the energy price volatility is negligible compared to diesel and is thus assumed to be less volatile. The reason behind fixing the volatility to a static value is to protect company information on energy prices volatility information, as this is very crucial in managing and controlling commercial information which contributes significantly in business operating costs.

Volatility can also be assessed using MCS through generating random iterations.

6 Results Analysis

Requirements for real options analysis

The requirements aim to enable an environment to facilitate the effective delivery of results (Mun J. , 2006). The proposed requirements are contextualised to align and address the content relevant to a specific case study. The generic requirements are divided into five points.

- *The existence of the financial model*

  The only requirement not met under this case study in the existence of the financial model. However, this does not necessarily demotivate the researcher because the real options valuations can be based on options pricing techniques.
- *The existence of uncertainty*

  The uncertainty exists in the energy commodity prices, technology availability, regulatory framework, incentive and taxation.
- *The uncertainty must have been sought to have a direct impact on the project investment*

  The changes in energy prices directly affects project profitability. The regulatory framework uncertainty affects capital allocation and prioritisation of projects in a resource constrained environment. Furthermore, the unavailability of tried and tested solution at an industrial scale directly affects project implementation approach, hence the need to minimise project risks by adopting a phased approach.
- *Management capacitated and empowered to make decisions*

  The management is assumed to be pro real options to ensure climate change commitments are achieved at a cost effective and economical viable manner.
- *Competent management to make decisions when required*

  The fair assumption is such that management will intervene to minimise project risk and capitalise in harness gains when opportunities present manifest.

6.1 **Discount Cash Flow - NPV**

The net present value is the present value of expected cash flow less the initial investment, $NPV_0 = PV_0 - I_0$. If the current market conditions are unfavourable, the project can be delayed further to the future time, T, until such time that NPV_T is greater than NPV_0.

The investment decision is based on the NPV performance, given the below scenarios:

- If PV_T is greater than I_0, that is present value at time, T, is greater than the initial project investment, then the decision is to invest in the project.
- If PV_T is less than I_0, then do not invest in the project.

Contextualising the investment decisions using case study data, we refer to the pie charts in figure 13 and 14. The charts depict annual diesel average consumption by the asset under study. The asset constitutes 52% of the total process plant consumption. The fuel consumption split is based on real data from the process plant, however, for illustrative purposes we scaled a figure with a measured actual consumption from the process plant at drying process. This aims to protect and ensure the company information is kept confidential and protected from other competitors in the market.

Assume total annual diesel consumption of 16 million litres, and the asset under study demand of 8 480 000 litres, with associated GHG emission of 22 943 tCO_2e. The emission factor of 2.70553 tCO_2e per cubic meter. The case study highlights two scenarios in the table format, where the asset under study consumes diesel based on business as usual scenario as well as 12% partial electrification of the drying process. Bothe scenarios are tabulated in the table 11 below, on a per annum basis.

Table 11 is used to illustrate the concept of DCF and real options analysis on the same dataset. There is a direct relationship between diesel consumption and scope 1 GHG emissions. This relationship is evident in a scenario of partial electrifying driers, diesel consumption decreases with the associated emissions.

Table 13 BAU vs 12% Partial Electrification of Drying Process

Scenario	Circuit demand (litres)	GHG Emissions (tCO2e)	Disel Reduction (%)	Power Requirements MW)
Business As Usual (BAU)	8,480,000	22,943	0	0
Partial Electrification (12% reduction)	7,462,400	22,190	12	1

Based on table 11 and the model inputs in section 5.9 (depicting diesel and electricity tariffs) applicable to the dataset. The diesel costs are higher than electricity costs, thus it is quite evident that partial electrification will immediately results in energy cost reduction. Cost avoided on fuel consumption is $1.02mil (difference between BAU and 12% partial elec., then multiply the difference by the diesel tariff). This immediate saving is misleading because is exclude the cost of electricity (additional 1MW load) and operations and maintenance costs. The realistic energy savings will thus include thee above to determine actual NPV.

Furthermore, the constraint exists in the system whereby there is no sufficient electrical power capacity to supply 1MW load. The deficit on the load requirement is 400kW. In order to test the first phase of the solution, a trade-off analysis is required to run other parts of the circuit on diesel generators for the rainy seasons (1 month on average) in a year during phase 1 duration.

The trade-off study may seem less valuable in short-term, however there are prospects of success for long term value should the concept prove to be successful. The success of a 1MW phase 1 project will enable the business to spend capital with certainty and expand electrical power network capacity and demand.

In order for other loads to remain connected after 1MW has been utilised for electrical reheaters, the prudent and temporary solution is to supply those loads with diesel generators. The assumptions necessary to estimate diesel requirements to cover power deficit is tabulated below.

Monthly Consumption	Month 1 (30 days)	Total CO_2e (tonnes)
Diesel Generator (Aggreko) - (litres)	89 289	242
Estimated kWh	297 600	
Hours per month	744	
l/h - combined gensets	120	
Max Genset Generation kW	400	
kWh = energy content of diesel in kWh x diesel eff @ 80% loading	297 600	
l/kW	223	

Input and Assumptions		
Emission factor	2,70553	l/kgCO2e
Energy Content	1 liter of diesel is equivalent to 10 kWh energy content	
	Using the attached diesel generator eff curve	
1 of diesel produces	3,333	kWh
0.3l of diesel produces	1	kWh
Diesel price (USD/L)	1	
Diesel costs (USD)	$ 89 288,93	
Number of genset	1	
Genset Output	400	kW

