



Analysing financing models for energy efficiency projects in the South African mining sector

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A low-carbon, energy-efficient future will be driven less by sentiment or politics than by the disciplined, financially sound execution of high-return projects in efficiency, clean generation and storage. This dissertation is a modest contribution to that transition and rests on the support, guidance and grace of many people.

My late grandfather often said: “Die lewe is soos ’n Jawbraker, hard maar lekker.” (Oupa Willem Burger). The MBA journey has reflected this: demanding and at times exhausting, yet deeply rewarding and a fitting metaphor for life. I am profoundly grateful to the Lord, who sustained me through the hardest stretches. “I sought the Lord, and he heard me and delivered me from all my fears” (Psalm 34:4), and “Even there your hand will guide me, your right hand will hold me fast” (Psalm 139:10). These promises have been a constant source of strength.

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ABSTRACT

South African mining companies face mounting pressure to reduce energy costs and lower greenhouse gas emissions. However, the adoption of mine-site energy efficiency projects (EEPs) remains constrained by financial barriers and competing capital demands (Burger *et al.*, 2024; Chavalala & Nhamo, 2014; Minerals Council South Africa, 2023). This study evaluated the impact of alternative financing models and capital structures on the bankability of EEPs in the South African mining sector, considering realistic tariff, incentive and risk conditions. A systematic literature review was conducted to map available financing sources – including internal funding, commercial and concessional debt, leasing and energy services company (ESCO)/performance-contracting structures – and to identify gaps in project-level financial analysis. Based on these insights, a lender-grade quantitative modelling framework was developed that integrates Megaflex tariffs, Eskom demand-side management incentives, Section 12L income tax allowances, corporate tax, and company-specific weighted average costs of capital. The framework was applied to three representative EEPs (a heat-pump water-heating retrofit, a compressed-air valve-optimisation project and a battery energy storage arbitrage project) across five mining companies and twelve financing models, generating 180 simulations. The results indicate that for projects with strong technical and economic foundations, concessional energy efficiency loans combined with optimised debt-equity mixes generally deliver the highest net present values and strong discounted internal rates of return. In contrast, relying solely on internal funding and prime rate debt remains feasible, but it is less value-efficient. For the compressed-air valve-optimisation project, leasing is particularly appealing as it transforms large, stable savings into immediate net cash surpluses while spreading capital costs as operating charges, whereas leasing and ESCO models tend to erode value for more marginal projects. The battery energy storage system arbitrage case is only weakly viable under current assumptions, indicating the need for additional value streams or stronger incentives. The study concluded with decision-oriented recommendations for mines, financiers and policymakers on structuring EEP finance to overcome capital constraints, enhance project bankability and support a more sustainable, energy-efficient mining industry.

KEYWORDS

Energy efficiency, Project finance, Financing structures, Mining, Energy management

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LIST OF ABBREVIATIONS

Abbreviation Description

AAR	Accounting Rate of Return
BESS	Battery Energy Storage System
CI&A	Commercial, Industrial and Agricultural
COP	Coefficient of Performance
DDMP	Demand Management Programme (Eskom)
DSM	Demand-Side Management
EEP	Energy Efficiency Project
ESCO	Energy Services Company
ESG	Environmental, Social and Governance
EUL	Equipment Useful Life
IDC	Industrial Development Corporation
IDM	Integrated Demand Management (Eskom)
IRR	Internal Rate of Return
M&V	Measurement and Verification
MIRR	Modified Internal Rate of Return
NERSA	National Energy Regulator of South Africa
NPV	Net Present Value
PI	Profitability Index
ROI	Return on Investment
SARS	South African Revenue Service
SDG	Sustainable Development Goal
ToU	Time-of-Use
WACC	Weighted Average Cost of Capital

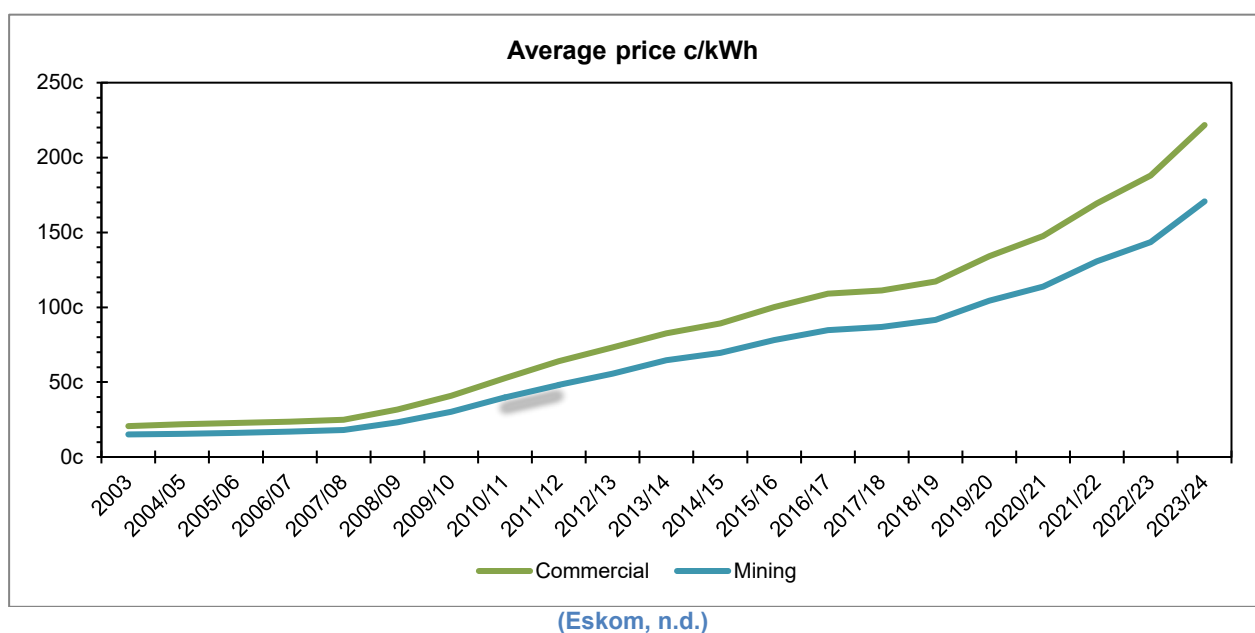
1 Chapter 1: Introduction and overview

Chapter 1 introduces the reader to the purpose and context of this study by outlining the financial, operational, and environmental challenges faced by the South African mining sector, with a particular emphasis on the need for energy efficiency projects (EEPs). It highlights why financing continues to be a central barrier to the implementation of EEPs, despite their proven benefits, and explains the importance of identifying suitable financing models. This chapter also defines the scope of the study, identifies gaps in existing research, presents the research questions and objectives, and provides a brief overview of the methodology. In doing so, Chapter 1 establishes the relevance of this research and prepares the reader for the more detailed analysis that follows in subsequent chapters.

1.1 Introduction and background

The South African mining industry is struggling to maintain economic viability due to rising operational costs (Burger *et al.*, 2024; Chavalala & Nhamo, 2014). These costs are expected to escalate further due to the year-on-year increases in electricity tariffs (Xolo *et al.*, 2025). Figure 1 shows the average electricity tariff increases for mines and commercial industries in South Africa. Over the last 20 years, mines have experienced an average yearly tariff increase of 13.24% (Eskom Holdings SOC Ltd, n.d.). The unreliable South African energy supply presents an additional operational challenge for the industry. In 2023, the principal risk for the South African mining industry was identified as electricity supply, which includes unreliable electricity supply, the risk of blackouts and unsustainable tariff escalation (Minerals Council South Africa, 2023).

Figure 1: Year-on-year mining average electricity tariff increase



The energy-intensive nature of mining activities significantly contributes to environmental degradation, particularly through high greenhouse gas emissions, such as carbon, due to their considerable dependence on coal-fired power stations for electricity (Chavalala & Nhamo, 2014; Huisman, 2014; Sovacool *et al.*, 2020; United Nations Framework Convention on Climate Change (UNFCCC), 2025). The implementation of regulations aimed at aligning operations with stringent environmental sustainability goals, such as carbon taxes, is another cause of operational cost increases (Chavalala & Nhamo, 2014; Cocks, 2024; South African Revenue Service (SARS), 2019; United Nations, 2015; World Bank, 2020). South Africa's updated Nationally Determined Contribution commits to reducing 398–510 MtCO₂e by 2025 and 350–420 MtCO₂e by 2030 (Department of Forestry Fisheries and the Environment, 2021b). In 2017, regulations were implemented for reporting national greenhouse gas emissions (United Nations Industrial Development Organization (UNIDO), 2019). The carbon tax was introduced in June 2019 at a relatively modest headline rate of R120/tonne carbon dioxide equivalent (tCO₂e) (Treasury., 2022). Table 1 shows the planned escalation of the carbon tax rate (Treasury., 2022). Considering a conversion rate of 0.906 tCO₂e/MWh and the energy-intensive nature of the South African mining industry, the carbon tax presents a significant risk for operational cost increases (Department of Forestry Fisheries and the Environment, 2023).

Table 1: Carbon tax rate (R/tCO₂e)

2023	2024	2025	2026	2027	2028	2029	2030
R159	R190	R236	R308	R347	R385	R424	R462

(Treasury., 2022)

Enhancing energy efficiency is widely regarded as one of the most effective and practical immediate strategies for reducing energy costs, addressing energy security concerns and decreasing greenhouse gas emissions (Painuly, 2009; Sarkar & Singh, 2010) (Organization., 2019). Consequently, there is an escalating demand for integrating energy efficiency and green energy projects in mining operations to mitigate environmental impacts and reduce operational costs (Igogo *et al.*, 2020). The demand for EEPs in South Africa is further driven by government incentives and tax breaks (Eskom Holdings SOC Ltd, 2025b; Sarkar & Singh, 2010). In the context of a green economy, a mine's competitive advantage is closely tied to its ability to acquire and implement clean, energy-efficient technologies and projects. These technologies are expected to reduce both environmental impact and operational costs (Chavalala & Nhamo, 2014).

Securing funding is often crucial for the success of projects (Doty & Turner, 2004). Many facility managers would concur that EEPs are worthwhile investments (Doty & Turner, 2004). Typically, EEPs decrease operational expenses, carry a low risk-to-reward ratio, often enhance productivity,

and have even been linked to increases in a company's stock value (Doty & Turner, 2004; Wingender & Woodroof, 1997).

Despite these advantages, numerous cost-effective EEPs remain unimplemented due to financial limitations (Alliance to Save Energy, 2011; Doty & Turner, 2004; Huang & Li, 2011; Rezessy & Bertoldi, 2010; Sarkar & Singh, 2010; Woodruff *et al.*, 1996). Financing these energy efficiency initiatives presents unique challenges. Research on manufacturing facilities revealed that initial costs and capital constraints accounted for over 35% of the reasons why cost-effective EEPs were not implemented (Doty & Turner, 2004; United Nations Industrial Development Organization (UNIDO), 2019; Woodruff *et al.*, 1996). These projects often compete with other priorities, such as safety and operational costs, for internal financing and may ultimately not be implemented (Painuly, 2009). This is especially a problem in the mining industry, which tends to rely more on internal financing due to higher capital investment risks (Barburski & Holda, 2023). In addition, elevated global consumer inflation of almost 7%, along with high international policy and long-term interest rates, has caused the cost of capital for South African mining companies to increase (Minerals Council South Africa, 2023). This, in turn, has led to a higher minimum attractive rate of return on mining capital, making it even harder for EEPs to qualify for internal financing. EEPs also have to compete with production-related projects for internal financing. When considering the high internal rate of return (IRR) from mining precious metals, this poses a formidable challenge (Rezessy & Bertoldi, 2010). The West Wits Qala Shallows mining project in Krugersdorp reported an IRR of 81% (Duffy, 2025). According to the literature, real discount rates of between 9% and 12 % for mining projects in South Africa are appropriate (Birch, 2016). The fluctuating commodity prices are associated with higher risk and can contribute to a significantly higher cost of capital (Brigham & Ehrhardt, 2008).

The capital-intensive nature of EEPs, combined with inherent mining risks such as fluctuating commodity prices and regulatory uncertainties, makes traditional financing unsuitable. Additionally, EEPs do not generate revenue streams; instead, they offer cost savings. Furthermore, the equipment and assets involved in these projects are typically not suitable for use as collateral. These contributing factors make EEPs unsuited to traditional financing, greatly hindering their implementation (Painuly, 2009).

The general growing demand for energy management projects has led to a surge in financing sources and programmes tailored to this sector (Henner, 2020). Alternative financing mechanisms such as green bonds, energy performance contracts, and public-private partnerships have proven effective in mobilising capital while distributing risk (Doty & Turner, 2004; Liu & Bah, 2021; Matji & Ruiters, 2016). While financing instruments that are suitable for these projects exist, uptake remains disappointingly low in many emerging economies (Taylor *et*

al., 2008). This shows that there is scope to increase EEP uptake through the appropriate application of available financing mechanisms. Selecting the correct financing source and structure can contribute to better project return on investment (ROI) and net present value (NPV) (Doty & Turner, 2004).

Although financing models for EEPs have been studied in various sectors, there is a lack of research specific to the South African mining industry. This study addresses this gap by analysing the financing sources and structures applicable to EEPs in this sector, providing recommendations to overcome the identified barriers. Timely selection of appropriate financing models is essential, as delays can result in lost cost savings and missed opportunities for time-sensitive incentives such as grants and rebates (Doty & Turner, 2004).

1.2 Scope of the study

This study focuses on EEPs implemented at mining sites in the South African mining sector and the financing models used to support their implementation. The process starts with a systematic literature review and market analysis to identify and classify relevant financing sources, capital structures, incentives and barriers affecting EEPs in this context. Building on these insights, the study uses case study data from three representative EEPs in deep-level mines along with financial parameters from five major South African mining companies to simulate a structured set of financing models. Thereafter, it assesses their impact on project cash flows and financial performance indicators, including payback period, discounted payback period, NPV, IRR, modified internal rate of return (MIRR), ROI and profitability index (PI). The scope is limited to project-level financial feasibility from the perspective of South African mining companies and energy services company (ESCO) arrangements, rather than macroeconomic impacts or detailed technical optimisation of the projects themselves. Finally, the combined findings from the literature review and quantitative simulations are used to develop practical recommendations for selecting and structuring financing models for EEPs in the South African mining sector.

1.3 Gaps in current research

The systematic review presented in Chapter 3 reveals that, although there is extensive literature on financing EEPs and project finance in capital-intensive sectors, the coverage is uneven and important gaps remain regarding mine-site EEPs in South Africa. Many studies primarily focus on financing structures, capital allocation, and contextual factors such as policies, tariffs, and sustainability. However, there is a notable lack of research that translates these existing instruments into feasibility analyses at the project level that are suitable for lenders. Additionally, only a limited number of studies focus on modelling EEPs in the mining sector, and even fewer examine South African operations using realistic Megaflex tariff paths, demand-side management

(DSM) and Section 12L incentives, as well as company-specific weighted average cost of capital (WACC) and coverage ratios such as debt service and loan life across multiple financing structures. There is also limited comparative evidence on how internal capex, project finance/special-purpose vehicle structures, leasing and ESCO or shared-savings models perform when applied to the same underlying EEPs. Additionally, it is unclear how these choices influence bankability and capital allocation decisions in mining companies. Bankability, with regard to projects, refers to the condition in which a proposed project is deemed financially acceptable and suitable for financing, particularly by banks, creditors, and other financial institutions (Painuly, 2009; Rezessy & Bertoldi, 2010).

This study addresses these gaps by providing structure-specific, South African context-aligned cash flow and financial performance simulations of representative mine-site EEPs under a range of financing models, thereby linking the largely conceptual and contextual insights in the literature to decision-grade evidence for financing EEPs in the South African mining sector. A more in-depth analysis and discussion of the existing literature and present research gaps are provided in Section 3.1 and Section 3.2 of this study.

1.4 Problem statement

The South African mining sector is facing increasing pressure to remain financially feasible due to rising operational costs (Burger *et al.*, 2024; Cocks, 2024; South African Revenue Service (SARS), 2019; United Nations Framework Convention on Climate Change (UNFCCC), 2025; World Bank, 2020). There is a growing demand for EEPs to lower operating costs, reduce carbon footprints and capitalise on government incentives and tax benefits associated with energy efficiency (Eskom Holdings SOC Ltd, 2025b; Igogo *et al.*, 2020; Organization., 2019).

Numerous cost-effective EEPs remain unimplemented due to financial limitations (Alliance to Save Energy, 2011; Doty & Turner, 2004; United Nations Industrial Development Organization (UNIDO), 2019; Woodruff *et al.*, 1996). These projects often compete with other priorities, such as safety and operational costs, for internal financing and may ultimately not be implemented (Painuly, 2009; United Nations Industrial Development Organization (UNIDO), 2019). EEPs are, for various reasons, also unsuitable for traditional financing (Painuly, 2009). While these projects are not suited for traditional financing, there has been an increase in financing options tailored to them (Doty & Turner, 2004; Liu & Bah, 2021; Matji & Ruiters, 2016). While financing instruments suitable for these projects exist, uptake remains disappointingly low in many emerging economies (Taylor *et al.*, 2008). This shows that there is scope for increasing EEP uptake through the appropriate application of the available financing mechanisms.

Selecting the correct financing source and structure can, in addition to realising a project, also provide better project ROIs and NPVs (Doty & Turner, 2004). There is a necessity for an analysis of the various financing sources and structures available to EEPs in the South African mining sector. This analysis aimed to identify the most suitable sources and structures for the sector and enhance both project implementation and financial performance.

1.5 Research questions

In line with the gaps identified in Section 3.2, this study investigates how alternative financing sources and capital structures influence the financial feasibility and bankability of EEPs in the South African mining sector. It is guided by the following primary research question:

What financing models and capital structures can most effectively improve the financial feasibility and bankability of representative EEPs in the South African mining sector, considering realistic tariff structures, incentives and risk conditions?

The study also addresses the following secondary research questions:

1. Which financing sources and structures are currently accessible to mine-site EEPs in South Africa, and how can they be systematically classified (for example, internal funding, corporate debt, leasing, and ESCO/performance-contracting models)?
2. How do alternative financing models affect project-level financial performance indicators (such as NPV, IRR, MIRR, payback period, discounted payback period, ROI and PI) and cash flow patterns for different EEP types and mining companies?
3. How can these comparative insights be translated into practical guidance that addresses the identified financing barriers and supports the increased uptake of EEPs in the South African mining sector?

1.6 Research objectives

This section sets out the objectives that the research aims to achieve in response to the identified problem and research questions.

1.6.1 Primary objectives

The primary objective of this study is to determine alternative financing sources and capital structures of EEPs in the South African mining sector, and to identify the financing models that most effectively support their implementation under realistic South African tariff, incentive and risk conditions.

1.6.2 Secondary objectives

The following secondary objectives, when achieved, collectively support the attainment of the primary objective and align with the research questions outlined in Section 1.5:

- To identify, classify and describe the financing sources and structures currently available for EEPs in the South African mining sector, including internal funding, debt instruments, leasing arrangements and ESCO/performance-contracting models.
- To develop and apply a quantitative financial modelling framework that simulates representative EEPs across multiple mining companies and financing models, using South African electricity tariffs, incentives and company-specific WACCs as inputs.
- To compare the financial performance and cash flow characteristics of alternative financing models using indicators such as NPV, IRR, MIRR, payback period, discounted payback period, ROI and PI for each project and company context.
- To derive evidence-based, decision-oriented recommendations on the selection and structuring of financing models that address identified financial barriers, enhance project bankability and support increased uptake of EEPs in the South African mining sector.

By providing a structured evaluation of financing options and publishing its findings, the study aims to increase awareness and uptake of EEPs in the South African mining sector.

1.7 Overview of methodology

This section provides a brief overview of the methodology that was applied in this study; a more detailed description can be found in Chapter 2. The research commenced with a systematic literature review aimed at synthesising existing academic research, industry reports, and credible grey literature on EEP financing sources and structures. This review identified key financing mechanisms, barriers to project implementation, and optimisation strategies relevant to the South African mining context. A funnel research approach was used to progressively narrow the scope of the reviewed literature to include only those studies that were most pertinent to the study's objectives. This ensured a focused and critical evaluation of financing models, forming the foundation for the subsequent quantitative analysis.

Following the literature review, a detailed quantitative financial analysis was conducted to evaluate the financial feasibility of various financing models applied to mining sector EEPs. Using real project data, the study simulated financing scenarios and assessed their performance using key financial indicators such as cash flow diagrams, project payback period, NPV, IRR, MIRR, ROI, and PI. The findings from this quantitative analysis, along with insights gained from the

literature review, were used to provide evidence-based recommendations aligned with the objective of this study.

1.8 Purpose statement (significance of the study)

This study aimed to evaluate the financing sources and capital structures available for EEPs in the South African mining sector to address the financing barriers that hinder their implementation. By assessing the various available models, the study sought to identify the most effective mechanisms for increasing implementation and improving the profitability of EEPs in the South African mining sector.

Theoretical contribution: This research enhances academic and scientific understanding by analysing various financing sources and structures while evaluating their advantages and disadvantages concerning project adoption and financial performance in the South African mining industry. This study provides insights into which financing models are best suited to the South African mining sector, contributing to the broader discourse on sustainable finance in high-risk, capital-intensive industries.

Practical contribution: The study provides a framework for selecting optimal financing structures for EEPs that reduce operational costs while improving environmental, social and governance (ESG) performance. Policymakers will gain insights into structuring incentives, carbon tax regulations, and sustainability policies to promote private sector investment in EEPs.

Contribution to Responsible Management and Sustainable Development Goals (SDGs): This research aligns with several SDGs: SDG 7 (Affordable and Clean Energy), SDG 8 (Decent Work and Economic Growth), SDG 9 (Industry, Innovation, and Infrastructure), SDG 12 (Responsible Consumption and Production), and SDG 13 (Climate Action). It supports the transition to sustainable energy in the mining sector by reducing carbon footprints and operational risks while promoting responsible financial decision-making (United Nations, 2015; United Nations Industrial Development Organization (UNIDO), 2019).

This study aims to overcome financial barriers to enhance the adoption of EEPs, benefiting the mining industry, financial institutions, and the South African economy while promoting long-term environmental and economic sustainability.

1.9 Ethical considerations

This study adhered to North-West University's ethical research guidelines (North-West University, 2021) to ensure integrity, transparency, and compliance with relevant legal frameworks. No human participants were involved, and no personal or sensitive data were collected or processed.

The research relied exclusively on publicly available literature, existing academic and industry reports, and project data obtained from the South African mining sector.

Furthermore, the study complied with POPIA (*Protection of Personal Information Act 4 of 2013*), which governs data protection and privacy in South Africa. While this research did not involve personal data, adherence to the principles of data security, confidentiality, and responsible data usage was maintained.

The ethics number for this study is: NWU-00657–25–A4.

1.10 Chapter layout

The following section provides an overview of the chapter layout and structure followed in this paper:

Chapter 1 – Introduction and background

Chapter 1 introduces the study and sets out the financial, operational and environmental challenges faced by the South African mining sector, with a particular focus on the role and financing of EEPs. It defines the scope of the study, identifies gaps in current research, formulates the problem statement, research questions and objectives, and provides a brief overview of the methodology. The significance of the study, its ethical considerations and the structure of this chapter are also outlined.

Chapter 2 – Methodology

Chapter 2 presents the research methodology and the paradigm that guides the study. It sets out the epistemological, ontological and axiological assumptions underpinning the research design, and describes the systematic literature review approach, the quantitative financial analysis, and the process used to derive informed recommendations. The chapter concludes by motivating the combined methodological approach and explaining how it ensures academic rigour and practical relevance. This chapter also explains the quantitative financial analysis employed to interpret the data. This includes the theoretical calculations and concepts, as well as the methods used to assess the financial performance of different projects under various financing models. Justification for the selected approach is provided, along with detailed information on data sources, financial modelling techniques, and key financial indicators.

Chapter 3 – Systematic literature review and theory

Chapter 3 reports the results of the systematic literature review and develops the theoretical and contextual framework for the study. It first discusses the selection and critical analysis of the most

relevant previous studies, before elaborating on the South African mining context, the characteristics of EEPs, barriers to their implementation, available financing sources and structures, and applicable incentives. The chapter also outlines the financial feasibility and modelling principles that inform the simulations conducted in Chapter 4.

Chapter 4 – Quantitative analysis and results

Chapter 4 presents the quantitative financial analysis and resulting simulations. It describes the scenario design and classification of projects, companies, and financing models, and then applies the framework to three representative EEP case studies across five mining companies and twelve financing structures. For each case, the chapter reports cash flow diagrams and key financial indicators, comparing the performance of alternative financing models under realistic South African tariff, incentive and risk conditions.

Chapter 5 – Conclusion and informed recommendations

Chapter 5 synthesises the findings from the literature review and quantitative analysis to provide informed, decision-oriented recommendations. It addresses the research objectives, discusses which financing sources and structures most effectively support EEP implementation and financial performance, and proposes practical guidance for mining companies, financiers and policymakers. The chapter also highlights the limitations of the study and identifies priorities for future research before concluding with the overall remarks.