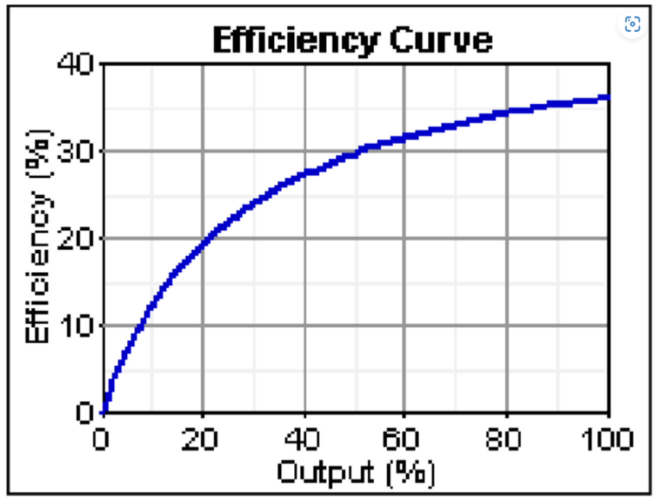


Figure 16 Estimated diesel: 400kW load.

The 400kW load generator load attracts additional $0.89mil for the 12% partial elec. solution. Below are the detailed business case calculations, including operations and maintenance costs.

Table 14 Case study detailed analysis

GHG Reduction							
Fuel Savings	**Ilm A dryer (Diesel Ltrs)**	**Total tonnes CO_2e**	**% CO_2 Reduction**	**If B20 % CO_2 Reduction**	**Additional Power Demand (kW)**		
0%	8,480,000	22,943	0%	0%			
12%	7,462,400	20,190	-12%	-10%	1000		
Running hours	6932.5	Hrs					
	79%	Utilisation		20,189,747			
OPEX							
Operational costs per year							
Fuel	89,289						
Labour (staff)	45,400	*Maintenance, used the same as a reheater. Exc man hours, existing labour*					
Other- Processing, Marine & Support	554,600	*Electricity*	Estimated electricity costs			$ 0.08	
Total Costs per Year	(689,289)						
Income/Savings per year							
Improved plant output	0						
Other - increased revenue (net)	0						
Other	(1,017,600)	*Fuel saving*	Estimated Fuel cost		$ 1.00		
Total Income/Savings per year	(1,017,600)						
Scrap Value							

Therefore, using the above inputs, the NPV technique suggest that the project could be accepted if the expected NPV(i)>0 and declined if NPV(i)<0. The assumption built in the model is that cash flow, C_t, is the net (including inflation) between costs and savings per annum.

The NPV is the calculated using the following table with $C_0 =$ \$1 859 205.00 $(initial\ cost\ from\ model\ input\ table), i = 14\%$ and C_tV^t =\$1 836 309.

$NPV(i) = -C_0 + \sum C_tV^t = -12\,897 < 0, payback = 6\ years\ and\ IRR = 14\%$;
thus, according to the NPV guidelines this project cannot proceed as it erodes the value of the business. Thus investment valuation based on DCF technique is not attractive.

The cost on doing nothing, assuming BAU (no project implementation) for the period of 10 years yields to even higher business costs due to rising energy costs (CPI effect and diesel price volatility), including the unquantified cost of carbon taxes and environmental penalties.

6.2 Real Options Pricing

6.3.1 Black-Scholes model

The black-Scholes model is derived from solving the partial differential equations, and it has found its application in pricing European call and put options. Contextualising this model in to our case study application, the following is derived.

Asset price: The current value of the underlying asset (S) is the present value (PV) of the project cash after taking into account factors such as flow circuit production capacity, price of the product, depreciation (assume straight-line method), CPI etc. The DCF input data shows that PV is \$1 836 309. The value is calculated by discounting cashflow over the project life, 10 years as assumed on the DCF calculations.

Exercise price: is equal to the required project investments, K = \$1 849 205 (initial investment). Given the project implementation time and life of the asset, the required investment is subject to inflation pressures. The consumer price index (CPI) is assumed in the model inputs.

Time to expiration: the pilot project implementation time for the current circuit is 2 years, however the solution can be extended to other circuits, hence the time to expiration 8 years. The asset life is considered to be 10 years.

Volatility of the underlying asset: is basically due to the errors between estimated cash flow and the value of underlying asset. The cost variation pertains to the equipment expenditure, commodity and energy prices. So, for the purposes of this study, it is assumed in the input model as 30%

Risk free interest rate: the interest rate is assumed to be 5%

Dividend: the project assumes no dividends payable.

The above input data is then tested on the following real options.

6.3.1.1 *Option to Defer*

The decision to delay the project implementation is equivalent to a European call option. Supposed the project is delayed for 2 years, the technology improves, and diesel price increases. Investment is \$1 849 205, present value is \$1 836 309, risk free interest rate = 5%, and variation of future cashflow is 30%. Given the above project parameters, the opportunity cost to wait (equivalent to a European call option of the project) is \$383 277, and the calculation details using B-S model are shown in table 15. This is what is basically a strategic Net Present Value of the project

Table 15 Black-Scholes European call option

INPUT VARIABLES	INPUTS	OUTPUT VARIABLES	CALCULATIONS	OUTPUTS
Standard deviation (annual)	0,3	d1	d_1= (ln(S_t/K)+(r+σ^2/2)(T-t))/(σ√(T-t))	0,431
Time to expiration (years)	2	d2	d_2=d_1-σ√(T-t)	0,007
Risk-free rate (annual)	0,05	N(d1)	NORM.S.DIST(d1, TRUE)	0,667
Stock Price	1 836 308,54	N(d2)	NORM.S.DIST(d2, TRUE)	0,503
Exercise Price	1 849 205,00	Call Option	$C(S_t,t) = S_tN(d_1) - Ke^{-r(T-t)}N(d_2)$	383 276,49

The option value derived from deferring the project is static NPV plus the NPV determined from the traditional approach, which can be represented mathematically as:

Expanded NPV = static NPV+ real option value.

= (-12 897) + \$383 277

= \$370 380

The wait option gives the business a strategic NPV of \$383 276, when compared to the NPV of -\$12 897. If the market is favourable after two years (given the input assumptions), the business will exercise the real option in the money. If the market is unfavourable (NPV was used as a sole analysis technique), the company will choose not to invest in the project. However, the option value of \$370 380 that sums NPV and real option value suggest that the project can still be implemented. The cost benefit will thus be an opportunity cost of strategic NPV as opposed to \$1 849 205 investment. Therefore, if the project under given parameters was evaluated using DCF techniques, it would have been unfavourable to proceed. Therefore, the inclusion of real options makes the project more valuable.

6.3.1.2 Option to Abandon

The decision to abandon the project implementation is equivalent to a put option. For the purposes of this study, the American option is considered after 2 years the project had commenced. The holder of a put option has a right but not an obligation to sell the asset at a specified time in future. The holder will review the market conditions and decide whether it is worthwhile to exercise the option. The exercise price is the project investment, K, and stock price is the sum of present value of future cashflow as adjusted by the inflation, S. Assume that the conditions are unfavourable (owing to rising electricity prices, decreasing diesel prices, delayed in carbon tax, no feasible technology etc) and electrification of dryers is abandoned at time T=2, then the real option value is $220 197.

INPUT VARIABLES	INPUTS		OUTPUT VARIABLES	CALCULATIONS	OUTPUTS
Standard deviation (annual)	0,3		d1	d_1= (ln(S_t/K)+(r+σ^2/2)(T-t))/(σ√(T-t))	0,431
Time to expiration (years)	2		d2	d_2=d_1-σ√(T-t)	0,007
Risk-free rate (annual)	0,05		N(d1)	NORM.S.DIST(d1, TRUE)	0,667
Stock Price	1 836 308,54		N(d2)	NORM.S.DIST(d2, TRUE)	0,503
Exercise Price	1 849 205,00		Put Option	$P(S_t,t) = Ke^{-r(T-t)}N(-d_2) - S_tN(-d_1)$	220 197,83

The value of the project prior including flexibility is not worthy investing, however after the real option to abandon the value is positive. Hence, the project can proceed and the project value can be harnessed after abandoning the investment owing to less favourable conditions. The expanded NPV >0, and can be represented as follows.

Expanded NPV = static NPV+ real option value.

= (-12 897) + $220 197

= $207 300

It follows from the analysis that if the project was evaluated using DCF techniques, it would have been unfavourable to proceed. Therefore, the inclusion of real options makes the project more valuable.

The same conclusion is being reached for both put and call scenarios. The results shows that real options analysis bring about much needed value when compared to the DCF.

6.3.2 Binomial (Lattice) model

Binomial lattice tree model works on the principle that the outcome of the node give rise to two options, up or down (on the value of the asset price), with assigned probabilities. This discrete numerical method finds application in the stock movement in financial options, namely the American style options. Since real options theory works on the same principle, the application of this principle is extended to simulate the investment outcomes of this study. The American options are chosen because of their characteristics to exercise the option until the expiration day, this is analogues to management flexibility to intervene during the course of the project. However, European options are analysed below to illustrate the point. The binomial lattice model is chosen because of its simplicity when compared to the binomial tree. It has a reduced number of nodes. The asset value of moving up and then down has the same probability as moving down then up.

6.3.2.1 Option to Defer

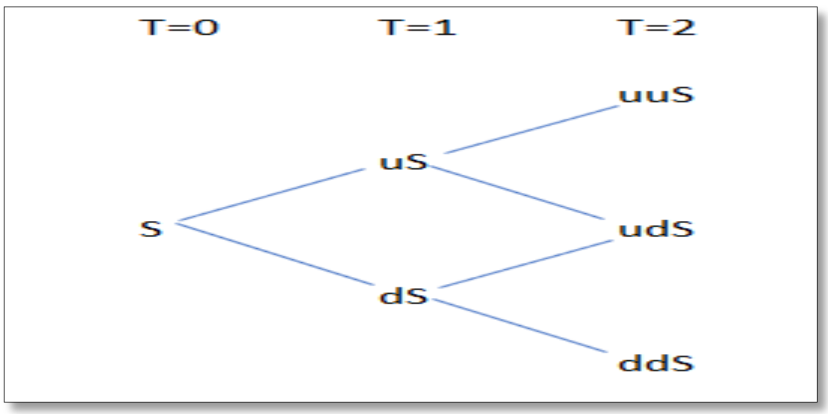
This option will be realised when the current macroeconomic indicators suggest that it will be less profitable to implement the project right away due to many uncertainties. The option entails that the solution is delayed until such time that relevant information becomes available and risk of uncertainty is minimal or eliminated.

The business can decide to implement the 1MWp partial electrification solution or to defer it to some time in future. The decision tree without an option to defer (no flexibility) is constructed and compared with options to defer. In this analysis, mathematical approach is preferred.

The favourable option is the one which yields highest NPV, hence the computation of NPV for each branch must be determined using the model input data. The cost of not implementing the solution, with a probability 1-p, is $0 because no amount has been spent. However, in greater details, the costs is higher arising from lost opportunities.