The dissertation is followed by the reference list, which lists all cited sources, and a set of appendices that provide supporting material, including detailed discussions of the core studies, tariff information and complete simulation results.

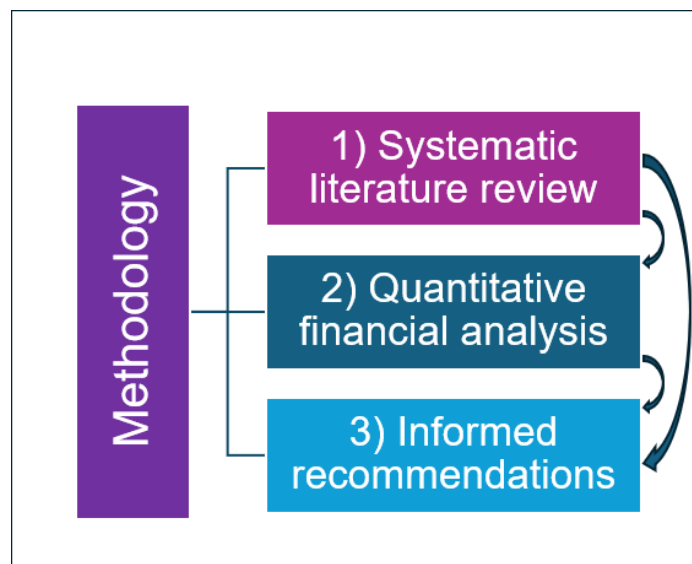
2 Chapter 2: Methodology

Methodology refers to the structured framework that encompasses the research design, methods, approaches, and procedures employed in a well-planned investigation aimed at uncovering new insights or knowledge (Keeves, 1990; Kivunja & Kuyini, 2017).

This chapter establishes the philosophical and practical foundations upon which this research is based. It outlines the guiding paradigm, underlying assumptions, and structured approach used to effectively address the research objectives. By outlining the research paradigm, systematic review design, and quantitative financial analysis, Chapter 2 provides both the rationale and the process through which credible and replicable findings can be generated. Establishing this foundation is essential to ensure that the study's conclusions are not only theoretically sound but also practically relevant within the context of energy efficiency financing in the South African mining sector.

This study's methodology involves three main steps: conducting a systematic review, performing a quantitative financial analysis, and developing informed recommendations. The methodology developed for this study is illustrated in Figure 2. More details and information on the individual steps are provided in the following sections.

Figure 2: Overview of methodology



(Source: Own compilation)

Before setting out the applied methodology, this chapter examines the research paradigm that informed its design, including the study's ontological and epistemological stance. This framing clarifies the logic of inquiry and the methodological choices that follow.

2.1 Research paradigm

A paradigmatic perspective encompasses the beliefs, assumptions and perspectives that form the basis of the researcher's understanding when investigating and interpreting findings within their field. This includes their worldview, theoretical framework, and methodological approaches (Kivunja & Kuyini, 2017). Lincoln and Guba define elements that characterise research paradigms, each playing a distinct role in shaping how knowledge is acquired, understood, and applied in research (Kivunja & Kuyini, 2017; Lincoln & Guba, 1985):

2.1.1 Epistemology

Epistemology is used to describe how we come to know something. Epistemology concerns the nature of knowledge and defines the relationship between the researcher and the subject of inquiry. The sources from which researchers can draw knowledge can be divided into four categories: intuitive knowledge, authoritative knowledge, logical knowledge and empirical knowledge (Kivunja & Kuyini, 2017).

This study primarily drew from empirical and authoritative sources. The research involved a quantitative evaluation and analysis of empirical financing models, as well as a review of existing research, industry reports, government regulations, and authoritative financial models related to energy efficiency financing.

2.1.2 Ontology

Ontology concerns the nature of existence or reality and what is considered to exist within the domain of research. Ontology is essential to a paradigm as it provides an understanding of the things that constitute the world as it is known (Kivunja & Kuyini, 2017).

This study followed an objective, structured and data-driven approach to understanding the financial realities of energy efficiency financing in the mining industry. The research for this study involved financial modelling, quantitative performance evaluation, and structured assessment of financing mechanisms. This study made the following key assumptions:

- Energy efficiency financing structures exist as objective entities. These financing structures are real, tangible mechanisms that influence the feasibility of EEPs.
- Financial performance indicators are measurable and comparable. They provide an objective basis for determining the viability of financing models.
- Economic constraints and capital investment risks in the mining sector are external realities. The study assumes that financial limitations, such as investment risks and capital

allocation decisions in mining operations, are external rather than socially constructed and can be systematically analysed.

- Optimal financing models can be identified through structured analysis.

2.1.3 Axiology

Axiology considers the philosophical approach to making value-based decisions or determining the right decisions (Finnis, 2011; Kivunja & Kuyini, 2017). Axiology shapes what is considered important and ethical in research. It affects decisions regarding study focus, methodology, and the interpretation of findings. It ensures that research adheres to ethical principles and maintains professional integrity.

This study emphasised pragmatism and ethical responsibility. It aimed to offer practical financial solutions for EEPs. The focus was on promoting economic viability and sustainability in South Africa's mining sector. The study maintained its objectivity through empirical financial analysis. While ethical considerations such as sustainability and responsible investment were acknowledged, the study maintained objectivity by relying on empirical financial analysis to guide its conclusions and recommendations. It also aligned with ethical principles such as transparency, responsible investment, and reducing environmental impact.

This study adopted a realist research paradigm, applying an objective, data-driven approach to analysing financing models for EEPs in the South African mining sector. This aligns with the positivist paradigm, emphasising objective reality, empirical measurement, and structured methodologies to derive generalisable conclusions. This study drew on empirical and authoritative knowledge, using quantitative financial analysis and a systematic literature review to evaluate financing structures. The ontology assumed that financing mechanisms, investment risks, and economic constraints exist as measurable external realities, while the methodology followed a structured framework incorporating financial modelling and performance evaluation. Although axiology acknowledges ethical considerations such as sustainability and responsible investment, the study maintained objectivity by relying on empirical financial analysis. This study adopted a framework that ensured the findings contribute to both financial viability and environmental sustainability, providing data-driven recommendations to improve energy efficiency financing in the mining sector.

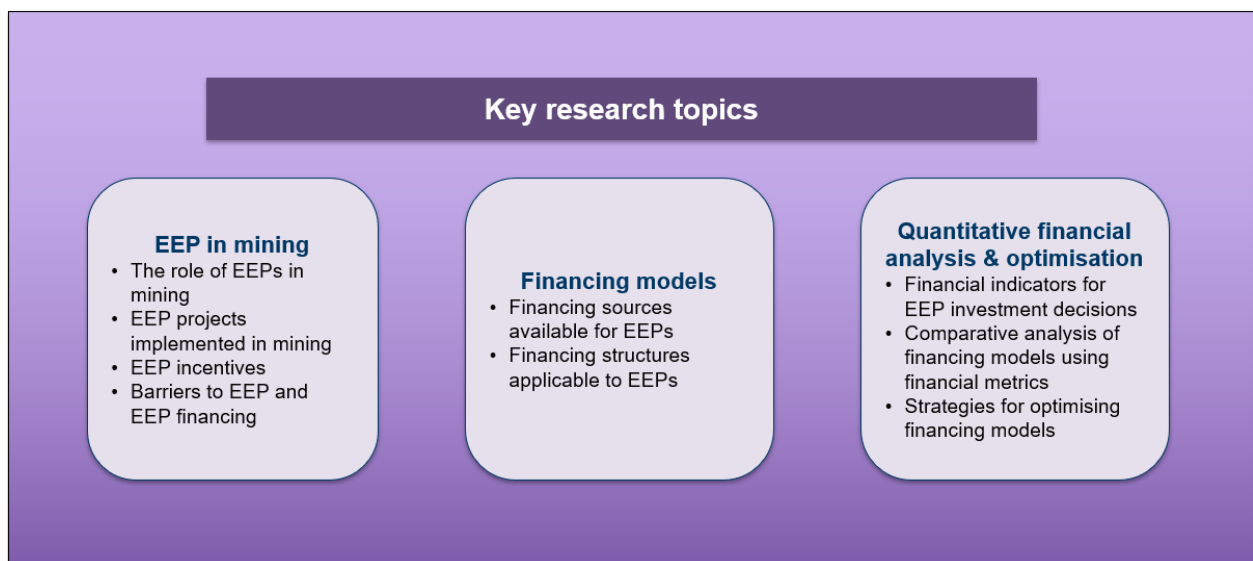
2.2 Systematic literature review

This study followed a systematic review structure for the literature review. A systematic review is a structured synthesis of existing research that addresses a specific research question (Petticrew & Roberts, 2006). Systematic reviews seek to consolidate all known knowledge on a topic area

(Grant & Booth, 2009). These reviews often link to peer-reviewed papers but can also include credible grey literature. This grey literature includes government reports, industry documents, technical guidelines, working papers, websites and conference proceedings. Incorporating it can provide valuable insights not found in traditional academic sources (Petticrew & Roberts, 2006).

This study applied a systematic funnel research review approach to all available credible and academically acceptable sources relevant to the key topics specified in Figure 3. These topics were selected based on their direct relevance to understanding and addressing the research questions and objectives as specified in Sections 1.5 and 1.6. Initially, all credible academic literature and credible grey literature related to the role, incentives, and barriers associated with EEPs in mining, available financing sources and structures, and quantitative financial analysis methods were included. Additionally, the systematic review evaluated current market information to identify financing sources actively available for EEPs. Thereafter, a funnel research design was applied, progressively narrowing the literature to explicitly focus on financing models, quantitative analysis methods, and optimisation strategies specific to EEP financing within the South African mining sector.

Figure 3: Key research topics for the systematic review



(Source: Own compilation)

Inclusion criteria for this review included peer-reviewed journal articles, credible industry and government reports, technical guidelines, relevant working papers, and market analysis documents. Exclusion criteria removed literature that was older than 20 years (unless foundational), irrelevant to the defined topics, or primarily opinion-based without empirical or authoritative support. Sections 3.1 and 3.2 provide a more detailed explanation of the systematic literature review completed for this study, its results, and a critical analysis of the existing

literature. Summaries of the eighteen most relevant studies, selected according to the criteria specified in Section 3.1, are provided in Annexure A.

2.3 Quantitative financial analysis

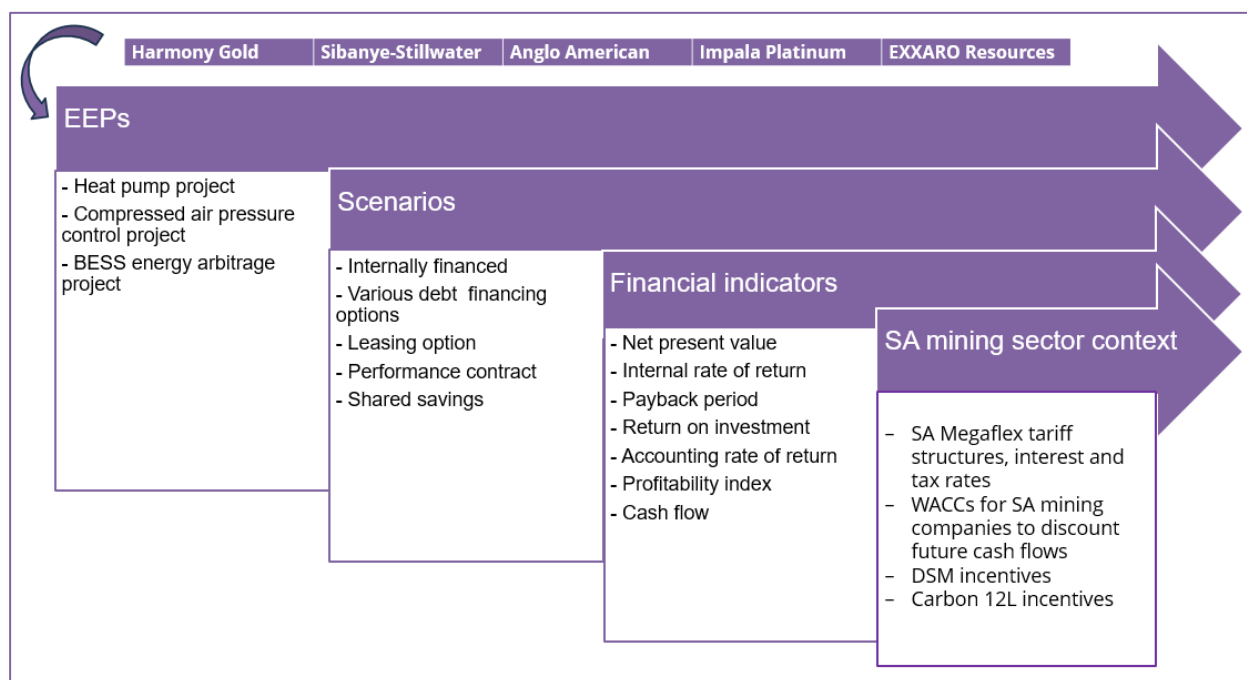
This section explains the quantitative analysis performed in Chapter 4, which is part of the methodology followed in this study. Quantitative analysis refers to a method of assessing the worth of an asset or investment based on economic, econometric, mathematical, and statistical methods or models (Moles & Terry, 2005). Quantitative analysis can include computing the payback period, NPV, IRR, or life cycle cost of a project with or without financing (Doty & Turner, 2004).

With the findings from the systematic review and case study data, this study simulated various financing models (sources and structures) against different EEPs within the context of South African mining. Real interest rates and relevant economic data specific to the South African mining environment were collected and used to ensure realistic financial modelling. Case study data on real EEPs were collected from projects in deep-level mines in the South African mining sector. The data collected included energy savings, project costs and performance. This data was used to ensure the simulation of realistic scenarios. This study completed 180 simulations of different financing models applied to different EEPs and scenarios.

Figure 4 provides a visual representation of the quantitative analysis simulation procedure. The scenarios cover five major South African mining companies and three representative EEPs: a heat-pump project, compressed-air pressure control, and a battery energy storage system (BESS) arbitrage project. These projects are based on actual implemented or planned initiatives in deep-level mines within the Bushveld Complex. More information on each project is provided in Section 4.2.

Each project was evaluated under twelve financing models, including internal funding, various combinations of debt at different rates and ratios, leasing, and several ESCO performance contract structures. More information on the workings of each of these models is provided in Section 3.3.4.

Figure 4: Quantitative analysis procedure



(Source: Own compilation)

For each case, the simulations generated a complete set of financial metrics, NPV, IRR, payback period, ROI, ARR, PI and cash flow profiles, as well as discounted versions of these indicators. All simulations were completed in Microsoft Excel™ according to the formulas and theories discussed in Section 3.3.6.

To keep the results grounded within the context of the South African mining sector, all energy savings cash flows were modelled using South African Megaflex tariffs, prevailing interest and tax rates, company-specific WACCs, and current DSM and Section 12L incentives applicable to these projects.

The results from these simulations were organised into summary tables for each project, subdivided by company and financing model, with the full set of financial indicators presented side by side to allow for direct comparison. Cash flow diagrams were used to compare the timing and shape of cash flows across financing options, as patterns such as large upfront outflows, staggered repayments, and level leasing charges have a material influence on project feasibility. Differences between internal funding, debt financing, and leasing were examined in terms of both headline indicators and cash flow patterns. These comparative insights, along with the findings from the literature review, were used to identify the financing models most suitable for specific types of EEPs in the South African mining sector and to inform the recommendations presented in later chapters.

2.4 Informed recommendations

This study developed recommendations for financing models of EEPs in the South African mining sector. These recommendations were derived through a credible and structured approach. Firstly, results from a systematic literature review identified prevailing financing models, along with their strengths, limitations, and suitability within the mining context. This was complemented by a quantitative analysis that calculated key financial indicators for scenarios in which different financing models were applied to EEPs. The quantitative analyses were conducted with consideration of the unique context of the South African mining sector. This quantitative analysis objectively assessed the financial viability and comparative performance of the financing options. By integrating insights from both analyses, this study offers well-informed recommendations for financing models that address identified financial barriers, enhance financial viability, and improve the uptake of EEPs in South Africa's mining sector.

2.5 Justification of methodology

The methodological design of this study is grounded in a realist, empirically-oriented paradigm that views financing mechanisms, investment risks and economic constraints in the mining sector as measurable external realities that can be systematically analysed (Kivunja & Kuyini, 2017; Lincoln & Guba, 1985). By combining a systematic literature review with quantitative financial modelling, the methodology provides both a conceptual and empirical basis for addressing the research questions on how alternative financing models and capital structures influence the feasibility and bankability of EEPs in the South African mining sector. This integrated design is well-suited to a context where financing barriers are widely recognised, yet project-level evidence that is directly usable by mines and financiers remains limited (Alliance to Save Energy, 2011; Doty & Turner, 2004; Painuly, 2009).

The systematic literature review is justified by the fragmented and uneven nature of existing knowledge on EEP financing, particularly within the mining sector and, more specifically, in the South African context. A systematic review, defined as a structured synthesis of existing research that addresses a specific research question (Petticrew & Roberts, 2006), is appropriate when there is a need to collate dispersed evidence across academic, policy and industry sources and to identify both what is known and where gaps remain. Systematic reviews aim to compile all known knowledge on a specific topic area (Grant & Booth, 2009), which aligns with this study's objective to map the available financing sources, structures, incentives and barriers relevant to mine-site EEPs in South Africa. The inclusion of credible grey literature such as government reports, industry documents, technical guidelines and market analyses is essential in this field because many financing programmes, tariff structures and incentives are documented outside

traditional academic journals (Eskom Holdings SOC Ltd, 2025b; Peticrew & Roberts, 2006; Treasury., 2022; Xolo *et al.*, 2025). By applying a funnel-type systematic search with explicit inclusion and exclusion criteria, the review ensured broad initial coverage, while progressively narrowing the focus to financing models, quantitative analysis methods, and optimisation strategies most relevant to EEPs in the South African mining sector. This provides a rigorous, transparent foundation for the theoretical framework in Chapter 3 and directly supports the secondary objectives related to identifying and classifying financing sources and structures.

The use of quantitative financial analysis is justified by the study's focus on project-level feasibility and the comparative performance of alternative financing models under realistic tariff, incentive and risk conditions. Quantitative analysis refers to the appraisal of the worth of an asset or investment based on economic, econometric, mathematical and statistical methods or models (Moles & Terry, 2005). It is particularly appropriate where decisions depend on measurable financial indicators such as payback period, discounted payback period, NPV, IRR, MIRR, ROI and PI, and where different financing structures must be compared on a consistent numerical basis (Doty & Turner, 2004). In this study, quantitative analysis is used to simulate cash flows and financial performance for three representative EEPs across five major South African mining companies and twelve financing models, capturing the interaction between project characteristics, capital structures and contextual variables such as Megaflex tariffs, carbon tax, corporate tax, company-specific WACCs, as well as DSM and Section 12L incentives (Birch, 2016; Department of Forestry Fisheries and the Environment, 2023; Eskom Holdings SOC Ltd, 2025b; South African Revenue Service (SARS), 2019; Treasury., 2022). This lender-grade modelling approach directly addresses the gap identified in Chapter 1, namely the lack of comparative, project-level analyses of EEP financing structures that reflect realistic South African conditions.

More broadly, the combined methodology is justified by its alignment with the study's realist and positivist paradigms, as well as the nature of the research questions. The paradigm section sets out that this study draws primarily on empirical and authoritative knowledge, employing quantitative evaluations of financing models together with a structured review of existing research. The systematic review component fulfils the authoritative knowledge strand by synthesising and critically analysing prior work on EEPs, financing barriers, incentives and financing instruments in mining and related sectors. The quantitative simulations operationalise the empirical strand by translating these conceptual and contextual insights into measurable, comparable outcomes for specific projects and financing structures. This combination ensures that the study's conclusions are both theoretically grounded and empirically testable, which is essential when proposing financing solutions in a high-risk, capital-intensive sector that faces rising energy costs, tightening environmental regulations and increasing capital costs (Birch, 2016; Burger *et al.*, 2024; Minerals Council South Africa, 2023; World Bank, 2020).

Finally, this methodological design positions the study to generate valuable, decision-oriented recommendations based on its findings. By first mapping the landscape of financing sources, structures, incentives and barriers, and then testing a structured set of financing models against real EEP case study data drawn from deep-level South African mines, the study links conceptual financing options to concrete project-level outcomes. The 180 simulations across three EEP types, multiple mining companies and twelve financing structures allow for a systematic comparison of how different capital structures, interest rates and incentive combinations affect bankability and financial performance, including in cases where traditional internal financing is constrained by high hurdle rates and competing production investments (Birch, 2016; Rezessy & Bertoldi, 2010). The integration of context-specific tariffs, tax instruments and incentives further ensures that the recommendations speak directly to the realities faced by South African mining companies, financiers and policymakers (Eskom Holdings SOC Ltd, 2025b; Organization., 2019; South African Revenue Service (SARS), 2019). As a result, the chosen methodology not only addresses the identified research gaps but also supports the development of practical guidance on structuring EEP finance to overcome capital constraints, enhance project bankability and contribute to a more energy-efficient and sustainable mining sector in South Africa.

3 Chapter 3 – Systematic literature review and theory

This chapter establishes the foundation for the study through a systematic literature review. Section 3.1 discusses the selection criteria for the eighteen studies identified as most relevant to the topic of this study, while Section 3.2 critically analyses their findings to highlight key insights and gaps. Section 3.3 develops the subject matter and theoretical framework, drawing primarily on these studies. Collectively, the combination of these sections provides the evidence base for the quantitative analysis in Chapter 4 and the recommendations in Chapter 5.

3.1 Previous studies performed

This section reviews the existing literature most closely related to the topic of this study. The purpose was to identify how financing models have been applied, the barriers they address, and how they can be optimised to enhance project uptake and financial feasibility. To ensure relevance and comparability, the selected studies were evaluated based on their alignment with the outlined selection criteria relevant to the topic of the study:

1. **EEPs in capital-intensive sectors:** This includes studies on EEPs or similar projects in mining and other capital-intensive industries.
2. **Financing sources and instruments relevant to EEPs and similar projects:** This includes research on financing mechanisms such as loans, equity, bonds, public-private partnerships, energy performance contracts, government incentives or green finance instruments relevant to EEPs.
3. **Financing structures and capital allocation:** Studies that evaluate how financing is structured, such as debt-to-equity ratios, project finance, or relationship lending, and their effects on financial feasibility.
4. **Financial feasibility assessment and optimisation for EEPs or similar projects:** Literature that discusses or assesses EEPs through financial metrics or develops models and approaches to optimise project financial performance.
5. **Contextual and sustainability considerations relevant to EEPs:** Studies that examine the broader environment in which EEP financing occurs. This includes emerging market conditions, regulatory and policy frameworks (such as carbon tax, subsidies, and DSM), prevailing financing conditions (interest rates, risks, and institutional behaviour), and links to sustainability and ESG objectives.

From the 82 studies and sources evaluated against the defined criteria, eighteen were identified as the most relevant. The discussions and comments on these studies, as well as the explanations of their significance, provided insights applicable to this research and can be found in Appendix A.

The literature discussed provides material value to this study by clarifying the financing barriers and mechanisms, as well as informing Chapter 4 and Chapter 5. Section 3.3 will serve to communicate all the theories, contexts and findings obtained from the systematic review of existing literature. Consistent with a focused review strategy, only the eighteen most relevant studies were selected and examined in depth. However, a broader range of sources, including recognised textbooks, technical guidance and primary source material, was also used to support assumptions, parameter choices, and evaluation criteria. This layered evidence base underpins the modelling decisions adopted later and strengthens coherence across the review, analysis and recommendations. Through the systematic review of existing literature, the research gap related to financing models for EEPs in the South African mining sector is clearly illustrated in the Section 3.2.

3.2 Critical analysis of previous studies

Table 2 summarises the previously discussed studies (as per Appendix A) to highlight their focus. The first column shows the relevant criteria, while the header row lists the studies included in the matrix. An X indicates that the study is relevant to the specified criterion.

The matrix indicates strong coverage of financing structures and capital allocation across most studies, with consistent attention to contextual and sustainability considerations, including policies, tariffs, carbon tax and DSM. There is also a reasonable treatment of financing sources and instruments; however, far fewer papers translate these instruments into decision-grade feasibility using lender metrics. Only a small subset rigorously engages in financial feasibility and optimisation, and even fewer do so specifically for mine-site EEPs. In short, the literature informs us more about how projects are framed in terms of structure and context than about how they are financed and proven to be bankable in terms of cash flow modelling, debt service coverage ratio, loan life coverage ratio, and sensitivity to South African tariff and incentive paths.

Table 2: Critical analysis of the previous studies (matrix)

Study	1 (Yun <i>et al.</i> , 2009)	2 (Painuly, 2009)	3 (Rezessy & Bertoldi, 2010)	4 (Chavalala & Nhamo, 2014)	5 (Sarkar & Singh, 2010)	6 (Huang & Li, 2011)	7 (Aslam <i>et al.</i> , 2023)	8 (Lee & Zhong, 2015)	9 (Barburski & Holda, 2023)	10 (Birch, 2016)	11 (Nel <i>et al.</i> , 2018)	12 (International Energy Agency, 2015)	13 (González-Ruiz <i>et al.</i> , 2021)	14 (Goosen, 2013)	15 (International Energy Agency <i>et al.</i> , 2024)	16 (Halsey <i>et al.</i> , 2024)	17 (Xolo <i>et al.</i> , 2025)	18 (Arndt, 2005)
EEPs in capital-intensive sectors	X			X					X		X	X	X	X	X		X	
Financing sources and instruments relevant to EEPs and similar projects		X	X		X	X	X	X		X	X	X	X	X		X	X	X
Financing structures and capital allocation	X	X	X	X	X	X	X	X	X	X			X			X	X	X
Financial feasibility assessment and optimisation for EEPs or similar projects	X											X			X	X		X
Contextual and sustainability considerations relevant to EEPs		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

(Source: Own compilation)

Study 13 helps to explain the matrix pattern. It organises the literature into three themes: Theme 1: project finance characteristics and applicability in mining, Theme 2: financing gaps and difficulties, and Theme 3: project finance risk and sustainability. Only Theme 2 is explicitly framed as a ‘gap’. However, important gaps also remain in Themes 1 and 3, especially regarding the shortage of lender-grade, structure-specific modelling and the weak evidence for small to medium enterprises and early-stage finance (González-Ruiz *et al.*, 2021). Read against the matrix set out in Table 2, the dense ticks related to financing structures/capital allocation and context/policy mirror Themes 1 and 3, while the relative sparsity under feasibility/optimisation and sources/instruments aligns with Theme 2’s emphasis on financing difficulties, reinforcing that practical, bankability-oriented evidence for mine-site EEPs remains underdeveloped.

In line with the matrix and the synthesis of Study 13, the gap is not conceptual but rather oriented toward feasibility and bankability. The field lacks lender-ready, structure-specific models that help convert mine-site EEP savings into debt-credible cash flows. Section 3.3 discusses the main

findings from the systematic literature review and develops the theoretical and contextual foundation underpinning the study.

3.3 Subject matter and theory

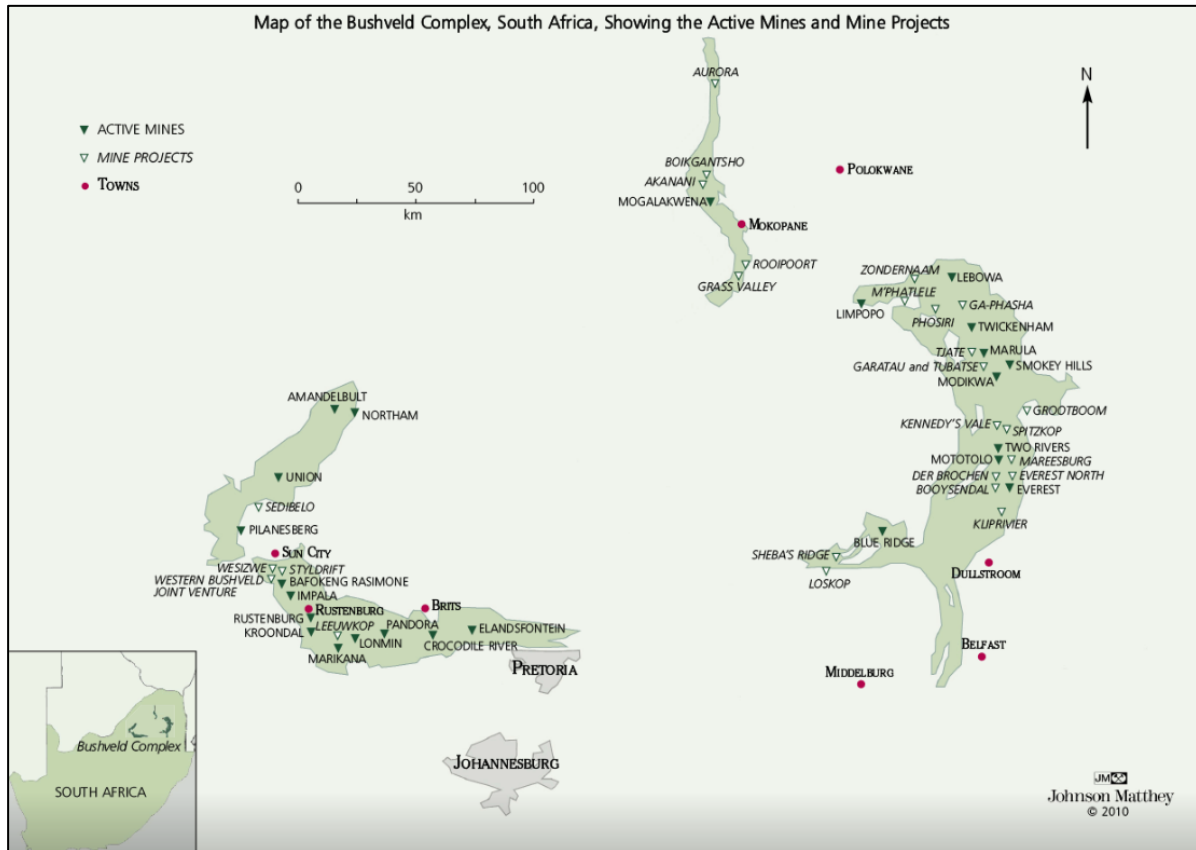
This section develops the theoretical and contextual foundation underpinning the study. Drawing primarily from the findings of the systematic literature review, it also incorporates insights from recognised textbooks, source material, and publicly available data. These supplementary sources are particularly relevant for grounding basic theoretical principles and identifying real-world financing options applicable to EEPs. The section explores the broader subject matter of energy efficiency in mining and the financial frameworks relevant to such projects, to establish a clear understanding of the operational environment, the financing barriers and opportunities that exist, and the rationale for selecting and structuring appropriate financing mechanisms for EEPs in the South African mining sector. The discussion is organised into six key themes, which together provide the conceptual grounding for the quantitative analysis presented in Chapter 4.

3.3.1 The South African mining sector

The South African mining sector is diverse and economically significant, spanning coal, platinum group metals, ferroalloys, manganese, iron ore, chrome, titanium and a range of industrial minerals such as clay, limestone and silica (Department of Forestry Fisheries and the Environment, 2024). South Africa also boasts the deepest and most complex mining complexes in the world (Burger *et al.*, 2024). The country's deep-level underground mining is concentrated in the Witwatersrand goldfields and the Bushveld Complex, which hosts most of the world's platinum group metals and underpins many of the country's deepest and most energy-intensive operations (Cawthorn, 2010; Phillips *et al.*, 2024).

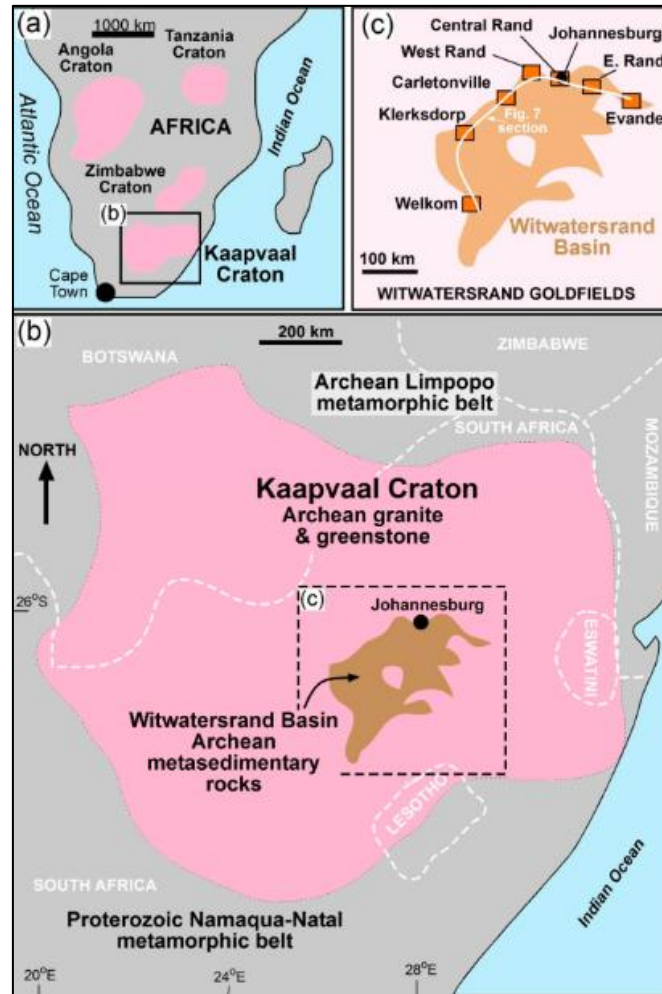
Figure 5 presents a map of the Bushveld Complex, showing the eastern, western and northern limbs. Major towns and cities are marked in red, while operational platinum mines and current projects are shown in green. Figure 6 provides a map of South Africa's goldfields. Figure 6 situates these goldfields within the Kaapvaal Craton, showing the location of the Witwatersrand Basin relative to Johannesburg and the seven principal Witwatersrand goldfields.

Figure 5: Map of the Bushveld Complex in South Africa



(Cawthorn, 2010)

Figure 6: Regional setting of the Kaapvaal Craton and Witwatersrand goldfields



(Phillips *et al.*, 2024)

The sector operates in one of the world's most energy-intensive economies. In the early 2010s, South Africa's total energy use per unit of gross domestic product exceeded twice the global average, and electricity consumption per capita was around 40% above the world average (International Energy Agency, 2015). About one-third of the total electricity requirements in the industry are for primary aluminium manufacturing and mining activities (International Energy Agency, 2015).

Electricity-intensive production and an ageing, coal-based power fleet have contributed to the problem, leading to load-shedding and reliability issues that have repeatedly disrupted industrial activity (International Energy Agency, 2015). In parallel, input costs have risen; for example, mining electricity tariffs increased sharply from the late 2000s to the early 2010s, as shown in Figure 1. Over the longer run, sustained annual tariff escalation has materially eroded margins (Burger *et al.*, 2024; Chavalala & Nhamo, 2014; Eskom Holdings SOC Ltd, n.d.). The Minerals Council South Africa (Minerals Council South Africa, 2023) identified electricity supply, including blackout risk and tariff escalation, as the industry's top risk in 2023. Structural trends are also

pushing energy demand upward. International evidence indicates that declining ore grades, increased mining depths, and greater remoteness all increase the energy required per unit of output, intensifying both cost and emissions pressures (Burger *et al.*, 2024; Igogo *et al.*, 2020).

Given the sector's dependence on grid electricity generated predominantly from coal, the emissions intensity of purchased power is a significant driver of Scope 2 emissions. Recent official grid emission factor estimates report a 2023 national generation grid emission factor of approximately 0.906 tCO₂e/MWh, underscoring the carbon exposure of electricity-reliant mines (Department of Forestry Fisheries and the Environment, 2023).

Policy signals reinforce the need for efficiency and low-carbon investments. South Africa's updated Nationally Determined Contribution commits to national emissions of 398–510 MtCO₂e by 2025 and 350–420 MtCO₂e by 2030 (Department of Forestry Fisheries and the Environment, 2021b), with an emphasis on a just transition and a focus on decarbonising electricity in the 2020s. Draft sectoral emissions targets identify mining mitigation levers, improved energy efficiency, fuel switching and clean energy, fugitive emission management in coal mining, and rehabilitation practices that enhance carbon sinks (Department of Forestry Fisheries and the Environment, 2024).

In summary, the South African mining sector is both energy– and electricity-intensive, exposed to reliability and tariff risks, and is increasingly shaped by national decarbonisation policy. This combination strengthens the commercial and policy rationale for mine-site EEPs and complementary clean energy procurement (Burger *et al.*, 2024; International Energy Agency, 2015; Minerals Council South Africa, 2023).

3.3.2 EEPs in mining

As established in Section 1.1 and Section 3.3.1, South African mining is both electricity-intensive and increasingly exposed to tariff escalation, reliability constraints and carbon-cost pressures, which strengthens the strategic case for near-term efficiency interventions that stabilise operating costs while supporting decarbonisation goals (Chavalala & Nhamo, 2014). Enhancing energy efficiency is widely regarded as one of the most effective and practical immediate strategies to reduce energy costs, address energy security concerns and lower greenhouse gas emissions (Organization., 2019; Painuly, 2009; Sarkar & Singh, 2010). Consequently, there is a rising demand for the integration of energy efficiency and clean energy measures in mine operations to mitigate environmental impacts and reduce operating costs (Igogo *et al.*, 2020; Sarkar & Singh, 2010). This demand is reinforced locally by incentives and tax benefits for qualifying projects (Eskom Holdings SOC Ltd, 2025b; GreenCape, 2024; Sarkar & Singh, 2010), and, more broadly,

by the competitive advantage associated with adopting clean, efficient technologies that lower both emissions and unit costs (Chavalala & Nhamo, 2014).

At an operational level, mines comprise multiple energy-intensive utility systems, including ventilation, refrigeration and water reticulation. In many operations, these systems attribute roughly half of electricity use to these services (Chavalala & Nhamo, 2014). Compressed air is frequently one of the largest single consumers of energy and can account for up to 40% of total mine electricity demand, making it a prime target for high-impact savings through leak reduction, pressure-band control and optimised scheduling (Goosen, 2013). The literature demonstrates that established industrial measures relevant to mining – such as high-efficiency motors with variable-speed or inverter control, pressure-control systems for water and compressed air, refrigeration optimisation, heat-pump applications and modern lighting options – are well-evidenced, typically showing simple payback periods of approximately 2 to 5 years when conditions are favourable (International Energy Agency, 2015). In addition to direct kilowatt-hour and kilowatt reductions, many projects deliver non-energy benefits. An example is the maintenance and service-level improvements that strengthen overall business cases when measured and verified appropriately (Nel *et al.*, 2018).

Recent market drivers further strengthen the case for mine-site efficiency. For commercial, industrial and agricultural (CI&A) users, electricity tariffs have risen dramatically and erratically, prompting firms to invest in on-site solutions that both reduce consumption and improve price predictability (Xolo *et al.*, 2025). In parallel, trade-exposed businesses face tightening sustainability requirements – including the European Union’s Corporate Sustainability Reporting Directive, Corporate Sustainability Due Diligence Directive, and Carbon Border Adjustment Mechanism – as well as emerging disclosure regimes in other key markets. These requirements are cascading into supply-chain due diligence expectations and incentives to lower the embedded carbon intensity of production (Xolo *et al.*, 2025). These forces collectively support a pipeline of EEPs as credible, financeable levers within broader decarbonisation and cost-management strategies, including tariff inflation, energy security risk and ESG-linked market access (International Energy Agency, 2015; Xolo *et al.*, 2025).

The remainder of Section 3.3.2 provides concise context for three project archetypes that are subsequently examined in detail: (i) water-heating system upgrades using industrial heat pumps, (ii) BESS systems configured for energy arbitrage, as an efficiency-adjacent, cost-reduction lever, and (iii) compressed air instrumentation and pressure-control. More information is presented on each of these types of EEPs as they are relevant to the scope of this study, and case study data from similar projects on deep-level mines operating in South Africa’s Bushveld Complex is available for use in this study.

Enhancing energy efficiency is widely regarded as one of the most effective and practical immediate strategies for reducing energy costs, addressing energy security concerns and lowering greenhouse gas emissions (Organization., 2019; Painuly, 2009; Sarkar & Singh, 2010). Consequently, there is an escalating demand for integrating energy efficiency and green energy projects into mining operations to mitigate environmental impacts and reduce operational costs (Igogo *et al.*, 2020; Sarkar & Singh, 2010). The demand for EEPs in South Africa is further increased by government incentives and tax breaks projects (Eskom Holdings SOC Ltd, 2025b; Sarkar & Singh, 2010). In the context of a green economy, a mine's competitive advantage is closely related to its ability to acquire and implement clean, energy-efficient technologies and projects. These technologies should reduce both environmental impact and operational costs (Chavalala & Nhamo, 2014).

3.3.2.1 Water-heating system upgrades with heat pumps

Heating accounts for almost 20% of energy use in industries and buildings globally and about one-quarter of energy sector emissions (International Energy Agency *et al.*, 2024). Water-heating, including ablutions, accommodation and cleaning, is a persistent load in deep-level mining. As outlined in Section 3.3.1, such utility services are material drivers of electricity use and carbon exposure, making them strong candidates for proven efficiency retrofits. Industrial heat pumps are particularly well-suited, as they deliver the same thermal duty with far less input energy and have an established deployment record across multiple industries (International Energy Agency *et al.*, 2024; Renewable Thermal Collaborative & Boston Consulting Group, 2018). Comprehensive energy optimisation of a heating system can therefore significantly reduce energy consumption and costs (International Energy Agency *et al.*, 2024).

Heat pumps use a vapour-compression cycle to upgrade ambient or waste heat to the required supply temperature. Because they move heat rather than generate it, their efficiency is expressed as the coefficient of performance (COP). This is the useful heat output divided by the electrical energy input. Typical industrial applications achieve a COP of approximately 3 to 4.6, meaning around 3 kWh to 4.6 kWh of heat per 1 kWh of electricity. This corresponds to roughly 50% to 60% less energy than boiler-based systems for comparable temperature lifts (Renewable Thermal Collaborative & Boston Consulting Group, 2018; International Energy Agency & Tsinghua University Building Energy Research Center, 2024).

Case studies show robust savings and short payback periods when tariffs and temperature increases are favourable. For example, a dairy pasteurisation plant achieved a COP of 4.2 with an expected simple payback period of approximately 2.7 years compared to gas boilers, while lumber-drying pilots reported a COP of between 3 and 4.6, resulting in up to 57% fuel savings

(Renewable Thermal Collaborative & Boston Consulting Group, 2018). Broader datasets indicate that energy reductions in light industry process-heat retrofits range from approximately 45% to 70%, with payback periods between 0.9 and 2.4 years (International Energy Agency *et al.*, 2024).

Recent technical assessments report that the installation costs for residential heat-pump water heaters are typically two to four times higher than those of standard electric resistance units, depending on market conditions and the specific site (Booth, 2024). Although industrial heat pumps can have higher upfront costs than boilers, life cycle costs are often lower due to superior efficiency. In some contexts, the cost per unit of heat approaches coal-boiler levels over the plant's life. Heat pumps also support decarbonisation and ESG compliance by cutting Scope 2 emissions, which are benefits that strengthen as grids decarbonise and carbon prices rise (International Energy Agency *et al.*, 2024). These features align with the cost and market access pressures facing South African mines.

Water-heating heat pumps are attractive in situations where (i) a steady low- to medium-temperature hot water demand exists, (ii) ambient or waste heat sources are available, such as condenser loops, cooling water, and ventilation exhaust, and (iii) tariff structures reward kilowatt-hour reductions. Current high-temperature models already cover a large share of low- to medium-temperature industrial heat. Next-generation units extend this range further, widening applicability (International Energy Agency *et al.*, 2024; Nadel *et al.*, 2024).

Heat-pump upgrades are technically mature and demonstrably efficient improvements with COPs of approximately 3 to 4.6. Additionally, they are financially feasible with documented short payback periods. It is these characteristics that make them the ideal candidates for EEP in the comparative financing simulations under South African mining conditions. Accordingly, this project type is carried forward to Chapter 4 for quantitative evaluation under alternative financing models (International Energy Agency *et al.*, 2024; Nadel *et al.*, 2024; Renewable Thermal Collaborative & Boston Consulting Group, 2018).

3.3.2.2 Compressed-air instrumentation and control for pressure regulation

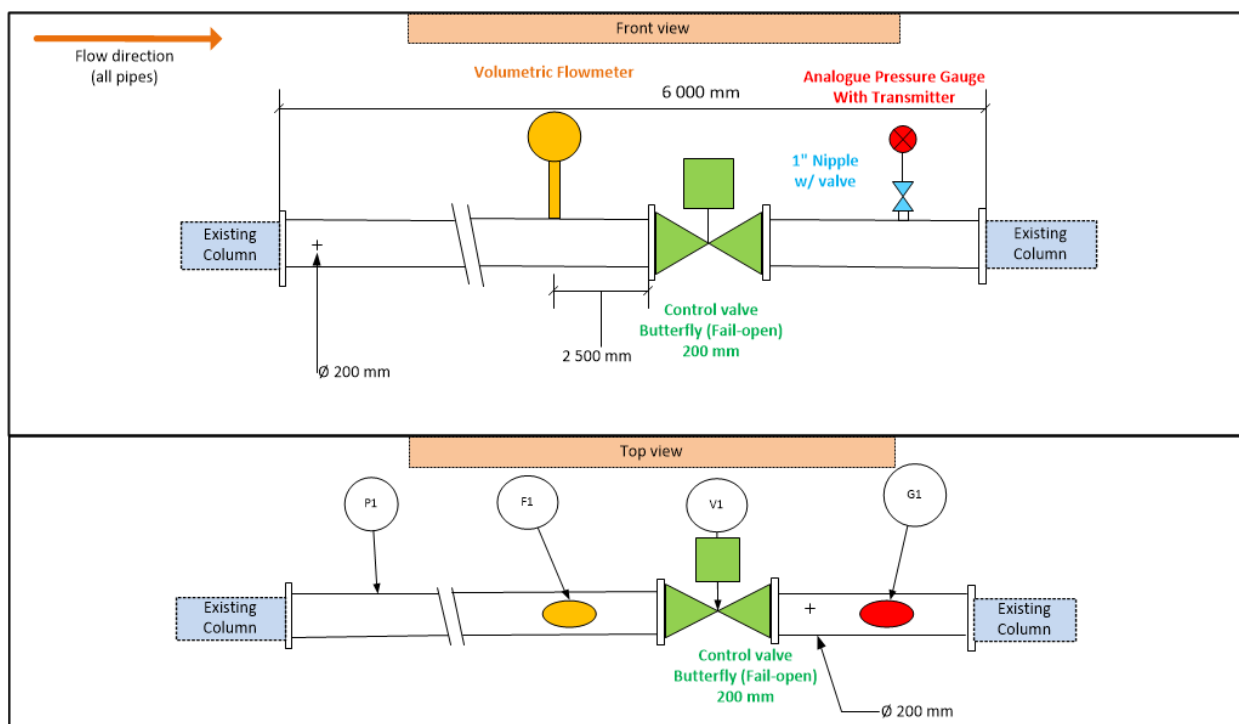
This section provides the context relevant to the level's compressed-air instrumentation and control in a deep-level mine in the Bushveld Complex. Compressed air underpins deep-level mining operations necessary for driving drilling, loading, agitation and refuge ventilation across multiple levels with sharply varying demand. Many sites still operate with basic controls that maintain a single high set point to satisfy the most demanding end uses, wasting air and electricity (Liebenberg *et al.*, 2012). Automated, measurement-based pressure control that matches supply to actual, level-by-level requirements is, therefore, a proven energy efficiency and DSM lever (Liebenberg *et al.*, 2012).

Compressed air is widely used across industries because it is easy to produce and relatively safe to handle; however, its generation is costly and often inefficient, underscoring the value of targeted optimisation (Goosen, 2013). Compressed air is a notoriously inefficient energy carrier, with typical usable power around 19%. Additionally, electricity can account for approximately 80% of a compressor's five-year life cycle cost. Hence, any reduction in unnecessary pressure or flow is directly remunerative (Liebenberg *et al.*, 2012). As Goosen (2013) notes, the apparent convenience of compressed air conceals high production costs and inherent inefficiencies, making pressure and flow optimisation particularly impactful.

In South African mines, compressed-air plants are among the largest single loads, frequently accounting for around one-fifth of total electricity use and, in certain platinum operations, they can account for up to 40% or more, making pressure optimisation a high-impact target (Burger *et al.*, 2024; Goosen, 2013). Such pressure-control projects also align well with Eskom's DSM initiatives. The relevant DSM incentives are discussed in more detail in Section 3.3.5.2.

Control architecture determines whether those savings are realised. In many plants, simplistic strategies keep multiple compressors online to maintain a fixed discharge pressure, causing blow-off and avoidable losses (Liebenberg *et al.*, 2012). Instrumentation-led control, using pressure and flow transmitters at critical points in compressed-air distribution networks, automated valve sequencing, and dynamic set point and bandwidth logic in conjunction, can be used to reduce run hours, suppress blow-off and align supply with demand in real time, while safeguarding minimum pressures for critical equipment (Goosen, 2013; Liebenberg *et al.*, 2012). Figure 7 provides a drawing of a typical level's compressed-air instrumentation and control assembly. In a mine, these assemblies are typically installed on each level.

Figure 7: Level compressed-air instrumentation and control assembly for DSM



(Source: Own compilation)

Evidence from South African gold mines demonstrates both the underlying mechanism and the magnitude. A retrofit of an automatic compressor cascading with pressure-bandwidth control achieved a reduction of 1.25 MW (from a baseline of 7.22 MW) during Eskom's evening peak. This translates to a 17.3% reduction in power by moving away from a single high set point and actively managing pressure (Liebenberg *et al.*, 2012).