Furthermore, the outcome of the decision tree leverages by using real options managerial flexibility with the options to defer, and leveraging from this flexibility the business defers the investment opportunity to a specific time in future. This scenario builds from the no option to defer case above and delay this investment for n years in future and re-run the same scenario combining both tree into one.

Using the simple tree that represents a delay of the investment by two-period (T=2). The binomial tree model with risk neutral probability (p), up-factor (u) or down-factor (d) over a time interval, $\delta t = 1/24$. The probability of moving from time T=0 to T=2 with the up-factor is p, and with the down factor is (1-p).



The pay-out for a call option (option to defer) is $\frac{pC_u+(1-p)C_d}{1+r}$ and

$C_u = \max\,(S_u - K, 0)$,

$C_d = \max\,(S_d - K, 0)$

The risk-free probability is given by

$$p = \frac{(1+r) - d}{u - d}$$

The analysis focuses only on the 2-year project delay, and the summarised project value and option payoffs are tabulated before.

Period 0	Period 1	Period 2	Project Value	Call Option Value
initial stage	*u*	*u*	*uuS*	*max(uuS-K,0)*
	u	*d*	*udS*	*max(udS-K,0)*
	d	*u*	*duS*	*max(duS-K,0)*
	d	*d*	*ddS*	*max(ddS-K,0)*

Period 0	Period 1	Period 2	Project Value (mil)	Call Option Value (mil)
initial stage	1,063	1,063	$2.08	$0.23
	1,063	0.941	$1.84	$0
	0.941	1,063	$1.84	$0
	0.941	0.941	$1.62	$0

It is clear that deferring the option to undertake the project in 2 years' time gives the project a competitive and higher value, as opposed to implementing it immediately. The PV at time T=2 is $2 075 562; thus, the *max(uuS-K,0)* is $226 357 > 0.

6.3.2.2 Option to Abandon

The option focuses on the possibility that the project cannot be implemented owing to unfavourable conditions and high project risks coupled with unknows. The option to abandon limits potential losses from implementing the project. So once the project has been abandoned, it may not resume from where it ended however it will have to start at the beginning as a new project. The project is abandoned to obtain the project scrap value, and the table below shows the value (greater than $0.2246) entrenched in the project for the d factor path, namely ddS. The other option could be the temporary shutdown of the project following the path udS or duS ($0,0129).

Using the similar binomial lattice approach, the option to abandon is equivalent to the European put option. The pay-out for a put option (option to abandon) is $\frac{pP_u+(1-p)P_d}{1+r}$ and

$P_u = \max(K - S_u, 0),$

$P_d = \max(K - S_d, 0)$

The analysis focuses only on abandoning project after T=2, and the summarised project value and option payoffs are tabulated before.

Period 0	Period 1	Period 2	Project Value	Put Option Value
initial stage	*u*	*u*	*uuS*	*max(K-uuS,0)*
	u	*d*	*udS*	*max(K-udS,0)*
	d	*u*	*duS*	*max(K-duS,0)*
	d	*d*	*ddS*	*max(K-ddS,0)*

Period 0	Period 1	Period 2	Project Value (mil)	Put Option Value (mil)
initial stage	1,063	1,063	$2.08	$0.00
	1,063	0.941	$1.84	$0.0129
	0.941	1,063	$1.84	$0.0129
	0.941	0.941	$1.62	$0.2246

Given the probabilities, analysis shows that the project can be safely abandoned in future under the uuS route, as it gives $224 571 disposal value.

6.3.3 Option to Expand

The outcome of the pilot test analysis can result in the expansion from 1MWp to 3.4MWp solution, provided the project trade-off shows positive results. This is equivalent to 240% expansion from the initial 1MW installation, and the associated exercise price is $3 401 967. The option to expand is equivalent to the call option, and through traditional valuation techniques it shows that the project is valuable (static NPV >0) and can proceed with no issues. The only concern is the analysis is based on the assumptions that technology will work as planned and can be extended, this assumption remains untested without 1MW solution and detailed 3.4MW solution technical studies. This uncertainty is managed through a phased approach commencing with detailed engineering studies and capex development analysis. Further to that, also to analyse the cases of deferring and abandoning projects until such time the conditions are favourable. For such reason, the option premium or strategic NPV is omitted for a full-scale rollout. The note worth taking, is to highlight without detailed analysis that the inclusion of option flexibility component in the project will drive the project value higher.

6.3 Summary of Results.

The main objective of the research was to investigate the use of real options theory to evaluate capital intensive energy projects to address DCF drawbacks and obtain value entrenched in these projects. The results shows that ***H1*** can be accepted that real options theory derives more value than DCF techniques.

7 Conclusions

Real options come handy in an investment environment coupled with risks and uncertainties. The real options theory plays a crucial and integral role as a strategic technique in capital investment decisions. The implementation of this technique over the traditional discounted cashflows highlights the positive business impact in achieving business goals - profitability and climate change commitments. The future investments opportunities based on real options provide alternative solutions to enable optimal resource allocation considering the urgency and economic viability of the solution. Furthermore, real options theory analysis inspires confidence to management entrusted to make effective decisions; this is enabled using a systematic learning approach. The systematic approach affords management necessary experience on how to react to changing environment over time, in favour of the investments. The experience gained during the execution of intervening strategies give management freedom and comfort to deal with ad-hoc and uncertain problems facing investment portfolios. Thus, management develop skills to conceptualise and understand project risks (and rewards) over time as well as effective risk management processes. The assumption underlying real options is such that management will act accordingly, when required to do so by changing market conditions. It further suggests that management is confident, competent and act in the best interest of the company to minimise risks, improve gains and keep business reputation intact. In addition, input factors were assumed for missing data points with reasonable support from the literature. This was also concluded to ensure company data remains protected.