3.3.2.3 BESS for energy arbitrage

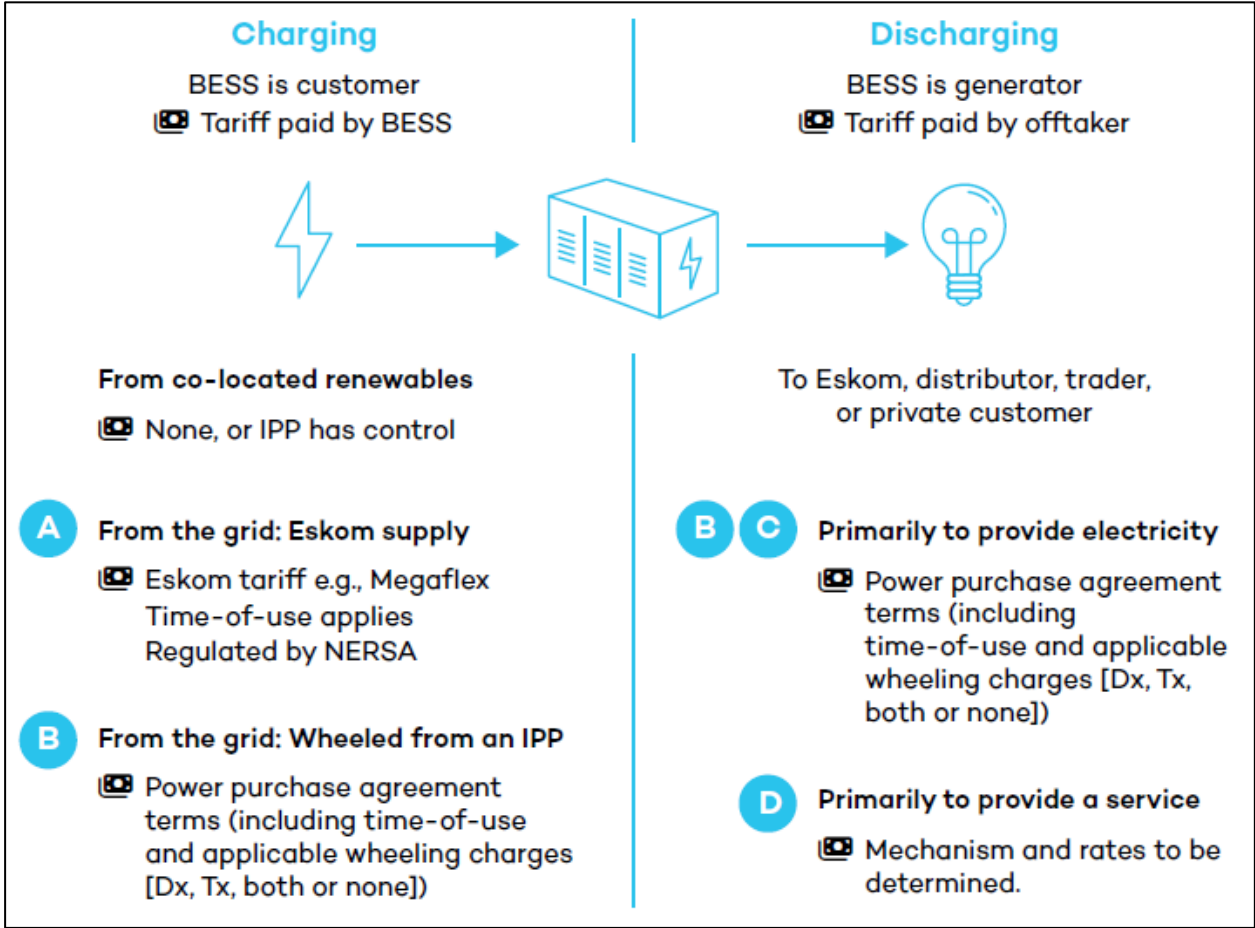
Recent interview evidence from *Watts in Store (Part 2, South Africa)* indicates that decreasing battery costs are beginning to make pure energy arbitrage viable for some private sector projects in South Africa. However, the report emphasises that stacking multiple value streams, such as arbitrage with ancillary services or reducing peak demand, materially strengthens project economics. On this basis, BESS is positioned not only for arbitrage but also as a platform for diversified revenues in South African contexts (Halsey *et al.*, 2024).

What is energy/tariff arbitrage, and why do tariffs matter?

Energy/arbitrage charges a battery when electricity prices are low and discharges it when prices are high (Halsey *et al.*, 2024). The business case depends on tariffs, which can be naturally divided into the charging and discharging prices faced by the user. Additionally, the locations of both the charging source and the customer in the network further affect these tariffs (Halsey *et*

al., 2024). Figure 8 from the *Watts in Store (Part 2, South Africa)* report clearly explains the BESS energy/tariff arbitrage, the business model, and the factors influencing charging and discharging tariffs (Halsey et al., 2024).

Figure 8: BESS energy/tariff arbitrage business model



(Halsey et al., 2024)

A South African market analysis presents a concrete arbitrage case for industrial users. It explains that the system should charge during off-peak hours and discharge during peak hours to capture the time-of-use (ToU) price spread (Xolo et al., 2025). On Eskom’s Megaflex ToU (long-distance zone, < 500 V) during the high-demand season, the off-peak rate is about R1.07/kWh while the corresponding peak rate is approximately R6.52/kWh, making CI&A users prime candidates for arbitrage (Xolo et al., 2025). The same source notes the possibility of quantifiable bill savings for large users through peak-demand shaving via energy arbitrage (Xolo et al., 2025).

Demand for Li-ion BESS is expected to continue due to a strong business case, growing value-stacking opportunities, and the role of storage in enabling more effective on-site renewables for decarbonisation (Xolo et al., 2025). The case study, BESS for energy arbitrage, in Section 4.2.3 is based on a project that is in the pipeline for a major mine in the Bushveld Complex. This project was included in the analysis due to the recent increase in demand for these projects and the

relatively available research on this emerging type of energy cost reduction. Li-ion systems are widely adopted as a preferred energy security solution compared to advanced lead acid batteries and diesel generators. Long lifespans and efficient operation have the potential to offset higher upfront costs and improve levelised cost of storage over the asset's lifetime, while the systems also support voltage and frequency stability to reduce power-quality risks (Xolo *et al.*, 2025). Although the suspension of load-shedding in April 2024 reduced immediate demand, ongoing risks linked to ageing generation and distribution assets, as well as load reduction in overloaded areas, continue to motivate BESS investment for security and quality of supply (Xolo *et al.*, 2025). For the CI&A behind-the-meter segment, the uptake of BESS is expected to stabilise at approximately 400 MWh per year ($\approx$ R2 billion per annum), with growth to around 2 GWh ($\approx$ R10 billion) by 2030 (Xolo *et al.*, 2025).

In combination, (i) the significant ToU spreads available to large users, and (ii) the ability to shave peaks and stack services present a credible cost-reduction pathway for mines and CI&A facilities through BESS-enabled arbitrage under South African tariffs (Xolo *et al.*, 2025). Projects are most resilient when multiple services are accessible and dispatch is optimised with an appropriate energy management system and trading software. Nonetheless, some private actors already perceive arbitrage-only opportunities as battery costs decline (Halsey *et al.*, 2024). Accordingly, arbitrage-led BESS should be treated as a DSM investment that complements efficiency measures and supports higher utilisation of embedded renewables (Halsey *et al.*, 2024; Xolo *et al.*, 2025).

3.3.3 Barriers to financing and implementation of EEPs

EEPs typically reduce operating costs, carry favourable risk-return profiles, enhance productivity, and have even been linked to higher firm value (Doty & Turner, 2004; Wingender & Woodroof, 1997). Yet, many cost-effective EEPs are not implemented due to financing and delivery frictions (Alliance to Save Energy, 2011; Doty & Turner, 2004; Huang & Li, 2011; Rezessy & Bertoldi, 2010). Surveys repeatedly identify upfront costs and capital constraints as leading reasons, even when payback periods are short (Doty & Turner, 2004; Organization., 2019; Woodruff *et al.*, 1996). In summary, strong fundamentals are often undermined by how projects are appraised, financed and executed (Painuly, 2009).

Common obstacles for the financing of EEPs include: (i) high pre-investment and transaction costs relative to small, dispersed projects; (ii) information and credibility gaps on both the customer and financier sides; (iii) low collateral value of energy efficiency equipment; and (iv) internal budgeting biases that prioritise 'core' production capex and demand very short payback periods for 'auxiliary' spending (International Energy Agency *et al.*, 2024; Rezessy &

Bertoldi, 2010; Sarkar & Singh, 2010). These factors depress bankability, even when lifetime savings are evident.

Mining's volatile commodity cycles, technical risks and heavy sustaining capex translate into high hurdle rates and tight capital rationing. EEPs rarely increase throughput and therefore fall short compared to production-linked investments, despite their attractive economics (Painuly, 2009). Traditional collateralisation is awkward because metering, controls and heat-recovery assets are site-specific, while lenders remain cautious about underwriting 'savings' cash flows without robust measurement and verification (M&V) and covenant frameworks (Nel *et al.*, 2018; Rezessy & Bertoldi, 2010). Classic project-finance structures are suitable for large, single-asset projects with contracted revenue. EEPs often lack the size required to absorb high transaction costs and have no third-party offtake unless they are aggregated or credit-enhanced (González-Ruiz *et al.*, 2021). Further, non-energy benefits such as reliability, maintenance, quality and safety are frequently omitted from appraisals (Nel *et al.*, 2018).

In South Africa, macro-financial conditions have increased the cost of capital for local miners, raising the minimum acceptable rates of return and tightening internal rationing, which is unfavourable for savings-led projects competing with high IRR production capex (Birch, 2016; Duffy, 2025; Minerals Council South Africa, 2023; Rezessy & Bertoldi, 2010). Mines' preference for internal financing further crowds out EEPs when commodity cycles support exceptional IRRs on core projects (Barburski & Holda, 2023; Painuly, 2009).

Unpredictable Eskom tariff trajectories complicate savings forecasts and deter investment based on avoided energy costs (Halsey *et al.*, 2024). Wheeling and billing rules are still being standardised; municipal variability and capacity constraints create uncertainty regarding charges and settlement, affecting the embedded generation and storage that underpin arbitrage or peak-shaving (Halsey *et al.*, 2024). Regulatory complexity, despite the easing of the 2023 ERA Schedule 2, persists around storage and requires multi-layer approvals, including grid codes, new-generation regulations, and municipal procurement rules for contracts longer than 3 years). This raises transaction costs and elongates timelines (Halsey *et al.*, 2024). Uneven municipal capacity further slows permitting and due diligence for distributed energy and storage, adding an administrative burden to mine-site EEPs (Xolo *et al.*, 2025).

EEPs underperform in implementation not because their economics are weak, but because bankability is undermined by small scale, information gaps, low collateral, and internal budgeting biases. Mining magnifies these effects through high corporate hurdle rates, throughput-first capital allocation, and omitted non-energy benefits (Birch, 2016; Nel *et al.*, 2018). In South Africa, tariff uncertainty, evolving wheeling and billing practices, multi-layered regulation, and municipal

capacity constraints further increase transaction costs and discount rates. Addressing these frictions, while fully valuing non-energy benefits and adopting bankability enablers, can unlock investable pipelines in South African mines (Doty & Turner, 2004; Nel *et al.*, 2018; Rezessy & Bertoldi, 2010).

3.3.4 Financing models and capital structures

Financing models and capital structures are central to the implementation and success of EEPs in capital-intensive sectors such as mining. Despite the proven benefits of EEPs, including decreased operational expenses and favourable risk-to-reward ratios, many cost-effective projects remain unexecuted due to financial limitations and high upfront costs (Doty & Turner, 2004; United Nations Industrial Development Organisation, 2019a). Selecting the correct combination of financing sources and structure is crucial, as it can significantly contribute to improved project performance metrics such as ROI and NPV (Doty & Turner, 2004). Mining is characterised by high investment risk, technical risks, and commodity price volatility, which translate into high hurdle rates and tight capital rationing. This makes the optimal financing structure particularly important for EEPs, which often lose out to high IRR production-related projects (Barburski & Holda, 2023).

This section details the primary financing mechanisms available for EEPs in the South African mining sector, forming the theoretical basis for the quantitative analysis presented in Chapter 4.

3.3.4.1 Available financing sources and structures

Financing mechanisms suitable for EEPs generally encompass debt, equity, mezzanine finance, project finance, and supplementary mechanisms such as guarantees and public programmes (Rezessy & Bertoldi, 2010). The choice among these options involves assessing accessibility, applicability, and the allocation of risk. The following subsections outline various financing sources and structures relevant to EEPs, providing the necessary details for comparative financial calculations

Internal financing

Internal financing involves issuing shares or utilising internal capital, such as retained earnings (Rezessy & Bertoldi, 2010). Equity is the residual claim against the company's assets.

Businesses often prefer the use of recourse finance for core business activities rather than for projects in auxiliary activities, such as energy efficiency (International Energy Agency *et al.*, 2024; Rezessy & Bertoldi, 2010).

Internal capital, however, generally represents the most important source of financing in the mining sector (González-Ruiz *et al.*, 2021). Internal capital is not 'free' financing; it carries an inherent cost – the cost of common equity (r_s), representing the opportunity cost (Brigham & Ehrhardt, 2008). This cost of finance shapes project economics.

The WACC is the average return required by all investors (Brigham & Ehrhardt, 2008). It is a crucial input for discounted cash flow analysis and is used as the discount rate when calculating the NPV (Brigham & Ehrhardt, 2008). The study used the WACCs from the major mining companies, as calculated from their annual financial statements.

Debt financing

In a market economy, funds flow from those with surplus capital to those who need it through the pricing system. The meeting of supply and demand determines the price of money: for debt, this is reflected in the interest rate, and for equity, it represents the cost of equity, which includes what shareholders expect in the form of dividends and capital gains (Brigham & Ehrhardt, 2008).

Debt financing refers to the acquisition of funds through borrowing: a lender provides capital to a borrower (the buyer of equipment) for a defined purpose over a fixed period. The borrower owns the system once the lender has been repaid (Rezessy & Bertoldi, 2010; Xolo *et al.*, 2025). It allows for the preservation of the business's capital and liquidity. However, this requires businesses to have a track record of creditworthiness (Xolo *et al.*, 2025).

The nominal cost of debt is the interest rate paid, r_d (Brigham & Ehrhardt, 2008). Commercial loans are often tied to the prime lending rate, which for South Africa as of October 2025 is 10.50% (South African Reserve Bank, 2025b). According to Xolo (2025), the interest rates for BESS and solar photovoltaic projects are risk dependent but usually below prime. The Industrial Development Corporation (IDC) offers loans through its Partnership Scheme at prime minus 3% (Mail & Guardian, 2012). The four most fundamental factors affecting the cost of money are (i) the expected rate of return on production opportunities, (ii) time preferences for consumption, (iii) risk, and (iv) inflation. Lenders rely on covenants to enforce bankability (Brigham & Ehrhardt, 2008).

Debt options include corporate, project and green loans under recourse or limited recourse structures, leasing arrangements and full or limited guarantees. Debt financing can include options whereby loans convert to a certain amount of equity ownership if the project is successful, thereby increasing the lenders' rate of return (Rezessy & Bertoldi, 2010).

Corporate balance sheet debt

Corporate balance sheet debt, also known as recourse financing or on-balance-sheet financing, is debt recognised as a liability on the company's balance sheet. The company's general assets secure the debt, meaning the company stands behind the project (Rezessy & Bertoldi, 2010). Funds are typically sourced from commercial banks (term loans) or the corporate bond market. General corporate capital market activities include sourcing bank debt for general corporate purposes or issuing bonds (Rezessy & Bertoldi, 2010).

Large mining producers often prefer corporate funding methods (Rezessy & Bertoldi, 2010). Debt financing offers an interest tax shield as interest payments are tax-deductible (Barburski & Holda, 2023; Brigham & Ehrhardt, 2008). The after-tax cost of debt, as shown in the following formula, is used in financial modelling to calculate the cost of debt while considering the tax benefits (Brigham & Ehrhardt, 2008). The tax shield applies only to interest, not to principal.

$$\begin{aligned}\text{After tax component cost of debt} &= \text{Interest rate} - \text{Tax savings} \\ &= r_d - r_d T_c \\ &= r_d(1 - T_c)\end{aligned}$$

Where:

- r_d = Interest rate
- T_c = Corporate tax rate (27%) (South African Revenue Service (SARS), 2025)

Utilising corporate debt increases financial leverage, which can magnify expected returns on equity but also increases financial risk (Barburski & Holda, 2023). Companies often prefer to reserve recourse financing for core business activities, making them hesitant to use it for auxiliary EEPs (Rezessy & Bertoldi, 2010). This option limits future borrowing capacity by tying up the company's balance sheet (Rezessy & Bertoldi, 2010).

Project finance

Limited recourse (project) finance, also called cash flow financing, funds a project primarily based on its own merits. It provides long-term capital secured by the project's projected cash flows, not the sponsors' balance sheets (Rezessy & Bertoldi, 2010).

This is structured through a special-purpose vehicle – an independent entity created solely for the project (González-Ruiz *et al.*, 2021). Project finance involves non-recourse or limited recourse debt (Rezessy & Bertoldi, 2010). This structure ensures that the debt is treated as off-balance-sheet financing for the sponsor, thereby increasing borrowing capacity (González-Ruiz *et al.*, 2021). Lenders are secured by a comprehensive security package, including asset cessions and

cash flow waterfalls, and can assume control through step-in rights if the special-purpose vehicle defaults (González-Ruiz *et al.*, 2021). The financing is based on project cash flow expectations and spreads the risk among different actors (Rezessy & Bertoldi, 2010). Due to the high transaction costs of complex structures, project finance is difficult to apply to small EEPs unless they are aggregated (González-Ruiz *et al.*, 2021). Smaller companies facing corporate debt barriers often turn to project finance (Rezessy & Bertoldi, 2010).

Project finance facilitates high leverage. The debt-to-equity ratio often falls between 60% and 40% and commonly allows for equity contributions as low as 15% to 20% (Machlin & Rummel, 2020; Rezessy & Bertoldi, 2010). Optimisation studies suggest that the equity contribution should remain within a narrow range, with a minimum practical or regulatory baseline of 20% and an optimal maximum of around 26.6%, to maximise profitability for the operator while maintaining financial stability for lenders (Yun *et al.*, 2009).

The loan interest rate is often described as a function of the level of equity capital and risk (Xolo *et al.*, 2025; Yun *et al.*, 2009). High leverage offers opportunities to incorporate debt aligned with the SDGs (González-Ruiz *et al.*, 2021). Loan tenors are typically long, ranging from 7 to 18 years, with the norm being in the 12 to 15 year range (Machlin & Rummel, 2020). Loans can be extended up to almost 15 years because lenders have greater control over the project (Rezessy & Bertoldi, 2010).

Sustainability-linked/green-labelled instruments

These instruments channel capital toward sustainability objectives (González-Ruiz *et al.*, 2021). Green bond proceeds are exclusively used for eligible green projects (Department of Forestry Fisheries and the Environment, 2021a). The JSE launched its Green Bond Segment in late 2017 (Department of Forestry Fisheries and the Environment, 2021a). Sustainability-linked bonds and loans are general-purpose financial instruments in which the cost of financing (coupon payment) is linked to the issuer's achievement of predefined sustainability performance targets related to key performance indicators (Maino, 2022a).

Sustainability-linked bonds and loans are forward-looking and suitable for hard-to-abate sectors, including mining (Maino, 2022b). Issuers benefit from a potential sustainability yield discount (or greenium) compared to conventional bonds (Maino, 2022b). Conversely, some firms may issue them as a costly signalling instrument (Maino, 2022b).

Sustainability-linked bonds receive an average yield that is 29.2 basis points lower at issuance in primary market transactions, referred to as a sustainability yield discount (Maino, 2022b). Conversely, failure to meet a sustainability performance target typically triggers a financial penalty

or coupon step-up, with 25 basis points being the most common structure (Maino, 2022b). Green bonds can yield savings ranging from 7 basis points to 134 basis points compared to comparable standard bonds (Wang & Chu, 2022).

Blended/stacked hybrids

Blended financing combines various funding sources and risk-mitigation tools (Aslam *et al.*, 2023; Rezessy & Bertoldi, 2010). This includes enhancing senior debt with external credit support, such as guarantees. Mezzanine finance (subordinated debt) is structurally positioned between senior debt and pure equity (Rezessy & Bertoldi, 2010). Mezzanine financing is subordinated capital that is priced between senior debt and equity. Subordination establishes repayment priority. Subordinated debt is paid only after operating costs and senior debt service, making it riskier and ranking it behind senior debt in terms of both collateral and cash flows (Rezessy & Bertoldi, 2010).

In EEPs, performance insurance and guarantees can reduce risk, helping to lower the required return. Guarantees reduce the lender's risk (Rezessy & Bertoldi, 2010). Energy savings insurance reduces the net cost of EEPs by reducing the interest rates charged by lenders (Rezessy & Bertoldi, 2010). Mezzanine debt is cheaper than equity, does not usually require sacrificing company control, and serves as patient capital (Rezessy & Bertoldi, 2010). Blended structures using concessional funds can improve the development finance institution's risk position on the subordinated loan facility (Rezessy & Bertoldi, 2010).

Leasing

Leasing is a way of obtaining the right to use an asset where the transaction involves the lessor, who owns the property, and the lessee, who obtains the use of the property (Brigham & Ehrhardt, 2008). Vendor financing is offered by equipment suppliers, often facilitated by commercial banks or their specialised leasing units, providing financing similar to that required for EEPs (Brigham & Ehrhardt, 2008).

Operating leases are treated as an expense, allowing for off-balance-sheet financing (Brigham & Ehrhardt, 2008). Financial (capital) leases are capitalised as assets and liabilities. Leasing is particularly suitable when physical assets constitute the bulk of the project expenditure.

To support leasing cost assumptions in financial modelling for EEPs, recent research indicates that lease payments for such equipment typically range from approximately 1% to 1.5% of the equipment's value per month (Yu, 2022). These rates, however, may increase for smaller or riskier projects, particularly when the residual asset value is low or the lease term is short. These figures provide a credible basis for estimating leasing costs in financial simulations for EEPs.

Performance-contracting and shared savings

ESCOs play a pivotal role in delivering EEPs through performance-based models (Arndt, 2005). These models are structured to use future energy savings as a source of project funding, thereby eliminating the need for, or reducing the amount of, upfront capital required from the client. Two dominant approaches within this model are shared savings and performance contracting, each offering different allocations of risk, responsibility, and reward (Arndt, 2005; Kats *et al.*, 2011).

Shared-savings contracts are particularly attractive for clients with limited capital, as the ESCO finances the entire project, including design, implementation and maintenance. The ESCO recovers its investment from a pre-agreed share of the verified energy savings. The client benefits from improved infrastructure and reduced energy costs without any upfront expenditure. In past South African shared-savings contracts, a 50/50 savings split was used, providing a balanced incentive between the ESCO and client (Arndt, 2005). While this model reduces risk for the client, it results in a smaller share of the savings compared to other models, such as self-financed models. Additionally, since the ESCO assumes both financial and technical risk, the cost of capital and risk premium are often embedded in their share of the savings (Arndt, 2005). Shared savings can be less favourable for clients capable of self-funding, as they would otherwise retain the full savings.

Performance contracting, by contrast, typically involves the client funding the project while the ESCO guarantees a minimum level of energy savings. If savings fall short, the ESCO compensates for the difference, making it a lower-risk option for the client in terms of performance delivery. A 80/20 savings split was used in past South African shared-savings contracts (Arndt, 2005). Financing may still be arranged by or through the ESCO, but the credit risk rests with the client. As outlined in the same report, this model has been adopted in cases where clients have access to capital but seek to mitigate the risk of underperformance (Arndt, 2005). A key benefit is that the client retains the bulk of the energy savings, provided that they exceed the guaranteed threshold. However, this approach places greater emphasis on accurate M&V, as well as on the client's willingness to carry financial exposure (Arndt, 2005; Kats *et al.*, 2011).

3.3.4.2 Financing source databases

The systematic literature review confirmed that financing is readily available for EEPs in the form of grants, tax incentives, and various funding mechanisms accessible to mining companies and ESCOs. Recognising that access to finance is often the number one challenge experienced by implementers, such as small, medium, and micro enterprises, specialised platforms and databases have emerged to connect those needing capital (seekers) with financiers and funding instruments (GreenCape, 2024). These resources play a pivotal role by providing transparency

and guidance, thereby helping to bridge the gap between project implementers and capital providers.

- **GreenCape green finance databases:** This resource provides relevant market information for sourcing green instruments and incentives, primarily focusing on the South African context (GreenCape, 2024). Maintained by the Green Finance Desk, this resource serves as a crucial intermediary by listing institutions that provide funding, detailing the types of funding available, and supplying contact details. It is considered ideal for any entity seeking a broad range of funding solutions and financial incentives, particularly those with a South African focus.
- **AlliedCrowds database:** This platform serves as a comprehensive aggregator and directory of alternative finance providers globally, specifically targeting the developing world (AlliedCrowds, c2025). It helps donors, investors, and entrepreneurs navigate the alternative finance space and is ideal for any entity seeking a broad range of financial solutions. Users can access the Capital Finder feature, which allows filtering by criteria such as sector (including green tech), type of capital (equity, lending, and grants), and funding type (crowdfunding, angel investing, venture capital, and impact investing). The purpose is to increase the flow of capital to deserving projects globally (AlliedCrowds, c2025).