The common managerial flexibility, the defer, allows the business to wait, observe and intervene. However, this is achieved at the expense of the cost of waiting. The cost is as a result of opportunities and benefits forgone by not immediately implementing the project at full scale. The theoretical trade-off analysis shows positive benefits associated with implementing the solution owing to low electricity prices when compared to diesel prices. Furthermore, the continued transparent reporting to stakeholders in the market shows that the business is marching forward with action plans gearing towards Net-Zero ambitions. However, the practical and empirical evidence analysis can only be understood with certainty after the solution has been implemented tested and proved to be successful.

The key consideration in applying real options theory / analysis in investment analysis is to understand the managerial flexibility options, and empower management to intervene with favourable and winning strategy. This calls for brave, having an element of risk appetite and competent individuals who can easily reach conclusion based on the sound judgement. Management flexibility alone without action is no different from traditional valuation techniques.

It is evident from the analysis that real options analysis results in positive business cases when the management flexibility is employed. The critical component remains the timing on when to intervene, and also it depends on the persons entrusted to exercise managerial flexibility decisions.

7.1 Summary of the Findings

The details on each technique are elaborated further in the above respective subsections. The distinction between DCF and real options theory / analysis is compared by means of the table in the literature review section. To further clarify the point and summarise the results, we borrow the graphical representation by (Locatelli, Mancini, & Lotti, 2020) to illustrate the key differences when evaluating investments using both methods.

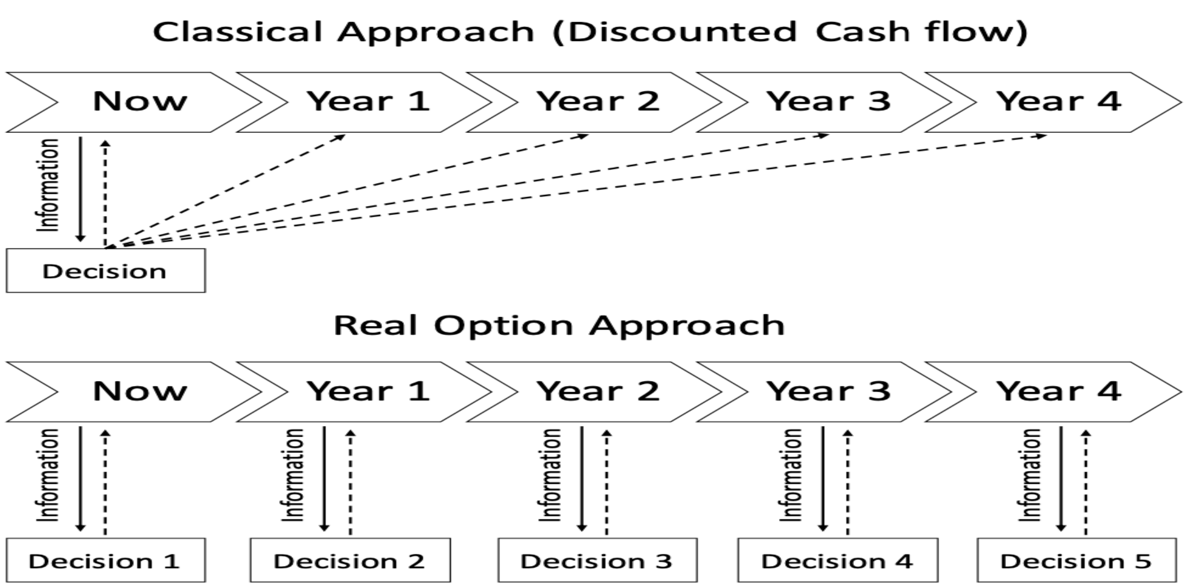


Figure 17 DCF vs Real Options methods (Locatelli, Mancini, & Lotti, 2020)

The option value is computed using the formula methods discussed by (Aarle, 2013) and (LenosTrigeorgis, 1993): The below formula indicate that option value is the summation of the real option and the traditional NPV, and this is evident that real options work in conjunction with the DCF techniques.

Total Project Value = Net Present value + Adjusted Option Value +Abandonment value
Expanded NPV = Passive NPV + Option premium + Strategic value
Expanded NPV = Passive NPV of expected cash flows + value of options from active management

For the purposes of this report, the simplistic approach similar to the ones above uses this mathematical formula: *Option Value = static NPV+ real option value.* This is the summation of the project value without flexibility and the one with flexibility built in the project. The options are always non-negative regardless of the value of the static NPV, this is so because the main objective of intervening is to improve the project gains and minimis losses - hence it is crucial to enable the flexibility to harness this value.

Real option value could be either defer, abandon and expand depending on the scenario under study.

The values obtained from both Black-Scholes and Binomial models suggest that enabling managerial flexibility increases the value of the projects when compared to the DCF approach. The overall value option shows positive NPV across all scenarios, hence it is profitable to exercise the option at time T=2.