These financial resources are important tools for enabling the successful implementation of EEPs by overcoming the institutional and informational barriers to capital access, thereby facilitating cooperation between those seeking to implement projects and those offering the necessary financing.

3.3.5 Relevant incentives applicable to EEPs in the South African mining sector

The legislative landscape in South Africa actively encourages the implementation of EEPs in energy-intensive sectors, including mining, through both incentives and penalties, thereby enhancing the overall financial benefit of these projects. Key among these instruments are the *Income Tax Act's* Section 12L allowance and the *Carbon Tax Act* No. 15 of 2019, as well as Eskom DSM incentives (Department of Forestry Fisheries and the Environment, 2021a; Eskom Holdings SOC Ltd, 2025b).

The subsections that follow summarise how these incentives work, typical thresholds, such as minimum saving sizes and time-of-day windows, remuneration formats (c/kWh and R/MW), and common conditions such as third-party verification and payment caps, so they can be correctly modelled alongside the financing structures evaluated in this study.

3.3.5.1 Carbon reduction incentives

The following subsections provide a brief overview and explanation of the carbon reduction related incentives that are applicable to the South African mining sector. In South Africa, the government offers tax rebate incentives to promote the implementation of EEPs, namely Section 12L, which is regarded as the carrot method. In contrast, the new policy planning has led to the implementation of a carbon tax specifically on greenhouse gas emissions. This is viewed as the stick method for the industry to lower greenhouse gas emissions (Nel *et al.*, 2018). The section also provides information related to these incentives, which were used as inputs for the simulations completed in Chapter 4.

Carbon 12L incentive

The Section 12L tax incentive programme acts as a powerful financial stimulus (the carrot) aimed primarily at tackling the perceived high initial capital cost associated with energy-efficient technologies (Department of Forestry Fisheries and the Environment, 2021a; Nel *et al.*, 2018).

South Africa's Section 12L provides a deduction of 95 c/kWh (or kWh equivalent) for verified energy efficiency savings (South African Revenue Service (SARS), 2024). Claims are limited to a single assessment year of performance, must be measured and verified by an M&V body accredited by the South African National Accreditation System, and require a South African National Energy Development Institute 12L certificate before the deduction can be claimed (typically in the year following the performance period).

The following formula shows how to calculate the carbon 12L incentive benefit (South African Revenue Service (SARS), 2024). The deduction directly reduces the company's taxable income, which, at the standard 27% corporate tax rate (South African Revenue Service (SARS), 2025), equates to roughly 25.65 cents of tax reduction per kWh saved (Botha, 2024).

$$\text{Tax benefit} = \text{Certified kWh savings} \times 0.95 \text{ R/kWh} \times \text{Firm's corporate tax rate}$$

The incentive was previously set to lapse for years of assessment ending before 1 January 2026. However, based on the National Treasury's recommendation, it will be extended to 31 December 2030 (for years of assessment ending before 1 January 2031) (Botha, 2024; South African Revenue Service (SARS), 2024).

Carbon tax

Initially, Phase 1 of the carbon tax was set to end by 2022, but it has been extended through 2025 to maintain support for the industry during the economic recovery. However, in Phase 2, the tax

is expected to become more stringent. The National Treasury's 2024 discussion paper proposes increasing tax rates and gradually reducing the basic allowance – starting at 50% in 2026 and decreasing by 2.5% each subsequent year. This adjustment aims to raise the effective carbon price to levels necessary for South Africa to meet its climate targets (Botha, 2024; Treasury., 2022).

Emission reductions and savings (MtCO_2e) can be calculated by multiplying the activity data (gigawatt-hour) by the grid emission factor ($\text{tCO}_2\text{e/GWh}$), which Eskom publishes in its annual reports (Department of Forestry Fisheries and the Environment, 2021a, 2024).

Mines do not pay the carbon tax directly on purchased Eskom energy. Instead, they save on the environmental and carbon-related charges embedded in Eskom's tariff per kilowatt-hour (currently the environmental levy, though policy is shifting towards a carbon tax that will be passed through with price neutrality). In practice, the kilowatt-hour saved is multiplied by the environmental or carbon rate per kilowatt-hour that the National Energy Regulator of South Africa (NERSA) allows Eskom to recover (Creamer, 2025).

As of the 2025/26 fiscal year, NERSA's tariff decisions continue to allow recovery of 3.5 c/kWh for the environmental levy. This environmental levy is already incorporated into the tariffs presented in the Eskom tariff booklet (Eskom Holdings SOC Ltd, 2025a). This study used the Eskom Megaflex tariffs for all simulations; therefore, the 3.5c/kWh does not need to be considered again in the calculations. For example, when calculating the financial savings achieved from an EEP, the calculation did not include the carbon tax savings in addition to the energy cost savings achieved, as the savings calculated using the Eskom Megaflex tariff booklet already incorporate the environmental levy saved.

3.3.5.2 Eskom DSM incentives

The Eskom Integrated Demand Management (IDM) Programme is a key mitigation action in South Africa's energy sector (Department of Forestry Fisheries and the Environment, 2021a). The primary objective of the IDM Programme is to promote energy efficiency and load management. It provides for the efficient use of energy resources and related incentives or rebates. Eskom Distribution has recently launched the Distribution Demand Management Programme (DDMP) to assist in reducing load-shedding and balancing the national supply and demand of electricity (Department of Forestry Fisheries and the Environment, 2021a). The current DDMP programmes utilise a performance-contracting approach. Projects must be financed upfront by the project developer or the customer. Once implemented, awarded contracts receive an incentive (rand/MW or cents/kWh) for achieved demand and/or energy reduction during specified periods (Eskom Holdings SOC Ltd, 2025b).

DSM options for heavy industry and mining

The DDMP offers solutions targeting CI&A users, which are highly relevant to the energy-intensive nature of mining (Eskom Holdings SOC Ltd, 2025b). Projects focusing on large energy users, such as those addressing compressed-air systems that can account for more than 40% of electricity use in some deep-level operations, as well as BESS arbitrage projects, align well with these initiatives (Liebenberg *et al.*, 2012; Xolo *et al.*, 2025).

1. Energy Efficiency Programme

Table 3 provides relevant information on the workings, requirements and remuneration related to Eskom's Energy Efficiency Programme.

Table 3: Eskom's Energy Efficiency Programme information

Detail	Explanation and Requirements
How it works (objective)	The Energy Efficiency Programme is an incentive-based programme designed to encourage customers to undertake EEPs they might otherwise delay. The primary aim is to reduce electricity usage throughout the entire day, thereby lowering the customer's electrical energy input cost and addressing capacity issues for Eskom in the short term.
Minimum requirements	The programme is open to all sectors, excluding the residential sector. Projects must achieve a minimum average demand reduction of 50 kW in the consumption baseline. This consumption baseline is measured over 14 hours daily (06:00 to 20:00), excluding weekends. The minimum energy saving applicable is 45 500 kWh per quarter. Projects must be implemented within six months.
Remuneration (incentive)	The incentive rate is 41.029 c/kWh based on the average demand savings achieved over the defined period.

(Eskom Holdings SOC Ltd, 2025b)

2. Load shifting and peak clipping (load management)

The DDMP groups load shifting and peak clipping under load management initiatives, aiming to optimise system load profiles (Eskom Holdings SOC Ltd, 2025b). Historically, peak clipping and energy efficiency were the two types of DSM projects implemented in mine compressed-air systems (Liebenberg *et al.*, 2012).

Table 4: Load Management programme information

Detail	Explanation and Requirements
How it works (objective)	The objective of load management initiatives is to reduce demand during the constrained evening peak periods. This is achieved by managing customer usage by clipping or shifting the peak load. Specifically, a peak clipping project aims to reduce electricity usage during Eskom's evening peak hours, typically from 18:00 to 20:00.
Minimum requirements	The programme is open to all sectors, excluding the residential sector. The minimum size for load shifting or peak clipping projects is 0.2 MW. The targeted demand reduction period is the Eskom-defined evening peak period for both summer and winter. Contractual target savings generally apply only on weekdays.
Remuneration (incentive)	The standard incentive rate for all DDMP performance-contracting programmes (including load management, load shifting and peak clipping) is R3 million/MW. Incentive rebates are paid quarterly over a 24-month sustainability term (eight quarters).

(Eskom Holdings SOC Ltd, 2025b)

The following general DDMP conditions apply to all programmes (Eskom Holdings SOC Ltd, 2025b):

- **M&V:** All approved proposals are subject to independent M&V of the proposed baseline. Eskom covers the cost of all required M&V reporting, but the project developer is responsible for the expenses associated with the necessary M&V equipment.
- **Performance cap:** Payments are capped at 100% performance, which means no payments are provided for overperformance.
- **Non-duplication:** Double dipping or claiming benefits from other incentive programmes is not permitted.

The Eskom IDM Programme is recognised as a foundational element of South Africa's mitigation strategy in the energy sector, promoting energy efficiency and load management through incentives and rebates (Department of Forestry Fisheries and the Environment, 2021a).

3.3.6 Project financial feasibility and modelling principles

This section provides an overview and explanation of the variables, tools and calculations used in this study to complete financial feasibility simulations and modelling of various project financing models and scenarios.

3.3.6.1 Variables

This section outlines the principal variables and assumptions that underpin the quantitative financial modelling conducted in Section 3.3.6.2. Each input plays a critical role in shaping the outputs of the financial indicators described in Section 3.3.6.2.

Weighted average cost of capital

The WACC represents the blended return required by debt and equity holders, weighted by their share in the firm's capital structure (Fernández, 2011). As such, it serves as the firm's overall discount rate, reflecting the opportunity cost of capital and forming the standard benchmark for valuing cash flows (Mauboussin & Callahan, 2023). In standard valuation, intrinsic value is the present value of free cash flows discounted at WACC. This study, where possible and applicable, estimated the WACC for mining companies based on their latest financial reports and publicly available financial data. Thereafter, the study applied it consistently in NPV, discounted payback period and PI calculations. Professional guidance likewise treats WACC as the benchmark hurdle for investment appraisal (Association of Chartered Certified Accountants (ACCA), 2025b). In this study, project cash flows were discounted at the firm's WACC. The following historical literature provides a basis for establishing relevant discount rate benchmarks in the South African mining sector:

- According to Smith *et al.* (2007) and Birch (2016), real discount rates of 9–12% are appropriate for mining projects in South Africa (Birch, 2016; Smith, 2012).
- This range is equivalent to 14.5–17.6% for WACC in nominal terms, assuming a 5% annual inflation rate (Smith, 2012).

In general, WACC is calculated using the following formula (Brigham & Ehrhardt, 2008; Hargrave, 2025):

$$WACC = \frac{E}{V} \cdot R_e + \frac{D}{V} \cdot R_d \cdot (1 - T_c)$$

Where:

- E = Market value of equity
- D = Market value of debt
- $WACC$ = Weighted average cost of capital
- R_e = Cost of equity
- R_d = Pre-tax cost of debt
- T_c = Corporate tax rate (27%) (South African Revenue Service (SARS), 2025)

The formula incorporates a tax shield on debt (since interest is tax-deductible).

Cost of equity

The cost of equity can be calculated using the following formula (Brigham & Ehrhardt, 2008):

$$R_e = R_f + \beta \times (R_m - R_f),$$

Where:

- R_f = Risk-free rate; South African government bonds yield 9.17% as of September 2025 (Organisation for Economic Co-operation and Development OECD, 2025).
- $R_m - R_f$ = Equity risk premium; for South Africa, an industry-standard equity premium is about 8.35% (Damodaran, 2025).
- β = Leverage.

This study estimated the WACC for five mining groups operating in South Africa to provide a realistic discount rate for project appraisal and to make the analyses applicable to the context of the South African mining sector. Each component is drawn from public sources and aligned with the firms' latest reporting dates to keep the estimates comparable and useful for decision-making.

Take note of the following:

- The cost of equity uses the capital asset pricing model with the South African risk-free rate from OECD long-bond yields, a South African equity risk premium from Damodaran (2025), and five-year monthly levered betas from reputable finance portals.
- The cost of debt is calculated by dividing the interest expense by the average interest-bearing borrowings from the same financial report.
- Capital structure weights use market values: equity is calculated as the share price multiplied by the number of shares issued, matched to the report date; the debt weight uses the latest interest-bearing balance (D_2).
- Only interest-bearing debt is included; non-interest liabilities are excluded. International Financial Reporting Standard 16 lease liabilities are excluded unless the related interest is clearly reflected in the reported interest expense.
- Tax shield: a 27% statutory corporate rate is applied.
- Currency and dating are consistent within each company: financials and share prices are aligned to the same date of the relevant financial report (either December 2024 or June 2025) and currency.
- Sources for all inputs (financial statements and market data) are cited in the table.

The resulting inputs and company-level WACC estimates are presented in Table 5.

Table 5: WACC and related variables for five mining companies operating in South Africa

Variables	Harmony Gold	Sibanye-Stillwater	Anglo American	Impala Platinum	Exxaro Resources
β	0.44 (Yahoo Finance, 2025a)	0.97 (Yahoo Finance, 2025b)	0.92 (Yahoo Finance, 2025c)	1.21 (Yahoo Finance, 2025d)	0.37 (Yahoo Finance, 2025e)
R_f	9.17% (Organisation for Economic Co-operation and Development OECD, 2025)				
$(R_f - R_m)$	8% (Damodaran, 2025)				
R_e	12.84%	17.27%	16.85%	19.27%	12.26%
Average debt ((opening debt+closing debt)/2)	R1.874 billion	R39.153 billion	R313.465 billion	R3.565 billion	R8.572 billion
Interest expense	R266 000 000 (Harmony Gold Limited, 2025)	R1.946 billion (Sibanye-Stillwater Limited, 2025)	R15.245 billion (Anglo American, 2025)	R263 000 000 (Impala Platinum Holdings Limited, 2025)	R974 000 000 (Exxaro Resources Limited, 2025)
R_d	14.20%	4.97%	4.86%	7.38%	11.36%
Share price (aligned with annual financial statements used)	R244.81 (Yahoo Finance, 2025f)	R14.98 (Yahoo Finance, 2025g)	R525.65 (Yahoo Finance, 2025j)	R158.93 (Yahoo Finance, 2025h)	R157.95 (Yahoo Finance, 2025i)
Shares outstanding	622 522 160 (Harmony Gold Limited, 2025)	2.831 billion (Sibanye-Stillwater Limited, 2025)	1.192 billion (Anglo American, 2025)	897 000 000 (Impala Platinum Holdings Limited, 2025)	241 534 848 (Exxaro Resources Limited, 2025)
E (share price x shares outstanding)	R152.40 billion	R42.402 billion	R626.575 billion	R142.560 billion	R38.150 billion
D_1	R1.794 billion (Harmony Gold Limited, 2025)	R36.618 billion (Sibanye-Stillwater Limited, 2025)	R324.320 billion (Anglo American, 2025)	R3.341 billion (Impala Platinum Holdings Limited, 2025)	R8.923 billion (Exxaro Resources Limited, 2025)
D_2	R1.953 billion (Harmony Gold Limited, 2025)	R41.687 billion (Sibanye-Stillwater Limited, 2025)	R302.610 billion (Anglo American, 2025)	R3.790 billion (Impala Platinum Holdings Limited, 2025)	R8.220 billion (Exxaro Resources Limited, 2025)
T_c	27% (South African Revenue Service (SARS), 2025)				
WACC	12.81%	10.51%	12.52%	18.91%	11.56%

(Source: Own compilation)

The following observations are noted from the results of the WACC estimates, calculations, and related financial reports:

- Harmony's comparatively lower WACC is consistent with modest interest-bearing borrowings and a strengthened cash position, as reflected in FY25 disclosures showing negative net debt relative to earnings before interest, taxes, depreciation, and amortisation, along with noted references to movements in borrowings (Harmony Gold Limited, 2025).
- Sibanye-Stillwater's blended WACC is muted by a sizeable debt load, along with a marked rise in finance expenses for 2024, which is consistent with borrowings of R41.7 billion and a year-on-year increase in finance costs (Sibanye-Stillwater Limited, 2025).
- Anglo American's mid-range WACC aligns with a large capital base and net debt of \$10.8 billion reported at HY2025, within the context of the group's ongoing portfolio simplification (Anglo American, 2025).
- Impala Platinum's higher WACC corresponds to an equity-heavy mix with active short-term funding; the annual financial statements show total borrowings of approximately R3.8 billion and a stable share capital base over FY25 (Impala Platinum Holdings Limited, 2025).
- Exxaro's moderate WACC is consistent with measured leverage and project finance exposures largely linked to the Johannesburg Interbank Average Rate, with extensive swap coverage disclosed in the 2024 annual financial statements (Exxaro Resources Limited, 2025).

Overall, Table 5's firm-level WACCs track the reported debt positions, finance costs and equity bases in the latest statements, yielding a coherent cross-section of corporate internal mining financing costs for 2024/25.

In September 2025, South Africa's consumer price index was 3.4% year-on-year. Earlier consumer price index readings for 2025 were between 2.8% and 3.0%. A real project rate of 9% to 12% suggests a discount rate of 12.5% to 15.7% for 2025 (Birch, 2016; Smith, 2012; South African Reserve Bank, 2025a). In this context, two companies (Harmony and Anglo American) are positioned within the band but towards its lower edge, while two companies (Sibanye-Stillwater and Exxaro) fall just below it. Only Impala lies above, consistent with Table 5's higher beta and equity weight for Implats, which drives a steeper required return. This pattern is expected, Smith (2012) and Birch (2016) discuss project-level hurdles, while a listed group's

corporate WACC is typically lower due to diversification and multi-jurisdiction exposure (Birch, 2016; Smith, 2012). Project hurdles encompass construction, geological, permitting, and ramp-up premiums. Accordingly, the estimated group WACCs remain valid as base-case discount rates for routine, on-balance-sheet brownfield efficiency projects like the ones analysed in this study (Association of Chartered Certified Accountants (ACCA), 2017).

Initial investment and operating costs

This study considered the initial investment outlay to include costs for equipment, engineering, installation, and any upfront development costs for the full EPCM of the specified EEP. In this study, cash outflows at $t = 0$ were not discounted and were treated as the project's cost base against which discounted inflows were compared (Brigham & Ehrhardt, 2008). UNIDO's feasibility guidance likewise emphasises the importance of identifying all upfront capital costs and subsequent operating effects within a defined project life for investment appraisal (United Nations Industrial Development Organization (UNIDO), 2021). Operating costs encompass all costs, including maintenance, operating labour, consumables and other recurring expenditures (United Nations Industrial Development Organization (UNIDO), 2021). Accordingly, this study discounted both the applicable operating expenses and the projected savings to their present value, ensuring that costs and benefits were assessed consistently.

Project savings (cash inflows)

Consistent with the International Performance Measurement and Verification Protocol, energy savings were defined as the difference between post-implementation energy use and the baseline period. This included routine and non-routine adjustments applied to ensure that both periods were evaluated under equivalent conditions, yielding a conservative estimate of what would have occurred without the intervention (Nel *et al.*, 2018).

Accordingly, the forecast cash inflows for this study comprised energy cost savings (as measured by the M&V convention mentioned above) and, where applicable, revenues such as government incentives and 12L carbon tax benefits. Estimating these flows was the most consequential step in capital budgeting and required inputs from engineering, operations, costing, and marketing (Brigham, 2008). This study drew on estimated and observed cash inflows from realised and planned projects in the South African mining sector.

Project life

The economic life used for discounting should reflect the period over which material cash flows occur, including any ramp-up and decommissioning phases (Brigham & Ehrhardt, 2008). In line with this reasoning, this study considered the equipment useful life (EUL) as the economic or

project life in the quantitative analysis. To ensure realistic and conservative simulations, the economic project life for projects was based on the lower-end EUL of the required equipment, as presented in Table 6.

Table 6: EEP equipment EUL

Equipment	EUL of equipment [Years]
Heat pumps (water)	10–13 (California Public Utilities Commission (CPUC), 2024)
BESS	10 (NYC Accelerator: New York City Energy Efficiency Corporation, 2024)
Valve/actuator control system	5–15 (Emerson Automation Solutions, 2020)

(Source: Own compilation)

Terminal value

Terminal cash flow refers to the cash flow resulting from the termination and liquidation of a project at the end of its economic life. Terminal value (terminal cash flow) is the after-tax, non-operating cash flow in the project's final year, comprising the asset's disposal/salvage proceeds (net of tax) and the recovery (reversion) of net working capital (CFA Institute, 2019). In this study, the terminal value was considered negligible at the end of the EUL for the heat-pump and pressure-control systems due to the high disposal and land dismantling costs, low collateral value, and high asset specificity (Rezessy & Bertoldi, 2010). For the BESS system, terminal value was, despite its lower specificity, still set to 0% of initial capex at EUL. This follows the World Bank's (2020) guidance that salvage values can be safely ignored for typical lifetimes and discount rates, explicitly noting that ignoring salvage value yields a conservative result.

Taxes and tax shields

Tax shield refers to the reduction in corporate tax that arises because interest is tax-deductible. The present value of these savings, known as the value of tax shields, adds to the firm's overall value (Fernández, 2011). In this study, taxes were modelled explicitly by using the after-tax cost of debt in WACC and recognising the impact of depreciation on taxable income, so all appraisal metrics (NPV, MIRR, discounted payback period, PI) were based on after-tax cash flows.

Corporate taxes influence both profit-based and cash flow-based measures (e.g., tax shields from depreciation and the after-tax cost of debt within WACC). Treatment followed standard corporate-finance practice, distinguishing between accounting profit, net cash flow, and net operating profit after tax (Brigham & Ehrhardt, 2008).

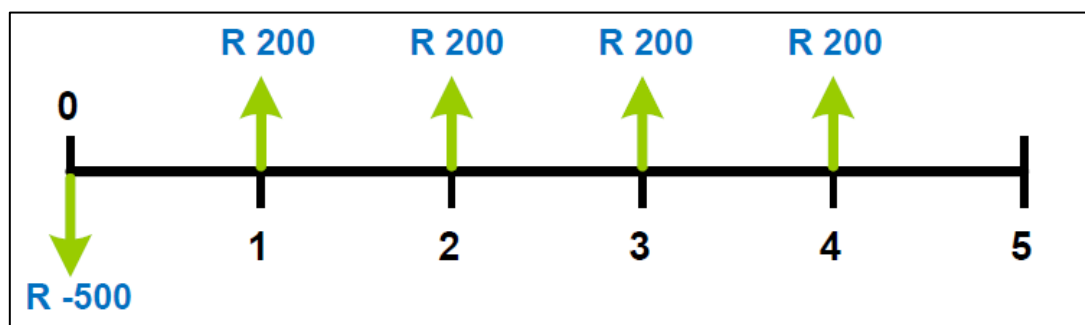
3.3.6.2 Financial performance analysis tools

This study used financial indicators and detailed cash flow diagrams to conduct a quantitative analysis of the financial performance of different financing models on EEPs in the South African mining sector. The following section explains and provides information on the financial indicators and tools used in this analysis.

Cash flow diagrams

Cash flow diagrams visually represent the timing and magnitude of financial inflows and outflows throughout a project's life cycle, clearly illustrating project liquidity, return timing, and investment phases (Doty & Turner, 2004). This study used cash flow diagrams to clearly compare and communicate the financial implications of each financing model, enhancing decision-making transparency and stakeholder understanding. Figure 9 shows an example of a cash flow diagram.

Figure 9: Example of a cash flow diagram



(United Nations Industrial Development Organization (UNIDO), 2019)

Net present value

NPV refers to the difference between the present value of all cash inflows and the present value of all cash outflows associated with a project (Birch, 2016; Doty & Turner, 2004; United Nations Industrial Development Organization (UNIDO), 2019). The present value is calculated using the firm's overall cost of capital as the discount rate. This study used the company's WACC as determined from the annual financial statements and other publicly available information. The formula for NPV is as follows (Bora, 2015):

$$NPV = \sum_{t=0}^n \frac{CF_t}{(1+r)^t} - C_0$$

Where:

- CF_t = Cash flow at time t
- r = Discount rate

- t = Time period
- C_0 = Initial investment

A positive NPV indicates that the project is financially viable and generates enough returns to repay investment costs, compensate for the capital invested, and provide surplus resources for other uses (Doty & Turner, 2004). NPV was used in this study to determine the added financial value provided by each financing structure.

Internal rate of return

IRR is defined as the discount rate at which the sum of discounted cash inflows equals the sum of discounted cash outflows, making the NPV equal to zero (Bora, 2015). The formula for IRR is given by Bora (2015):

$$0 = \sum_{t=0}^n \frac{CF_t}{(1 + IRR)^t} - C_0$$

Where:

- CF_t = Cash flow at time t
- IRR = Internal rate of return
- C_0 = Initial investment
- t = Time period

While both IRR and NPV consider the time value of money, IRR provides the expected percentage return, indicating project attractiveness based on relative profitability, whereas NPV measures the absolute financial value added by the project (Bora, 2015). IRR analysis was used in this study to clarify the comparative profitability of financing alternatives.