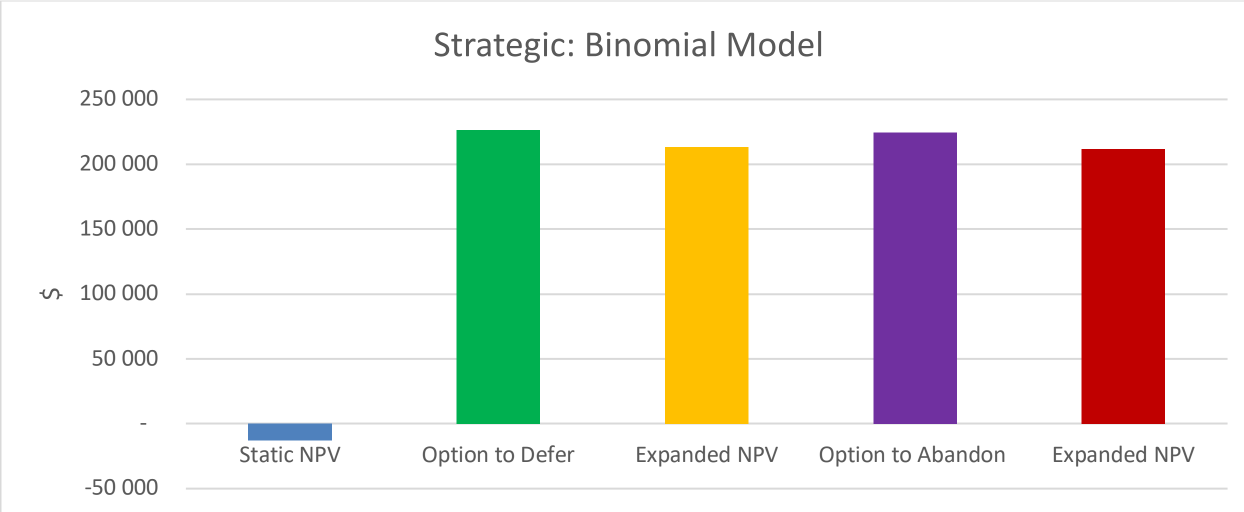


Figure 18 Expanded NPV: Binomial Lattice Model

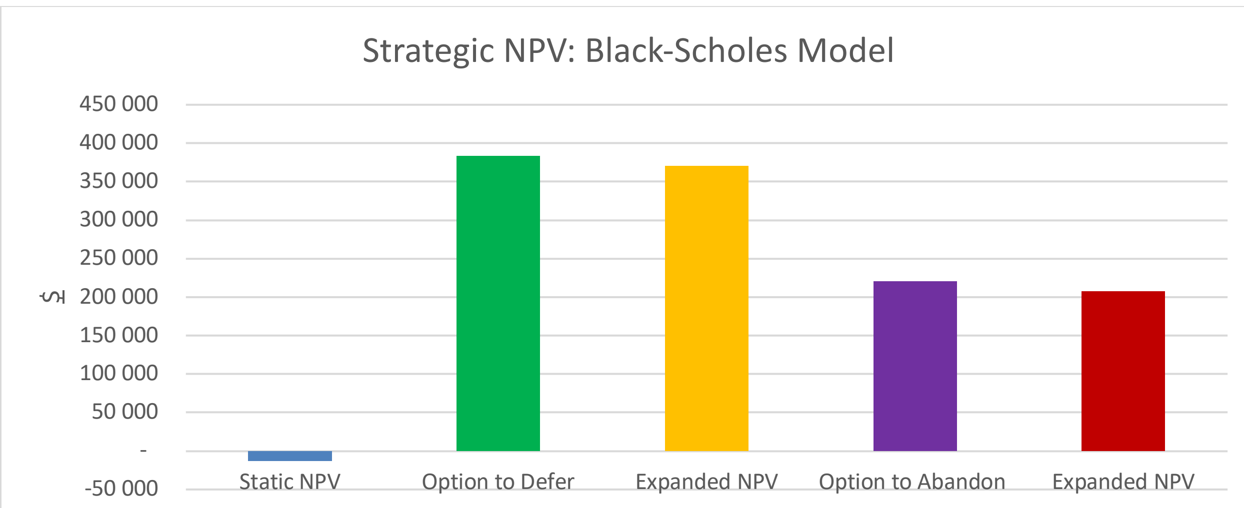


Figure 19 Expanded NPV: Black-Scholes Model

Furthermore, the option premium can be determined as the difference between expanded or strategic NPV and the static NPV. This is easily achieved through mathematical manipulation of the expanded NPV equation. Option premium is also referred to as option value. In line with (Barton, 2011), the option premium sought to introduce symmetry in to the project NPV probability distribution function by shifting it to the right of static NPV.

Results from both B-S and binomial lattices methods highlight positive value harnessed from evaluating energy projects investments under uncertainty and dynamic conditions. The objective of the research focuses on closing the gap of underutilising real options theory in capital intensive energy projects in the mining sector, this has negatively affected these projects as a result of competing constraints. The uncertainties associated with energy projects and scarce resources have marginalised these investments when evaluated using traditional valuation techniques, their value is hidden and end up not prioritised. Real options theory aimed at addressing this blind spot by enabling ,managerial flexibility throughout the life capital energy intensive projects. Results show positive outlook from analysis conducted from the real mining company dataset.

7.2 Policy implications

The majority of emissions are as a result of industrial activities of numerous processes that involves different forms of energy. The energy component constitute the majority of environmental degradation through production of harmful emissions. The world leaders and institutions have taken a firm position to limit the damage our activities have on the environment. The most aggressive and effective manner to intervene is to utilise non-renewable energy sources and energy carriers effectively through the implementation of energy efficiency initiatives and fuel switching (low carbon) solutions. Energy projects that can contribute meaningfully in aggressive global warming and climate change are capital intensive in nature. These projects compete with other business and strategic goals within the capital constrained businesses, and they seldom take long to pay back. Thus they turn to loose urgency in the prioritisation committees.

The adverse implications energy related activities have in nature is huge, and implications are well documented. However, the lack of clarity on available tax incentives and policies on carbon tax hinders the business to have effective funding model for decarbonising operations. The amount of energy reduction and switching to alternative sources require background work on research and development, hence the policy certainty is of paramount importance to understand the impact on the business and enable optimal capital allocation. Furthermore, incentives could be pivotal in expediting the rollout of climate change solutions.