Modified internal rate of return

The MIRR is an improvement over the traditional IRR, addressing some of its key limitations, particularly multiple IRRs and unrealistic reinvestment assumptions (Brigham & Ehrhardt, 2008). Unlike IRR, which assumes reinvestment at the project's IRR, MIRR assumes reinvestment at the firm's cost of capital, making it a more reliable measure of profitability. MIRR is calculated using the following formulas (Brigham & Ehrhardt, 2008):

$$\sum_{t=0}^n \frac{COF_t}{(1 + r)^t} = \frac{\sum_{t=0}^n CIF_t (1 + r)^{n-1}}{(1 + MIRR)^n}$$

$$PV \text{ of costs} = \frac{\text{Terminal value}}{(1 + MIRR)^n} = PV \text{ of terminal value}$$

Where:

- COF_t = Cash outflows at time t
- CIF_t = Cash inflows at time t
- r = Cost of capital (used to discount outflows and reinvest inflows)
- $MIRR$ = Modified internal rate of return
- n = Total number of periods
- $PV \text{ of costs}$ = Present value of total project costs
- $Terminal \text{ value}$ = Future value of all cash inflows, assuming reinvestment at the cost of capital

MIRR provides a single, unambiguous rate of return, making it a superior alternative to IRR for project evaluation, particularly in cases where financing sources differ (Brigham & Ehrhardt, 2008). It was used in this study to compare financing models for EEPs by ensuring a realistic assessment of reinvestment potential.

Payback period and discounted payback period

The payback period is defined as the time required for cumulative cash inflows or savings from a project to recover the initial investment cost. It represents how quickly an investment can return its original cost through the savings or revenues generated by the investment, offering a simple measure of financial risk and liquidity (Doty & Turner, 2004). The formula for the simple payback period is:

$$\text{Payback period} = C_0 / (\text{Annual cash inflows})$$

Where:

- C_0 = initial investment
- $\text{Annual cash inflows}$ = Annual net cash flow from project savings

If cash flows are uneven, the payback period is determined by summing the cumulative cash flows until the initial investment is fully recovered (Brigham & Ehrhardt, 2008).

The discounted payback period improves upon the traditional payback period by incorporating the time value of money and discounting future cash inflows before determining the break-even time. It is defined as the time required for the cumulative discounted cash inflows to recover the initial investment (Brigham & Ehrhardt, 2008). The formula for the discounted payback period is (Brigham & Ehrhardt, 2008):

$$DPBP = \text{Year before full recovery} + \frac{\text{Unrecovered cost at start of year}}{\text{Discounted cash flow during the year}}$$

Where:

- *Year before full recovery* = The last year where the cumulative discounted cash flow is still negative.
- *Unrecovered cost at start of year* = The absolute value of the cumulative discounted cash flow at the end of the year before full recovery.
- *Discounted cash flow during the year* = The present value of cash inflow during the year when recovery occurs.

This method provides a more accurate reflection of an investment's profitability by accounting for the time value of money (Brigham & Ehrhardt, 2008). This study calculated the discounted payback period as it accounts for the time value of money, ensuring a more accurate assessment of financial feasibility.

Return on investment

ROI is a financial metric used to assess the profitability of an investment relative to its cost (Phillips, 2023). The formula for ROI is:

$$ROI = \left(\frac{N_p}{I_c} \right) \times 100$$

Where:

- *ROI* = Return on investment (%)
- *N_p* = Net profit
- *I_c* = Initial investment cost

In this study, this measure was used to provide insights into the financial return for each rand invested in the project, highlighting the potential for financial optimisation. A higher ROI means the project yields greater savings per rand invested. This study also calculated the discounted ROI, which follows the same formula but uses the NPV in place of net profit, ensuring that ongoing operating burdens are reflected in the profit metric rather than just in gross savings.

Accounting rate of return

The accounting rate of return (AAR), also referred to as the average accounting return, is a profitability measure that relates the average annual accounting profit of a project to its initial investment (Association of Chartered Certified Accountants (ACCA), 2025a). Unlike discounted cash flow measures, AAR is based on accounting information reported in financial statements, such as profit after depreciation and taxes. The formula for AAR is expressed as follows (Association of Chartered Certified Accountants (ACCA), 2025a).

$$AAR = \frac{\text{Average annual accounting profit}}{\text{Initial investment}}$$

Where:

- *Average annual accounting profit* = Mean annual profit after depreciation and taxes
- *Initial investment* = Total upfront cost of the project at the start of implementation

AAR is particularly useful as a complementary indicator, as it provides a profitability perspective that ties directly to financial reporting. Managers, lenders and investors often assess projects using accounting-based measures, as these can be readily compared with other business ratios, such as return on assets or equity. Because it uses accounting profit rather than gross cash inflows, AAR also implicitly considers the impact of operating costs such as maintenance, overheads and depreciation, making it a practical measure of sustained financial performance. While AAR does not incorporate the time value of money, including it alongside indicators such as NPV, IRR, and ROI ensures a broader perspective. This study, therefore, considered AAR as an additional measure to highlight how financing structures for EEPs can be evaluated from both a cash flow standpoint and an accounting-based profitability perspective.

Profitability index

The PI, also known as the benefit-cost ratio, is a financial metric used to evaluate investment opportunities by comparing the present value of future cash inflows to the initial investment. PI is particularly useful in capital rationing scenarios where multiple projects compete for limited funds (Brigham & Ehrhardt, 2008). The formula for PI is (Brigham & Ehrhardt, 2008):

$$PI = \frac{\text{PV of future cash flow}}{\text{Initial cost}} = \frac{\sum_{t=1}^N \frac{CF_t}{(1+r)^t}}{C_0}$$

Where:

- *PV* = Present value
- *CF_t* = Expected future cash flow
- *C₀* = Initial investment
- *t* = Investment period
- *r* = Discount rate

A PI value greater than 1.0 indicates that a project is financially viable, as it generates more value than its cost, while a PI value less than 1.0 suggests that the project may not be worthwhile (Brigham & Ehrhardt, 2008). PI is particularly useful when comparing projects of different sizes,

as it standardises investment efficiency by indicating how much value is created per unit of investment.

In this study, the PI was used to assess the financial attractiveness of various financing structures for EEPs in the South African mining sector. Given the capital-intensive nature of mining, PI would help determine the most cost-effective financing methods.

Taken together, the financial indicators applied in this study provide a comprehensive framework for assessing the viability of financing models for EEPs in the mining sector. By combining measures that capture value creation (NPV, PI), profitability (IRR, MIRR, ROI, AAR), liquidity and risk (payback period, discounted payback period), and long-term sustainability through detailed cash flow analysis, this approach ensures that both short-term financial feasibility and long-term strategic performance are considered. This integrated application of tools enables projects to be evaluated on equal footing, regardless of their financing structure, while maintaining alignment with accepted financial practices. The results of these analyses form the foundation for the informed recommendations presented later in the dissertation. The next section applies the theoretical insights from Chapter 3 and uses them to complete the quantitative analyses.

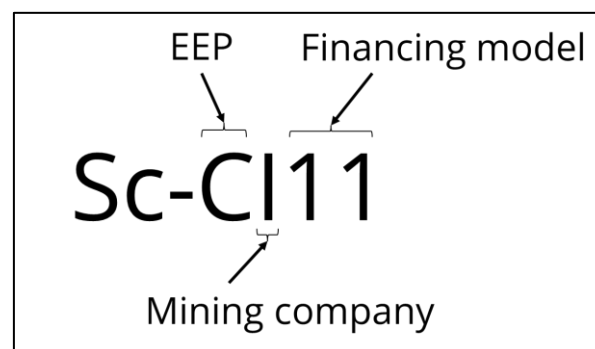
4 Chapter 4 – Quantitative analysis and results

This section presents the quantitative simulations used to compare alternative financing models and scenarios for the three representative EEPs. Building on the methodology outlined in Chapter 2 and the theoretical framework in Chapter 3, the analysis applies a consistent set of assumptions regarding tariffs, taxes, incentives, discount rates and EULs across all cases, to ensure comparability between companies and financing structures. The scenarios combine different mining companies, financing models (including internal funding, debt, leasing, and performance contracting), and project variants to generate a structured set of cash flow profiles and financial indicators.

4.1 Financing model simulations and scenarios

This section of the study provides an overview and explanation of the 180 scenarios simulated during the quantitative analyses. Figure 4 in Section 2.3 provides a visual representation of how the different scenarios were formed by varying the individual aspects relevant to them. Due to the high number of simulations, a naming and classification structure was developed to create a concise and appropriate ID for each simulation. Figure 10 illustrates the naming and classification structure developed in this study. The results of all the completed simulations are presented in Appendix C, which follows this ID structure for referring to the different scenarios.

Figure 10: Scenario naming and classification structure



(Source: Own compilation)

The following sections discuss the three main varying aspects of the different scenarios. Firstly, as previously mentioned, three different EEPs were selected to be simulated for different mining companies and various financing models. The EEP classification and naming convention are presented in Table 7. The theoretical and practical context relating to each of these types of projects was discussed in Section 3.3.2, and detailed information on the specific EEP case study is presented in Section 4.2. Each of these projects was selected because adequate case study information was available to successfully complete the quantitative financial analysis simulations. Projects A and B are proven EEPs with a track record of success in the mining and industrial

sectors (Goosen, 2013; International Energy Agency *et al.*, 2024), while Project C represents a new and upcoming technology. BESS has seen significant cost reductions in recent years, and this, coupled with electricity tariff hikes, provides a growing opportunity for energy arbitrage projects (Xolo *et al.*, 2025).

Table 7: EEP classification

EEP classification	
Heat pump	A
Compressed-air pressure control	B
BESS energy arbitrage	C

(Source: Own compilation)

An important aspect of this study is the WACCs calculated and used to discount future cash flows for five major mining companies operating in South Africa, as discussed in Section 3.3.6.1. By varying the WACC used to discount cash flows across different scenarios, this study was able to simulate the financial performance of the different projects and financing models for the various companies. This helped ensure that the study included different mining companies operating in South Africa and that the simulations were grounded in the reality of the South African mining context. Table 8 provides the naming and classification conventions used to indicate the relevant mine for the specified scenario.

Table 8: Mining company classification

Mining classification	
Harmony Gold	H
Sibanye-Stillwater	S
Anglo American	A
Impala Platinum	I
Exxaro Resources	E

(Source: Own compilation)

Twelve different financing models were selected for this study based on their relevance and applicability to EEPs in the South African mining sector. A detailed discussion of the financing models and structures available to EEPs in the South African mining sector, on which these twelve financing models are based, is provided in Section 3.3.4. Table 9 presents the naming and classification convention followed to indicate the relevant financing model for the specified scenario.

Table 9: Financing model classification

Financing model classification	
100% internally financed at WACC	1
80% debt at prime, 20% internally financed at WACC	2
73.4% debt at prime, 26.6% internally financed at WACC	3
60% debt at prime, 40% internally financed at WACC	4
40% debt at prime, 60% internally financed at WACC	5
80% debt at prime minus 3%, 20% internally financed at WACC	6
73.4% debt at prime minus 3%, 26.6% internally financed at WACC	7
60% debt at prime minus 3%, 40% internally financed at WACC	8
40% debt at prime minus 3%, 60% internally financed at WACC	9
Leasing at 1.5% of the initial cost	10
Performance contracting 80/20 split, 100% internally financed by WACC	11
Shared savings 50/50 split, ESCO 100% finance	12

(Source: Own compilation)

Financing Model 1 represents the scenario in which the mining company uses only internal funds to finance the relevant EEP. Despite businesses often preferring recourse finance for core activities, internal financing generally remains the most important source of financing for EEPs in the mining sector (González-Ruiz *et al.*, 2021; International Energy Agency *et al.*, 2024; Rezessy & Bertoldi, 2010). This makes Scenario 1 an example of the current typical financing model used for EEPs in the South African mining sector.

Financing Models 2–9 represent debt financing options at varying rates and ratios. The equity contribution varied between 20%, 26.6%, 40% and 60%. These ratios were selected because they encompassed the general range used and also tested the regulatory baseline of 20% and the optimal level of 26.6% (Machlin & Rummel, 2020; Rezessy & Bertoldi, 2010; Yun *et al.*, 2009).

Commercial loans are often tied to the prime rate, which was 10.50% as of October 2025. However, according to Xolo (2025), the interest rate is risk dependent and usually below prime (South African Reserve Bank, 2025). The IDC offers loans through its Partnership Scheme at prime minus 3% (Guardian, 2012). Hence, this study varied the interest rate between prime and prime minus 3%. This study considered debt financing to offer an interest tax shield, with interest payments being tax-deductible (Barburski, 2023; Brigham, 2008).

Financing Model 10 represents a leasing model in which the EEP equipment is leased instead of purchased. This scenario considers the whole lease payment to be a tax-deductible expense in accordance with South African tax laws (Brigham & Ehrhardt, 2008; Service, 2023). Recent

research shows that typical leasing costs are between 1% and 1.5% of the equipment's value (Yu, 2022). This study used 1.5% for Scenario 11 to account for its size and the volatile instability of the mining sector.

Financing Models 11 and 12 represent ESCO financing models. Model 11 represents a performance contract agreement with an 80/20 savings split between the mine and the ESCO, as is common in similar arrangements in South Africa. With this model, the mine finances 100% of the initial project cost, but a significant portion of the risk is transferred to the ESCO, as they guarantee a minimum level of energy savings (Arndt, 2005). Model 12 is based on a 50/50 savings split that was used in past South African shared-savings contracts. The larger 50% savings split for the ESCO requires that they also carry the capital risk and fund all initial capital for the project (Arndt, 2005).

4.2 Case studies and results

This section provides context from the three case study projects, including their estimated cost savings, and discusses the results of the quantitative analyses conducted on the financing models applied to them through the simulations.

Projects A and B are actual projects that were implemented in deep-level mines in the Bushveld Complex. Project C is based on a feasibility study completed for a proposal regarding a future capital BESS project at one of these mines. The information relating to these projects, which was used as input for calculations, is based on the data from this case study. Due to confidentiality agreements, the names of these mines will not be disclosed, and certain information will be omitted.

4.2.1 Water-heating system upgrade with heat pumps (EEP A)

This section provides the context and information related to EEP A. It also discusses the results from the quantitative analyses and their cash flow patterns under various financing models.

4.2.1.1 Background and context

This project is based on a heat-pump hot-water generation system that was installed to supply two new change houses built for a large mine. The change houses would have been supplied through a conventional electrical resistive hot-water generation system. The mine, however, decided to implement a more efficient heat-pump system after consulting an ESCO.

The system had an initial once-off cost of R3 830 000. Heat-pump systems typically cost between two and four times more than standard electric resistance units (Booth, 2024). This study

assumed that the heat-pump system cost was four times that of an electric heating system, which was estimated to be R957 700. Since the change house would have needed to have at least one electric resistance unit, the difference in cost was used as the initial once-off cost for the project. This included all equipment, delivery, installation, and services.

The electric resistive hot-water unit for this change of house would have had an estimated average heat load of 142.6 kW per hour. This would have resulted in an annual consumption of 1 249 502 kWh. The total yearly consumption for the heat-pump system is approximately 462 779 kWh. This results in an average hourly reduction of 89.8 kW and an annual energy saving of 462 779 kWh. This performance improvement is consistent with the roughly 50–60% reduction in energy consumption compared to boiler-based systems for comparable temperature lifts, as specified in the literature (International Energy Agency & Tsinghua University Building Energy Research Center, 2024; Renewable Thermal Collaborative & Boston Consulting Group, 2018).

It is assumed that the system consistently reduces energy throughout the day, 365 days a year. This provides a conservative estimate for savings calculations, as in reality, the system results in a larger portion of the savings on weekdays and during higher tariff periods. This allows for an average electricity tariff of 156 c/kWh, calculated using the appropriate Eskom Megaflex tariff structure and presented in Appendix B (Eskom Holdings SOC Ltd, 2025a). Using this tariff, an estimated annual saving of R1 228 861 is achieved.

The project resulted in a reduction of 458 922 kWh during the specified 14-hour daily period and hence also benefited from a R188 291 DSM tax incentive at the end of years 1 and 2 of the project, as per the Eskom Energy Efficiency Programme described in Table 3. The project's annual energy savings of 462 779 kWh also qualify it for a R320 497 12L carbon tax benefit at the end of year 2 of the project. The project is considered to operate for a minimum EUL of 10 years, as specified in Table 6. Figure 11 shows the heat-pump installation of the project on which the simulations for EEP A are based.

Figure 11: Change house heat-pump installation for case study EEP A

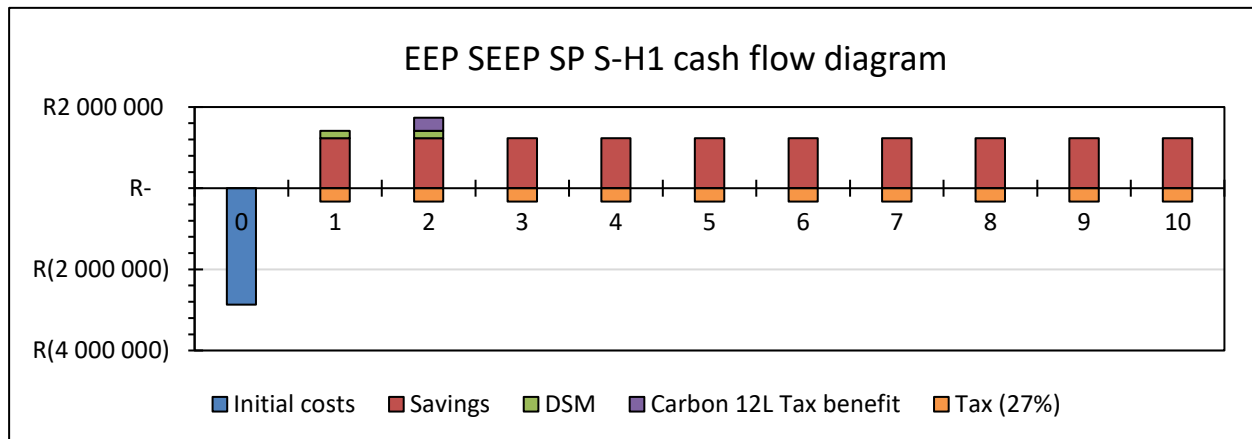


(Source: Own photograph)

4.2.1.2 Scenario and financing model cash flow analysis

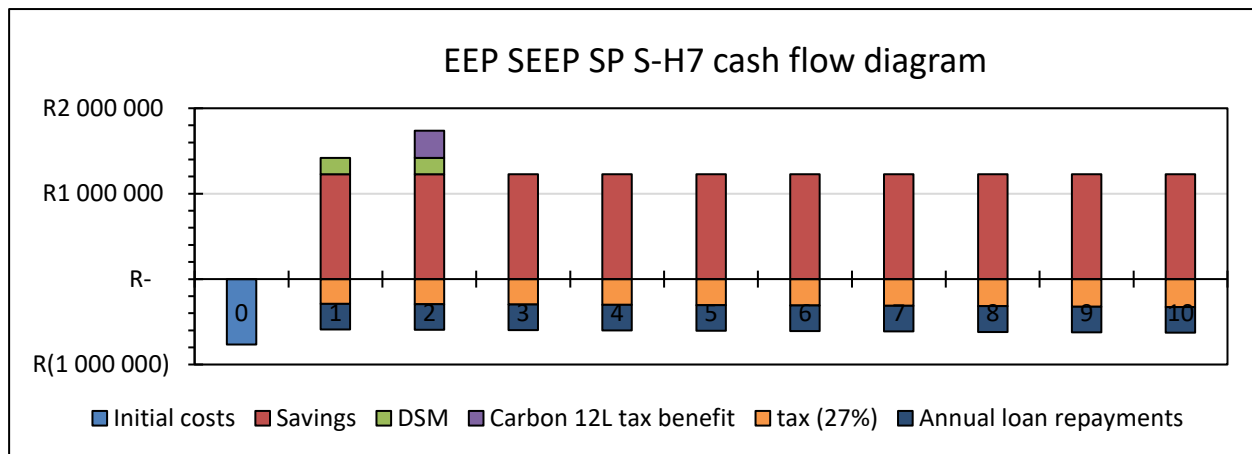
Figure 12 to Figure 16 that follow present EEP A for Harmony under representative financing models: Sc-AH1 (Model 1, 100% internal financing), Sc-AH7 (Model 7, 73.4% debt at prime minus 3% and 26.6% internal funding at WACC), Sc-AH10 (Model 10, leasing), Sc-AH11 (Model 11, performance contract) and Sc-AH12 (Model 12, ESCO shared savings). Sc-AH7 was selected to represent all debt financing options for Financing Models 2–9. All these scenarios' cash flow diagrams have a similar pattern with varying initial costs and loan repayment outflows. Harmony was selected at random, since the qualitative cash flow patterns are similar for the other mining companies. Each figure separates the main components of annual cash flow, including the initial investment, lease or loan payments, electricity savings, DSM incentives, Section 12L tax benefits and the 27% corporate tax. These diagrams show how different financing models affect the timing and size of net cash flows over the project life, which in turn explains the differences in the payback period, NPV, IRR, PI, and related indicators reported for EEP A in Table 12.

Figure 12: EEP Sc-AH1 cash flow diagram



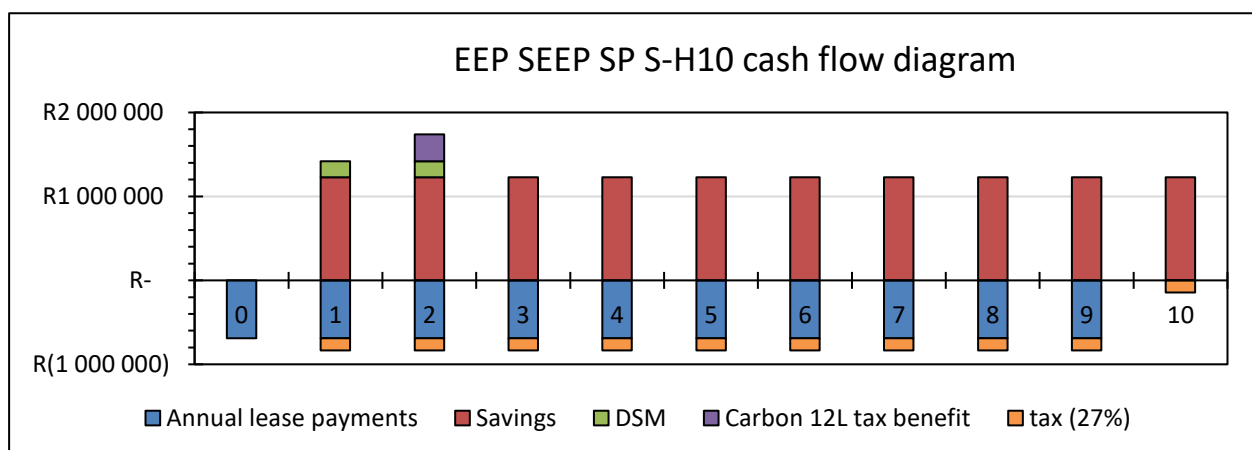
(Source: Own compilation)

Figure 13: EEP Sc-AH7 cash flow diagram



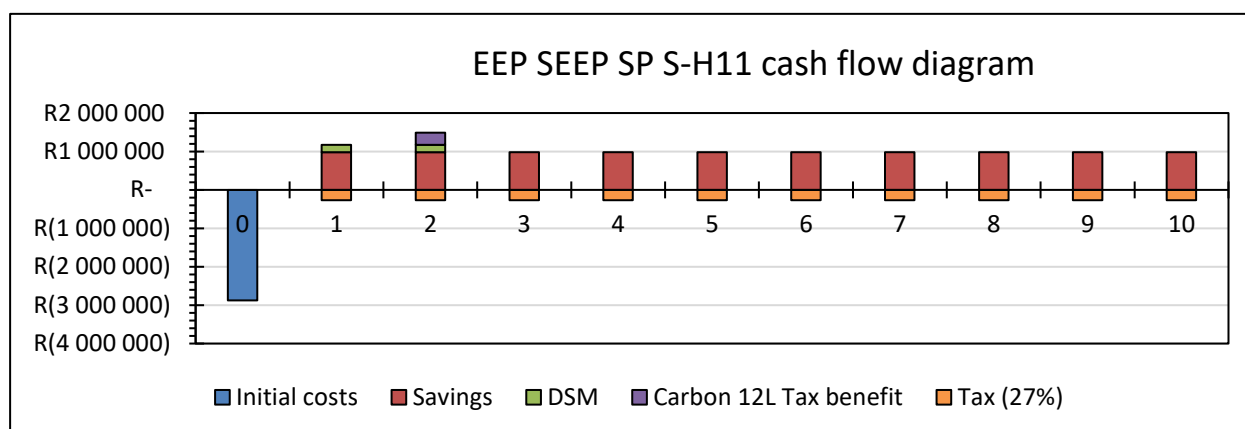
(Source: Own compilation)

Figure 14: EEP Sc-AH10 cash flow diagram



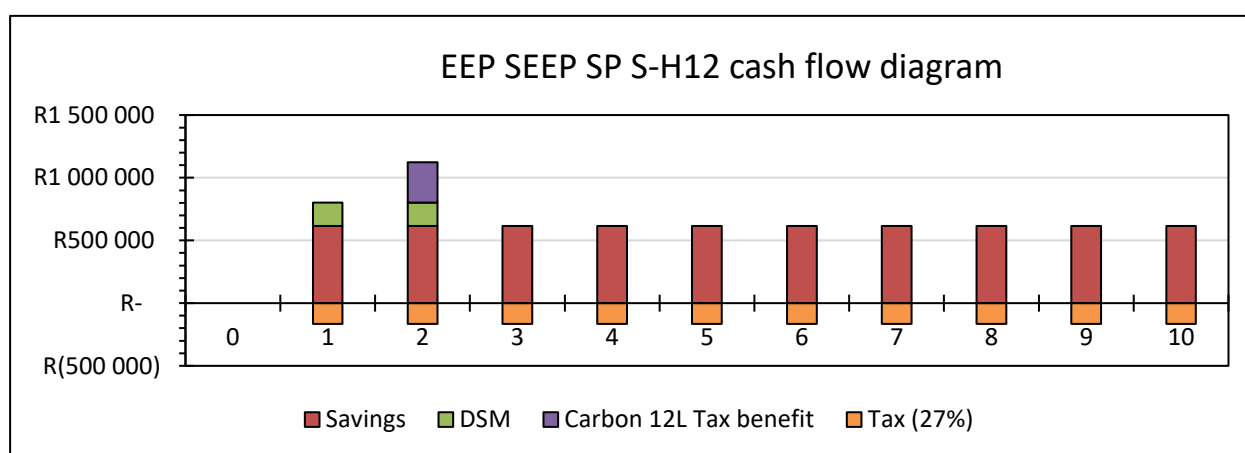
(Source: Own compilation)

Figure 15: EEP Sc-AH11 cash flow diagram



(Source: Own compilation)

Figure 16: EEP Sc-AH12 cash flow diagram



(Source: Own compilation)

Under 100% internal financing (Sc-AH1), the mine incurs the full capital outlay as a significant cash outflow in year 0, after which annual net cash flows remain consistently positive. Savings are temporarily boosted in the first two years by DSM and 12L benefits, and then stabilise. This structure maximises value creation but requires significant upfront capital. In the concessional debt example (Sc-AH7), the effective initial burden on internal funds is smaller, as 73.4% of the project is financed at prime minus 3%. The diagrams show a stream of annual loan repayments that reduce free cash flow in the early years but are comfortably covered by savings, while interest tax shields and the lower debt rate improve value relative to pure WACC funding. Under leasing (Sc-AH10), the initial capex disappears from the mine's cash flows and is replaced by level lease payments. Net inflows remain positive and relatively smooth; however, part of the project value is ceded to the lessor through the lease margin.

The performance-contracting case (Sc-AH11) demonstrates a large initial investment but lower annual savings for the mine, reflecting the ESCO's share of performance. This pattern lengthens

the effective payback period and explains the weaker NPV and PI, despite identical technical savings. By contrast, the shared-savings structure (Sc-AH12) shows no outflow at all in year 0. From the mine's perspective, only savings, incentives and tax effects appear, yielding immediate positive cash flow, but at a much-reduced level because a substantial portion of the benefit accrues to the ESCO. Taken together, the figures highlight a central trade-off that recurs throughout Chapter 4: internal and concessional debt financing captures the largest long-term net cash flows but requires balance sheet capacity, whereas leasing, performance contracts and shared-savings models ease capital and implementation constraints at the cost of giving up part of the economic upside.

4.2.1.3 Simulation results

The simulation results for Project A, summarised in Appendix C: Simulation Results, Table 12, indicate that the heat-pump water-heating upgrade is financially attractive across all five mining companies and all twelve financing models. In every scenario, the project yields a positive net profit and NPV, with simple payback periods ranging from 0.72 to 3.03 years and discounted payback periods varying from 0.79 to 5.61 years. Discounted IRRs range from 7% to 124%, with all cases comfortably above the respective company WACCs. Additionally, profitability indices remain above 1.0 in every scenario, confirming that the project adds value under all tested financing structures.

Across the full set of 60 simulations, the strongest overall performance is achieved by Sibanye-Stillwater in Scenario Sc-AS6, which combines 80% debt at prime minus 3 percentage points with 20% internal funding (Financing Model 6). This scenario delivers the highest NPV (R3 618 348.35), the highest discounted IRR (124%), the strongest discounted ROI and PI (both 6.30), and the shortest discounted payback period (0.79 years). At the other end of the spectrum, the weakest performance is consistently associated with the performance-contracting structure represented by Financing Model 11. For example, Sc-AI11 (Impala with an 80/20 performance contract funded 100% at WACC) produces the lowest NPV (R769 297.11), the lowest discounted IRR (7%), the longest discounted payback period (5.61 years) and the lowest PI (0.27), although even this case remains value-positive. Leasing (Model 10) also underperforms relative to conventional debt, demonstrating markedly lower NPVs and PIs, with only modest improvements in payback compared to the performance-contracting scenarios.

The pattern across financing models is very stable for all five companies. For each company code (H, S, A, I and E), the NPV and PI increase as the capital structure shifts from fully internally financed (Model 1) to a higher share of subsidised or concessional debt, peaking consistently at Model 6 (80% debt at prime minus 3% and 20% equity). For example, Harmony's NPV improves

from R2 599 111.30 in Sc-AH1 (fully internally financed) to R3 275 395.89 in Sc-AH6, while Impala's NPV increases from R1 550 201.40 in Sc-AI1 to R2 564 786.06 in Sc-AI6. Similar gains are observed for Anglo American (Sc-AA6) and Exxaro (Sc-AE6). These results confirm the theoretical expectation from Section 3.3.4 that introducing reasonably priced debt, particularly at concessional rates, lowers the effective cost of capital and enhances value creation for EEPs.

In the conventional debt structures (Models 2 to 9), the scenarios using prime rate debt already outperform pure internal financing in terms of both value and liquidity metrics; moreover, the introduction of concessional interest rates (prime minus 3%) further enhances performance. For all companies, Models 6 to 9 dominate Models 2 to 5 in terms of NPV, discounted IRR and discounted ROI, with only moderate differences in the payback period. This suggests that for projects with a short technical payback period, such as Project A, lenders providing below-prime energy efficiency loans (for example, through IDC-type schemes) can materially improve the economic case, even when equity contributions remain in the 20–40% range. In contrast, performance contracting (Model 11) consistently yields the lowest NPVs and the longest payback periods, reflecting a combination of higher effective capital costs and the sharing of savings with an ESCO, while still requiring the mine to carry the financing on its own balance sheet. Leasing (Model 10) performs slightly better than performance contracting in terms of payback period, but its NPVs and PIs are significantly lower than the optimised debt-equity mixes. This indicates that shifting costs into a level annual lease charge is not financially superior when competitively priced debt is available.

The ESCO shared-savings model (Financing Model 12) presents an interesting intermediate case. For all companies, Sc-AH12, Sc-AS12, Sc-AA12, Sc-AI12 and Sc-AE12 deliver NPVs ranging from approximately R3.0 million to R3.28 million, placing them close to the best debt-financed options, despite the mining company retaining only 50% of the savings. However, because the project is fully financed by the ESCO, the payback period, IRR and ratio-based indicators are not directly comparable from the mine's perspective and are therefore reported as not applicable in Table 10. From a mining company's viewpoint, these scenarios indicate that shared-savings energy performance contracts can still provide substantial economic benefits with no upfront capital outlay and limited risk, although the total value captured remains lower than that in the best self-financed debt structures.

Differences between companies are mainly driven by their WACCs. For any given financing model, the ranking of NPVs follows the WACC hierarchy used in the simulations, with Sibanye-Stillwater showing the highest NPVs, followed by Exxaro, Anglo American, and Harmony, while Impala consistently records the lowest NPVs and the longest discounted payback periods. For example, under Model 1 (100% internal funding), NPVs range from R3 107 873.28 for Sc-AS1

(Sibanye) to R1 550 201.40 for Sc-AI1 (Impala). Under Model 6, the NPV spread remains substantial, ranging from R3 618 348.35 (Sc-AS6) to R2 564 786.06 (Sc-AI6). This confirms that, while the heat-pump project is robustly viable in all cases, mines with higher WACCs sacrifice a significant portion of potential value unless concessional capital can be accessed or risk perceptions are improved.

Overall, the Project A simulations demonstrate that the underlying EEP is financially compelling across all companies and financing models; however, the choice of financing structure has a material impact on the magnitude of value created. Optimised debt-equity mixes using concessional energy efficiency loans (Model 6) provide the strongest performance across all indicators, while performance contracting and leasing structures are overshadowed on purely financial grounds. ESCO shared-savings models remain attractive where internal or low-cost debt is constrained, offering a capital-free route to implementation at the cost of some upside. These findings align with the literature that emphasises both the importance of lowering the effective cost of capital for EEPs and the potential trade-off between off-balance-sheet financing and value capture. Additionally, they provide a benchmark for comparing the more complex projects simulated in the remainder of Chapter 4.

4.2.2 Compressed-air instrumentation and control for pressure regulation (EEP B)

This section provides the context and information related to EEP B. It also discusses the results from the quantitative analyses and their cash flow patterns under various financing models.

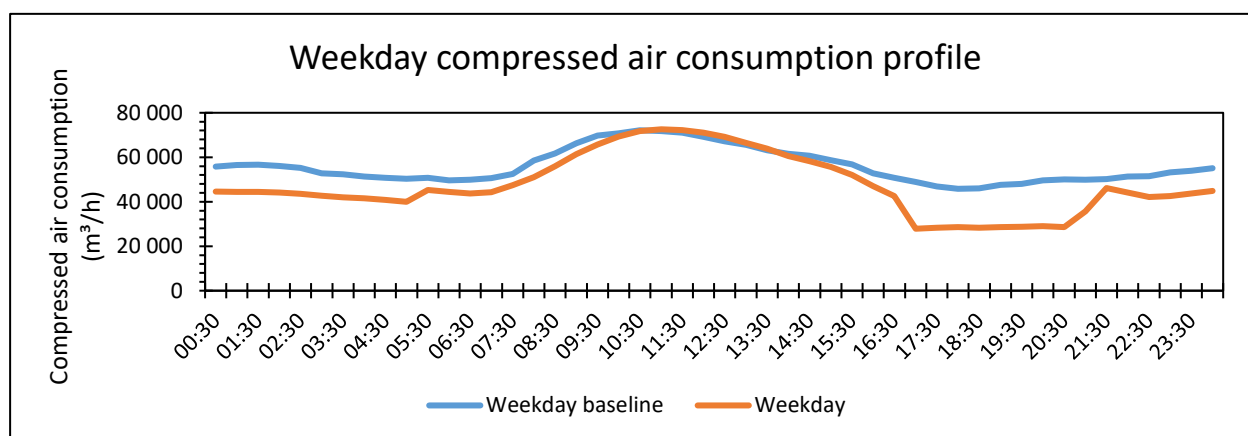
4.2.2.1 Background and context

This project is based on data from a compressed-air pressure-control system that was installed in a mine to regulate downstream pressure, reduce wastage and flow, and, in turn, decrease energy consumption. The system had a total one-off cost of R5 663 561, and according to Table 6, a minimum EUL of 5 years.

The system provided pressure and flow reduction during periods when it was not required. Figure 17, Figure 18 and Figure 19 show the reductions in flow achieved by the mine through this EEP. The mine in question had an average compressed-air intensity of 8.63 m³/h per kWh. The total annual energy savings achieved through this EEP is approximately 9 878 530 kWh. Using the Eskom Megaflex tariffs provided in Table 10 and Table 11: Eskom Megaflex mine winter electricity tariffs

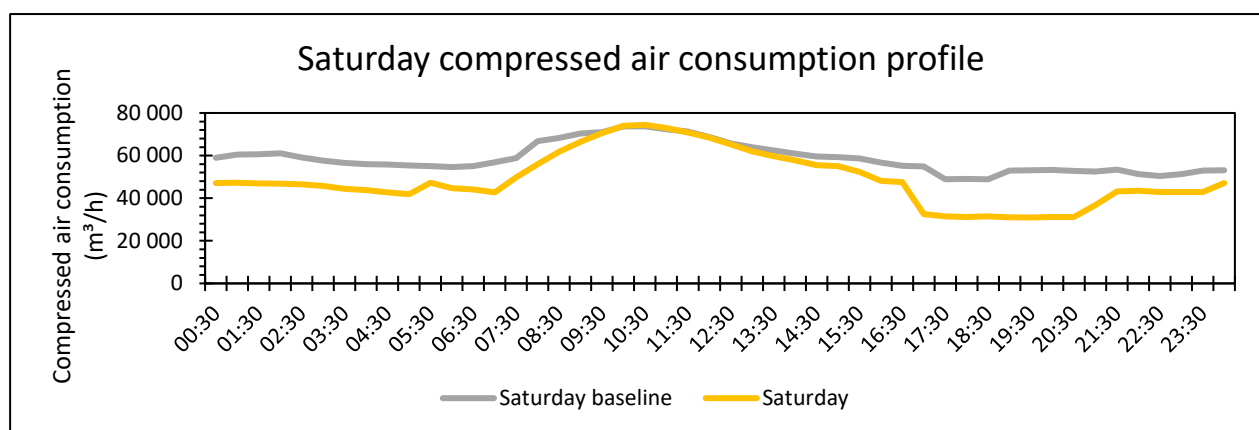
in Appendix B, this equates to a cost saving of R15 968 674 per annum (Eskom Holdings SOC Ltd, 2025a).

Figure 17: Weekday compressed-air consumption profile



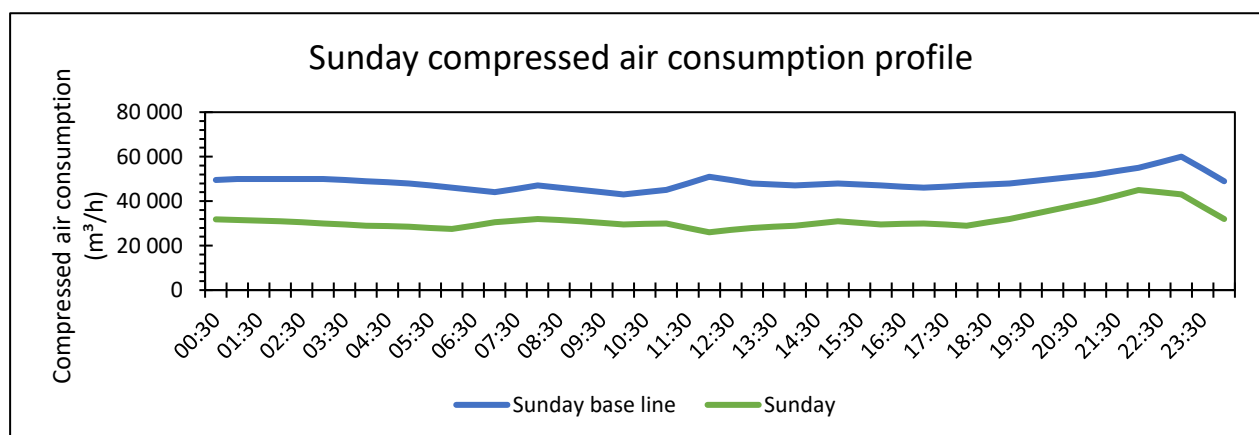
(Source: Own compilation)

Figure 18: Saturday compressed-air consumption profile



(Source: Own compilation)

Figure 19: Sunday compressed-air consumption profile



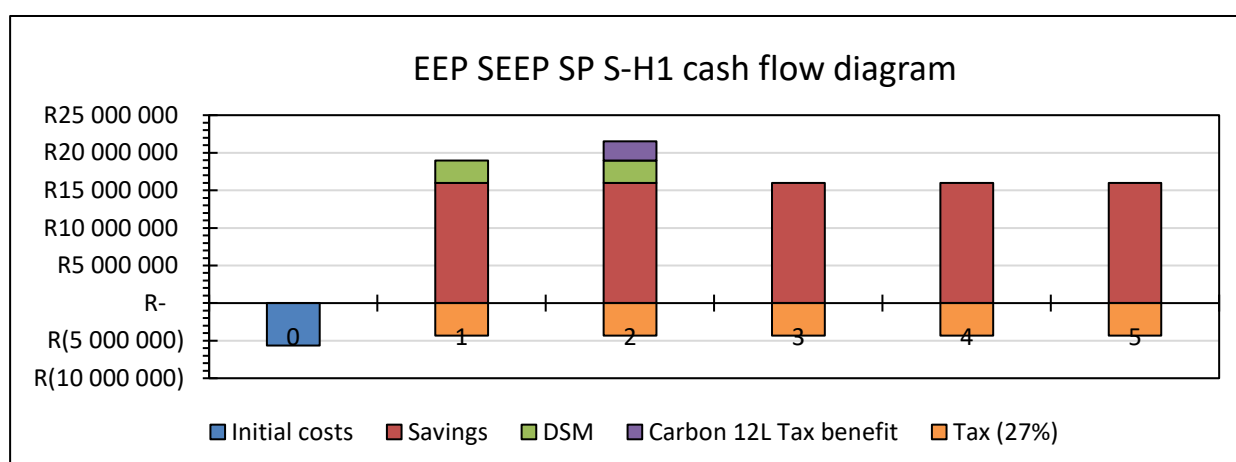
(Source: Own compilation)

This project produces peak Eskom ToU energy consumption of approximately 2 MW and hence qualifies for a R6 000 000 DSM incentive (R3 000 000 at the end of the first and second years of the project), in accordance with Table 4. Due to the project's energy saving of 9 878 530 kWh, it also qualifies for a R2 533 843 12L carbon tax benefit at the end of the second year of the project.

4.2.2.2 Scenario and financing model cash flow analysis

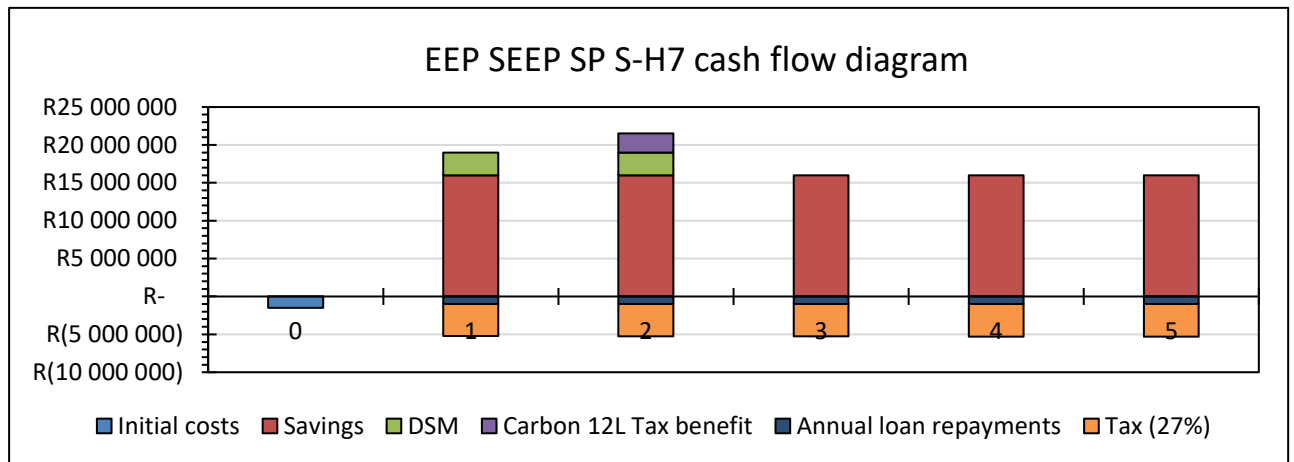
Figure 20 to Figure 24 present illustrative cash flow diagrams for EEP B, the compressed-air instrumentation and pressure-control project, for Harmony Gold under five representative financing models: Sc-BH1 (Model 1 100% internal financing), Sc-BH7 (Model 7, 73.4% debt at prime minus 3% and 26.6% internal funding at WACC), Sc-BH10 (Model 10, leasing), Sc-BH11 (Model 11, performance contract) and Sc-BH12 (Model 12, ESCO shared savings). Sc-AH7 was selected to represent all debt financing options for Financing Models 2–9. All these scenarios' cash flow diagrams have a similar pattern with varying initial costs and loan repayment outflows. Harmony was selected at random, as the qualitative patterns are similar for the other mining companies. Each figure separates the main cash flow components, namely initial investment, lease or loan payments, electricity savings, DSM incentives, Section 12L tax benefits and company tax at 27%. Because EEP B has a shorter project life (five years) than the other simulated EEPs, these diagrams are useful for showing how different financing structures shape the timing and distribution of its very large but relatively concentrated savings. They also help explain the short payback periods and high NPVs reported in Table 13.

Figure 20: EEP Sc-BH1 cash flow diagram



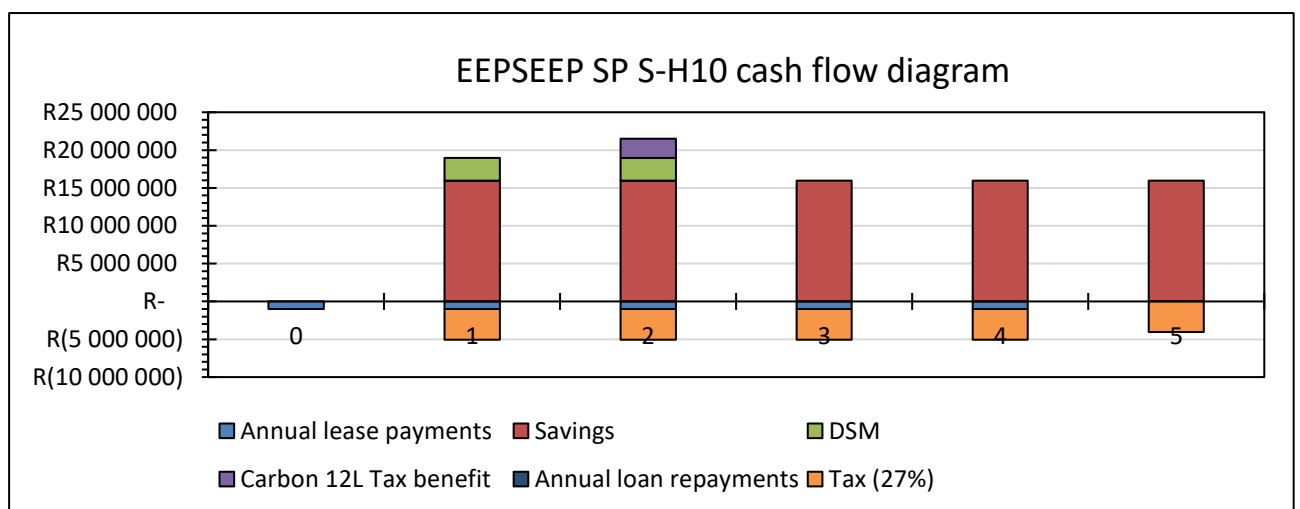
(Source: Own compilation)

Figure 21: EEP Sc-BH7 cash flow diagram



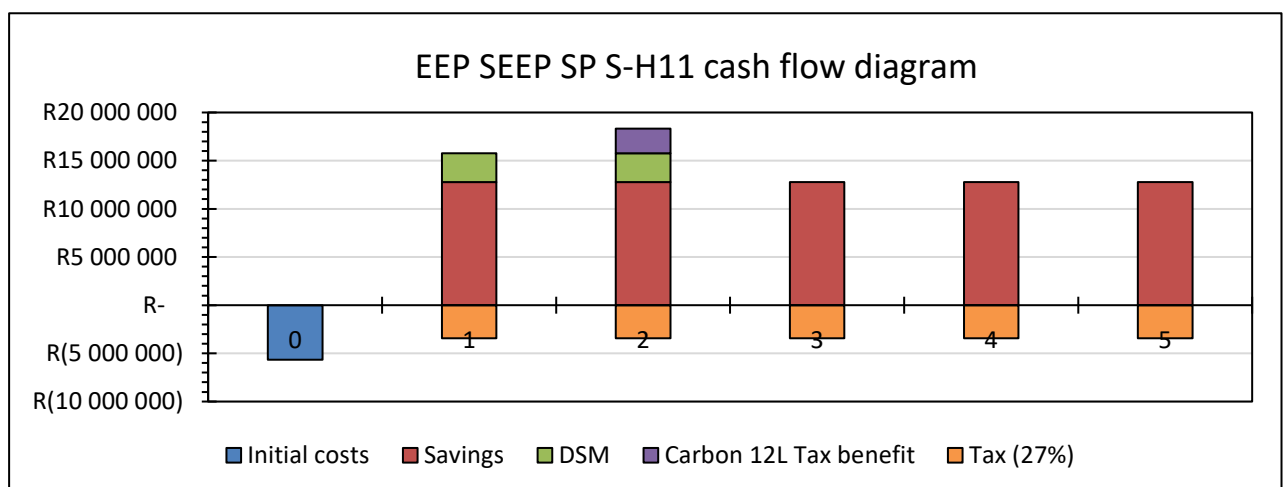
(Source: Own compilation)

Figure 22: EEP Sc-BH10 cash flow diagram



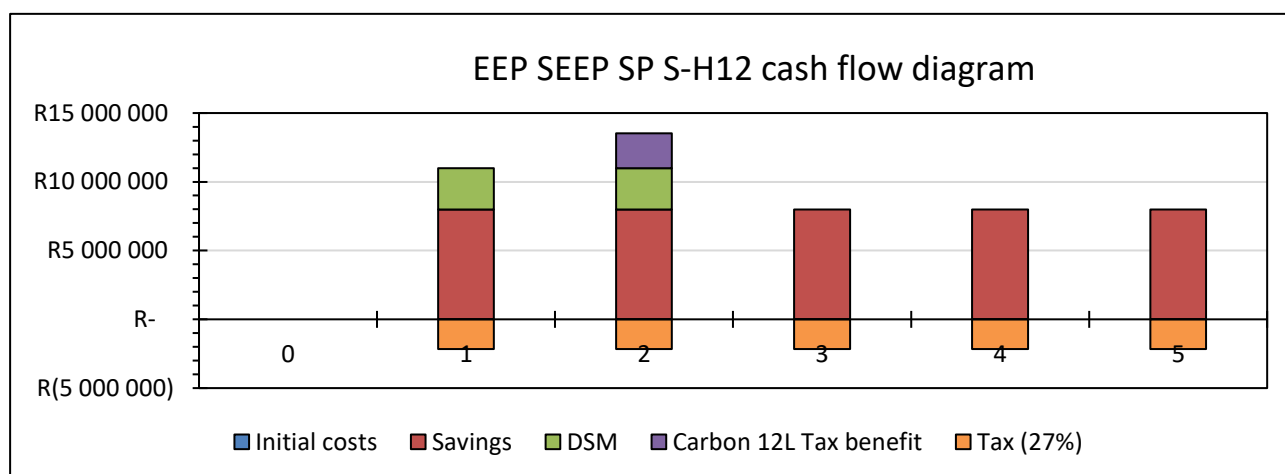
(Source: Own compilation)

Figure 23: EEP Sc-BH11 cash flow diagram



(Source: Own compilation)

Figure 24: EEP Sc-BH12 cash flow diagram



(Source: Own compilation)

In the 100% internal funding case (Sc-BH1), the mine incurs a once-off capital outflow in year 0, followed by significantly large positive cash flows predominantly driven by savings. The benefits of DSM and 12L in years 1 and 2 further enhance these inflows, which explains the very short payback period and high NPV.