7.3 Limitation of the study

The study is limited to the application of real option theory in project valuation scenarios within the mining industry, focusing particularly on the energy projects. The availability of data set constrained the results analysis to a specific case study in one mining company that comprises of mining and processing plants. However, the particular focus was on the process plant given the urgency and intensive use of energy by mineral drying loads. The scope was further constrained into energy project with specific attention to fuel switching projects from diesel powered to electric driven driers. Due to the time constraints, the cost associated with adopting and implementation of real options theory was not considered.. In real options analysis, the managerial flexibility to defer, abandon and defer were analysed in details. The limitation to a single company can also be attributed to the sensitiveness of energy data from mining companies, making it difficult to share with researchers as it may compromise their competitive advantage. The researcher is also in difficult position which could jeopardize the research because, at the time of this research, was employed by one of the mining companies within the sector. The study further limits the application of real options theory to two models, namely, binomial lattice and Black-Scholes models. This should provide a richer and more in-depth analysis of the available data set. Three hypothesis were stated, however due to time constraints only ***H1*** was tested as it considered as the main hypothesis in line with research objectives.

7.4 Areas for further research and recommendations

The real options analysis is more than just the numerical analysis and interpretation of results, it goes a step further and consider active actions taken by management to influence the outcome of the investment. Hence, real options theory approach is more process oriented with clear and decision-making elements. The value entrenched in real options solely depends on one taking actions, therefore without proper implementation the value can go unrealised.

The employment of real options theory still lacks behind in the energy efficiency project valuations, specifically for the mining sector. A further study is required to draw a comparative analysis of options pricing methods and tools discussed in this research with traditional valuation techniques for a multi-discipline project - that is affected by more than one factor. The resources required to simulate, analyse, and interpret real options analysis needs to be identified and be sought fit for purpose to improve the confidence level of the outcomes. The development of ready, plug and play models is required to ensure that ROT is as competitive as DCF models in real life applications. The proposed approach is to utilise dependable software such as R, MATLAB and Risk Simulator to produce and present results in a formal and comparable manner. The costs of implementing and maintaining real options analysis tools remains less researched, particularly for the application in the mining sector. This area need to be explored further to bring evidence based comparison. The senior management buy-in is necessary in developing necessary talent pool to utilise real options with DCF in investment analysis. The businesses need to appreciate and adopt modern investment valuations techniques that consider value-based approach such as PaR and VaR. A qualitative study is required to establish the views and /or a possibility of businesses to look at alternatives to the DCF methods.

Future works under the real options analysis for energy projects in the mining sector can be extended to include dynamic programming techniques and Monte Carlo Simulations. These methods have been deployed on real options analysis valuations in other real-life applications. The analysis can therefore enable researchers to understand the in-depth analysis of results using four well established theories to explain relationships (or non-existence thereof) of real options theory and capital budgeting using empirical evidence. Furthermore, the study can be extended to include multiple energy efficiency projects with complex interdependencies to ascertain the relevance and dependability of the theory. The results highlighted the theory is well developed and can be implemented in real life applications, however to improve the confidence level of the results, it is recommended to select input factors using historical data set (i.e., energy prices, up and down factors, risk-free interest rate, delta t) from the realistic practical data as opposed to assumptions.

The exercise of real options through managerial flexibility could result in potential loss of earning that could have been derived from the project, should it not have been deferred, abandoned, or scaled down. Therefore, a favourable trade-off is required to ensure that the value of management flexibility outweighs the benefits of implementing the project. The additional recommendation, provided the company approves of such in future, will be to revisit the project once it has been implemented and re-run the calculations to understand the impact of real options using actual data,

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8 Definitions

The operational definition is defined by (Ochara, 2016) as the process of specifying how various concepts or variables of the research will be measured. This research follows a quantitative approach and will thus measure a project's economic viability by checking the profitability, payback, and risks associated with selected energy projects. The definitions below are from the literature, and were contextualized for this study by the author of this report.

Ambition: an objective the business aims to achieve on which they pathway to deliver has not been fully developed with certainty.

Capital Asset Pricing Model: A model used in pricing of risky securities; it describes the relationship between risk and return.

Discounted Cash Flow: A valuation method used to estimate the attractiveness of an investment opportunity through comparing different projects.

Decision Tree (DT): A schematic tree-shaped diagram used to show different outcomes of the event.

Internal Rate of Return: The discount rate used in investment valuations, that when solved mathematically, make the NPV equal to zero.

Flexibility: the ability and capability to revise decisions in a project, regardless of if the project phase provided the intervention will minimise risk and improve gains.

Greenhouse gas: combination of anthropogenic emissions of carbon dioxide, hydrofluorocarbons, nitrous oxides, methane, perfluorocarbons, and Sulphur hexafluoride - measured in carbon dioxide equivalent.

Levelized Cost of Conserved Carbon Curve: refers to the difference in NPV prior and post energy and carbon reduction project implementation divided by the difference in total annual carbon emissions prior and post energy and carbon reduction project implementation.

Marginal Abatement Cost Curve: refers to the cost curve reflecting the cost per tonne of GHG emissions of the abatement project when compared to the business-as-usual performance.

Monte Carlo Simulation: a random number generator founded by Monte Carlo, used in investment valuations (among other areas) by running several simulation scenarios.

Net Present Value: refers to the valuation technique under the DCF. It is the sum of all present value cashflow, incorporating the income and outgo already discounted by the discount rate.

Real option: is a right, but not an obligation, to undertake a specific task in future at a cost to a tangible physical asset under uncertainty. It is useful to assess decision making under uncertainty to enable management flexibility capture business value not possible through DCFs.

Sunk Cost: refers to the cost that has been incurred in the project, and that cannot be recovered.

Target: an objective the business aims to achieve on which the planner delivery has been developed.

Weighted Average Cost of Capital: A method used to calculate the weighting of the investment into debt and equity, determining the total cost of capital. This is normally used in capital budgeting and expressed in percentage.

9 Appendices

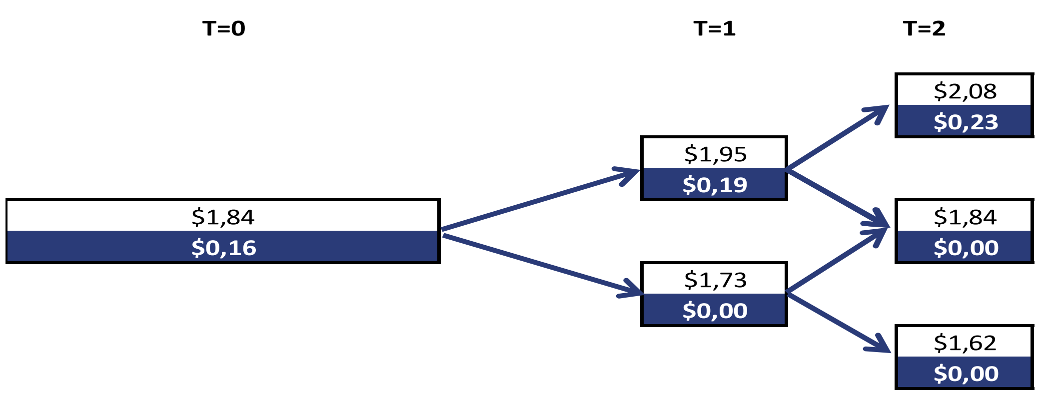
A. Binomial Lattice Model

Binomial Model Inputs	
volatility	0,3
u: up-factor	1,063151
d: down - factor	0,9406
PV: project value	1,836309
K: Project cost	1,849205
r: risk-free interest rate	0,05
p: probability up-factor	0,892689
1-p: probability down-factor	0,107311
Delta_t	0,041667

NPV($ million)

	0	1	2	3	4	5	6	7	8	9	10
0	1,84	1,95	2,08	2,21	2,35	2,49	2,65	2,82	3,00	3,19	3,39
1		1,73	1,84	1,95	2,08	2,21	2,35	2,49	2,65	2,82	3,00
2			1,62	1,73	1,84	1,95	1,95	2,21	2,35	2,49	2,65
3				1,53	1,62	1,73	1,84	1,95	2,08	2,21	2,35
4					1,44	1,53	1,62	1,73	1,84	1,95	2,08
5						1,35	1,44	1,53	1,62	1,73	1,84
6							1,27	1,35	1,44	1,53	1,62
7								1,20	1,27	1,35	1,44
8									1,13	1,20	1,27
9										1,06	1,13
10											1,00

B. Two-period Call Option Binomial Model



Based on the binomial lattice model, the call option pay-out is:

$$= \frac{pC_u + (1-p)C_d}{1+r}$$

$$= \frac{0.89*0.23 + 0.11*0}{1.05}$$

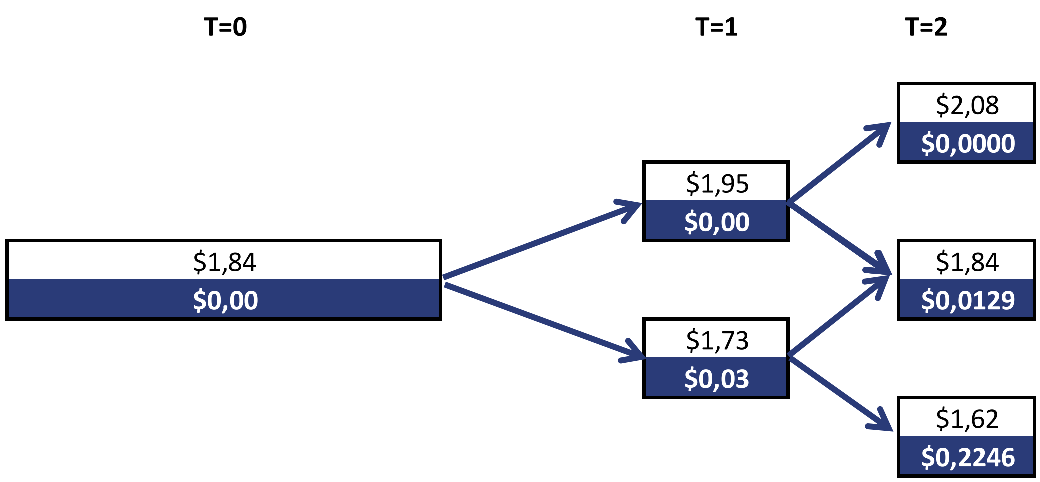
<u>=$ 194 952</u>

Strategic NPV = static NPV+ real option value.

Strategic NPV = -12 897 + 194 952

Strategic NPV **= $ 182 055**

C. Two-Period Put Option Binomial Model



Based on the binomial lattice model, the call option pay-out is:

$= \frac{pC_u+(1-p)C_d}{1+r}$

$= \frac{0.89*0+0.11*0.2246}{1.05}$

=$ 23 529

Strategic NPV = static NPV+ real option value.

Strategic NPV = -12 897 + 23529

Strategic NPV = **$ 10 632**