Under the concessional debt structure (Sc-BH7), most of the investment is financed with debt, resulting in a smaller initial cash outlay and annual loan repayments reflected in the cash flow. These repayments reduce free cash flow during the loan term but are easily covered by savings, while the lower interest rate and tax shield preserve most of the created value.

Leasing (Sc-BH10) removes the initial capex and replaces it with level lease payments. Net operating inflows remain strong and positive, although they are slightly lower than under Sc-BH1 because part of the project value is transferred to the lessor. In the performance contract case (Sc-BH11), the mine still funds the capex, but annual savings are reduced by the ESCO fee, resulting in smaller net inflows and a weaker NPV and PI compared to the fully self-financed case.

Finally, the shared-savings structure (Sc-BH12) shows no year 0 outflow from the mine's perspective. All visible cash flows are from Savings, DSM, and 12L benefits. Cash flows are partially offset by higher taxes due to a lack of tax shields. While annual inflows begin immediately, they are lower due to a significant portion of the savings going to the ESCO.

Debt financing captures the largest long-term benefit, while leasing, performance contracts and shared-savings structures ease capital and implementation constraints at the cost of passing some of EEP B's exceptional savings to external partners.

4.2.2.3 Simulation results

Table 13 in Appendix C: Simulation Results summarises the financing model simulation results for EEP B, the compressed-air instrumentation and control project for pressure regulation, across the five mining companies and twelve financing models. In line with the technical context outlined for compressed-air DSM in Chapter 3, this project delivers substantial and immediate electricity savings relative to its capital cost, which drives strong financial performance under every self-financed structure. Simple payback periods are consistently below 0.5 years, and discounted payback periods are below approximately 0.65 years for all Models 1–11. This indicates that even when financing charges are included, the initial investment is recovered within the first year of operation. The NPVs range from approximately R29 million to nearly R48 million, and all discounted IRRs remain well above the respective company WACCs used to discount future cash flows, confirming that EEP B is financially robust for all the mining houses considered. In financial terms, these results are almost surreal. As Table 13 shows, a once-off investment of approximately R5.7 million delivers compressed-air savings of about R16 million per year over a minimum five-year lifespan, resulting in very short payback periods and exceptionally high NPVs for every plausible financing structure.

Despite this generally favourable picture, there is still a distinct differentiation between the financing structures. For each company, the leasing model (Financing Model 10) produces the highest NPV and the strongest ratio-based discounted indicators. Under Sibanye-Stillwater's parameters, Sc-BS10 yields the highest NPV in the table at R47 680 309.52, with a discounted payback period of just 0.08 years, a discounted IRR of 1 238% per annum, and a PI and discounted ROI of 935%. Harmony, Anglo American, Impala and Exxaro exhibit the same pattern: Sc-BH10, Sc-BA10, Sc-BI10 and Sc-BE10 are the top-performing scenarios in each group, combining the largest NPVs with very high discounted IRRs and PIs. The lease structure therefore allows the mines to convert the large, stable savings from compressed-air optimisation into sizeable net cash surpluses in the very first year, while spreading the capital cost into a fixed lease charge, consistent with the advantages of leasing highlighted in Section 3.3.4.

The concessional debt structures (Models 6–9, with debt priced at prime minus 3 percentage points) are the financing models that performed best following the leasing model. For example, Sc-BS6 delivers an NPV of R45 855 271.58, with a discounted IRR of 1 094% per annum and a discounted ROI and PI of 4 048%. Similar patterns appear for the other mining companies in Sc-BH6, Sc-BA6, Sc-BI6 and Sc-BE6. These structures outperform the prime-rated debt mixes (Models 2–5) on every value-creation indicator, illustrating how lower-cost debt increases the share of savings retained by the mine, in line with the capital structure discussion in Section 3.3.4. However, the step-up from prime debt to concessional debt is slightly smaller in EEP B than in

the heat-pump project because the compressed-air project's cash flows are so strong that even prime-based financing yields short payback periods and very high coverage of the cost of capital.

The internally financed case (Model 1) and the prime rate debt mixes (Models 2–5) all remain highly attractive, but they fall below leasing and concessional debt. Under 100% internal funding at WACC, Sc-BS1 produces an NPV of R45 202 367.57, with a discounted IRR of 229% per annum and a PI of 1.798. Meanwhile, Sc-BH1, Sc-BA1, Sc-BI1 and Sc-BE1 achieve similarly short payback periods (with a discounted payback period of around 0.63 years) and high discounted IRRs ranging from approximately 200% to 226%. Blending in prime rate debt (Models 2–5) has only a marginal effect on the NPV for this project, as the savings comfortably exceed both the debt service and the implicit cost of internal capital. These results align with the modelling principle that when a project's unlevered IRR is significantly above all relevant discount rates, the capital structure affects the distribution of value between lenders and shareholders, rather than the basic feasibility of the project.

Performance contracting (Model 11) again emerges as the weakest of the self-financed options from the mine's perspective, similar to the heat pump case. Scenarios Sc-BH11, Sc-BS11, Sc-BA11, Sc-BI11, and Sc-BE11 all record the lowest NPVs and the longest discounted payback periods among Models 1–11 for their respective companies. For instance, Sc-BI11 yields an NPV of R29 345 066 with a discounted payback period of about 0.55 years. This is still extremely favourable in absolute terms, but it is clearly lower than the lease and concessional debt alternatives. This reflects the sharing of savings with the ESCO, which is intrinsic to an 80/20 performance contract, as discussed in Section 3.3.4.1. The mine effectively trades away part of the economic upside in exchange for external performance guarantees and implementation capacity. For EEP B, where the savings are large and predictable and the project has already been proven technically, the opportunity cost of that trade-off is high.

The ESCO shared-savings model (Financing Model 12) occupies its own category. Sc-BH12, Sc-BS12, Sc-BA12, Sc-BI12 and Sc-BE12 produce NPVs between approximately R24 million and R29 million for the mining companies. The payback period, discounted payback period, IRR and PI are not reported from the mine's perspective, as the ESCO provides 100% of the capital and recovers its investment from a share of the realised savings. Under these structures, the mines achieve substantial net benefits without any upfront capex, removing both the financing and implementation barriers highlighted in Sections 3.3.3 and 3.3.5. However, the value retained by the mine is significantly below what could be captured under internal, debt or leasing options. Shared-savings energy performance contracts are therefore most appropriate where internal capital is scarce or risk appetite is low, rather than in situations where the objective is to maximise NPV from a project with such strong fundamentals.

Differences between the mining companies mirror the WACC-driven patterns described earlier in the chapter. For any given financing model, Sibanye-Stillwater (S) consistently records the highest NPVs, followed closely by Exxaro (E), with Anglo (A) and Harmony (H) in the middle, and Impala (I) generally recording the lowest. Under internal funding, for example, the NPV ranges from R45 202 367.57 in Sc-BS1 to R36 488 063.30 in Sc-BI1. The ordering remains broadly consistent across all financing models. This confirms that while EEP B is well above the investment hurdle for all participants, companies with higher WACCs and tighter capital constraints capture less of the available value unless they can access cheaper funding or lower their perceived project risk. The finding reinforces the importance of company-specific discount rates in the modelling framework set out in Section 3.3.6.

In summary, the compressed-air instrumentation and control project is an exceptionally strong EEP across all financing models, with feasibility never in question. The financing choice for EEP B, therefore, does not determine whether the project proceeds; rather, it determines how the significant stream of savings is allocated among the mine, financiers and ESCO partners. Leasing (Model 10) is the financially dominant structure for this project across all companies in terms of NPV, while concessional debt (Models 6–9) offers a close second-best option, with very high discounted IRRs and PIs. Prime rate debt and internal funding remain highly attractive, but they are outperformed by cheaper capital and lease structures. Performance contracting (Model 11) delivers the lowest NPVs among the self-financed options, while shared-savings energy performance contracts (Model 12) provide a capital-free, albeit lower-value, route to implementation. These results, viewed alongside the findings from the heat-pump project, suggest that for proven, high-savings compressed-air optimisation schemes, the priority should be to secure lease or concessional debt finance where possible, reserving performance contracts and shared-savings structures for situations where internal capital or technical capacity is the binding constraint rather than project economics.

4.2.3 BESS for energy arbitrage (EEP C)

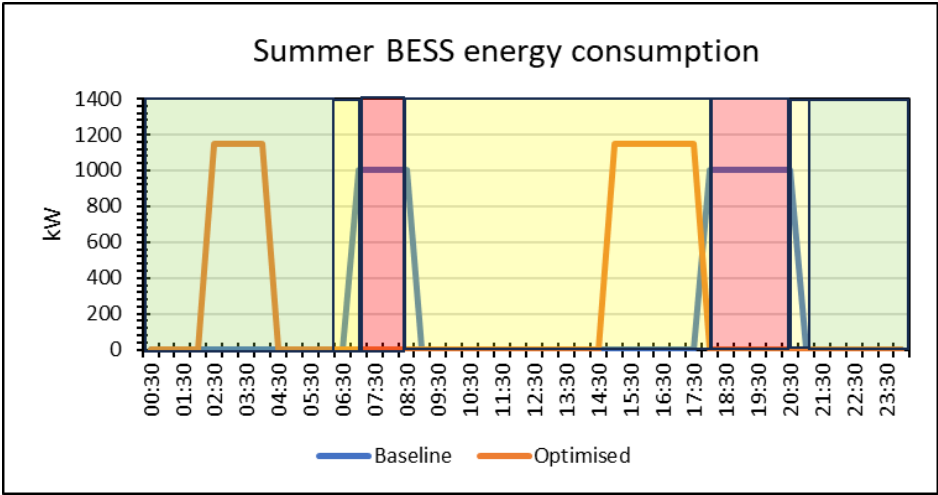
This section provides the context and information related to EEP C. It also discusses the results from the quantitative analyses and its cash flow patterns under various financing models.

4.2.3.1 Background and context

This project is based on data from a feasibility study for a proposed BESS energy arbitrage EEP, aimed at achieving cost savings by charging during off-peak periods and discharging during peak Eskom ToU periods. The system has a once-off initial cost of R11 700 000. The proposed system is a 1 250 kW/3 700 kWh system with a round-trip efficiency of 85% and features C2 charging, resulting in a charging time of approximately 2.5 hours. The system includes a full warranty for

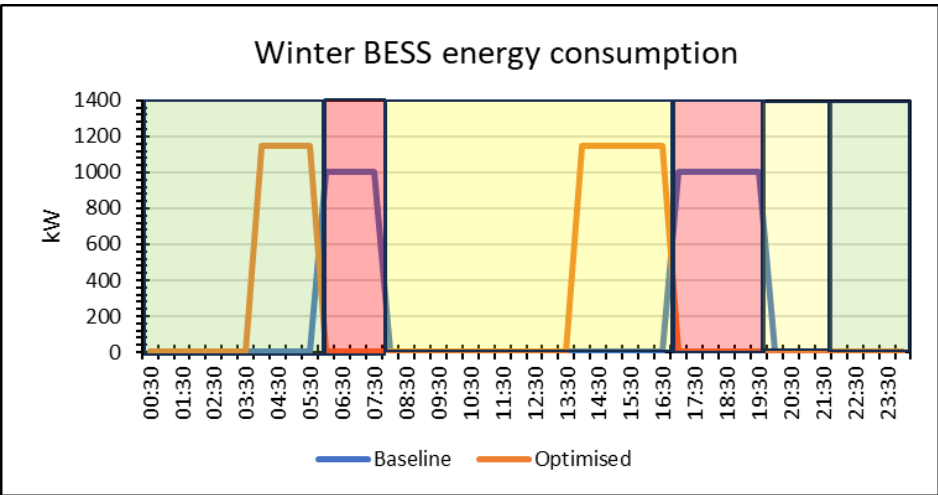
6 000 cycles, with each cycle being equivalent to an 80% discharge. This warranty allows for a three-hour 1 MW and a two-hour 1 MW discharge through Eskom’s respective peak ToU periods, while having to recharge for an equivalent period in one of the off-peak periods and one standard period every weekday for a period exceeding the EUL of ten years, according to Table 6. This system achieves an estimated annual cost saving through energy arbitrage equal to R1 528 687. Cost savings were calculated using the Eskom Megaflex electricity tariffs as illustrated in Appendix B (Eskom Holdings SOC Ltd, 2025a). Figure 25 and Figure 26 show the baseline compared to the optimised energy consumption profile for the energy arbitrage. In these figures, the red, yellow and green periods represent the high, standard and low demand periods, respectively, in accordance with Eskom’s Megaflex tariff structure. Note the shift in load to off-peak periods and the increased consumption resulting from inefficiencies (0.85 efficiency).

Figure 25: Summer BESS energy consumption profile



(Source: Own compilation)

Figure 26: Winter BESS energy consumption profile



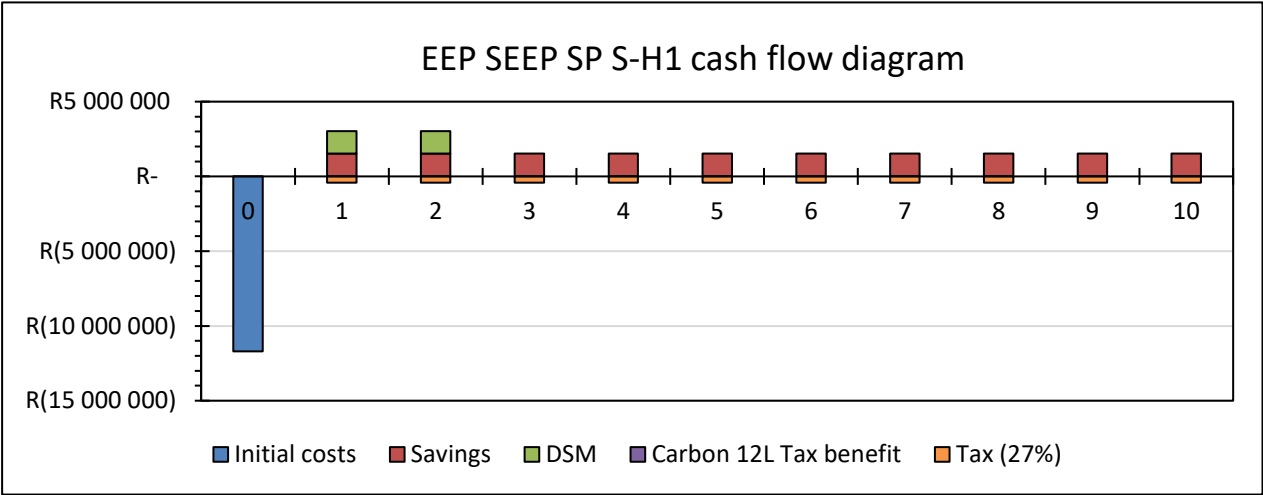
(Source: Own compilation)

As this project reduces peak demand by 1 MW, it also qualifies for a R3 000 000 DSM incentive, which will be paid over four quarters during the first two years of the project’s lifespan. For the purposes of this study, the project’s lifespan is considered to be 10 years. The project provides a cost saving but not an energy saving; hence, it does not qualify for a 12L carbon tax rebate. Additional information on BESS systems is provided in Section 3.3.2.3.

4.2.3.2 Scenario and financing model cash flow analysis

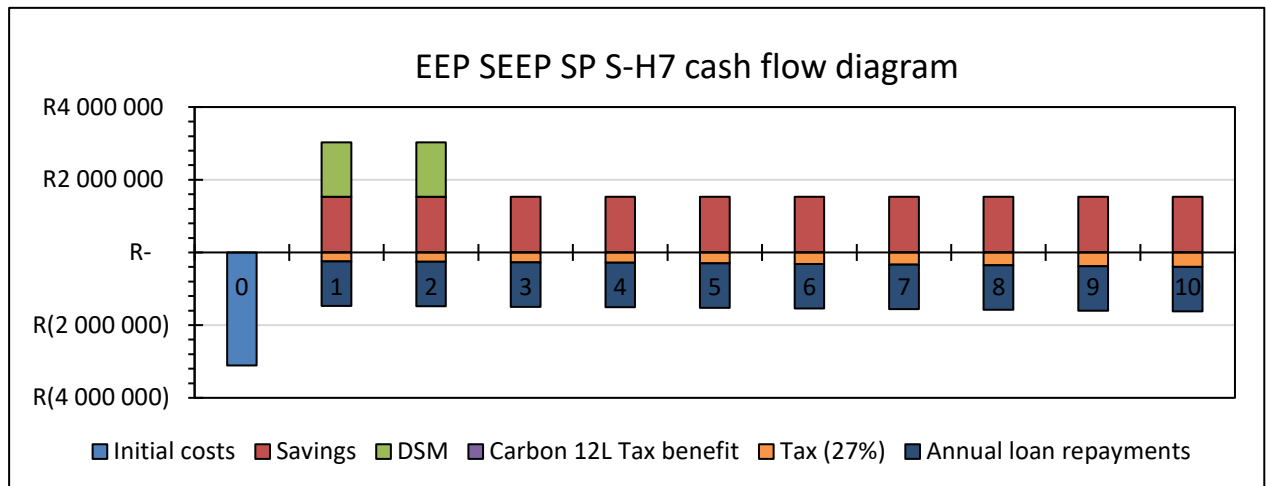
Figure 27 to Figure 31 represent cash flow diagrams for EEP C, the BESS energy arbitrage project for Harmony Gold, under five representative financing models: Sc-CH1 (Model 1, 100% internal financing), Sc-CH7 (Model 7, 73.4% debt at prime minus 3% and 26.6% internal funding at WACC), Sc-CH10 (Model 10, leasing), Sc-CH11 (Model 11, performance contract) and Sc-CH12 (Model 12, ESCO shared savings). Sc-AH7 was selected to represent all debt financing options for Financing Models 2–9. All these scenarios’ cash flow diagrams have a similar pattern with varying initial costs and loan repayment outflows. Harmony is used purely as an example again, since the qualitative cash flow patterns are similar for the other mining companies. Each figure separates initial investments or lease/loan payments, energy cost savings, DSM incentives, and company tax at 27%. Because the BESS is modelled over a ten-year economic life, in line with its lower-end EUL, these diagrams help illustrate how different financing structures shape a relatively long stream of arbitrage savings that, unlike EEP A and EEP B, is almost but not quite sufficient to recover the high upfront battery cost.

Figure 27: EEP Sc-CH1 cash flow diagram



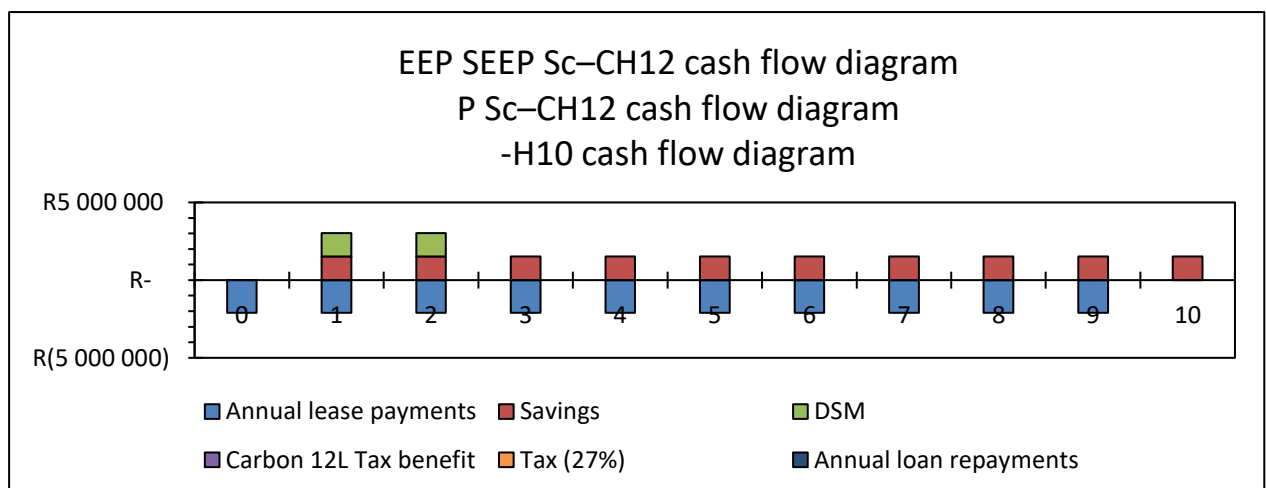
(Source: Own compilation)

Figure 28: EEP Sc-CH7 cash flow diagram



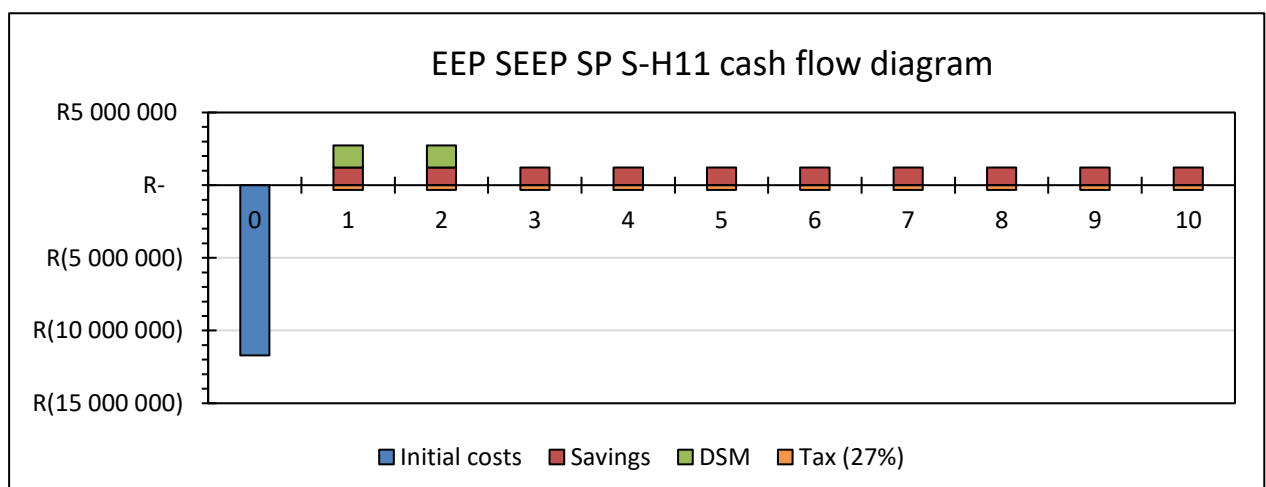
(Source: Own compilation)

Figure 29: EEP Sc-CH10 cash flow diagram



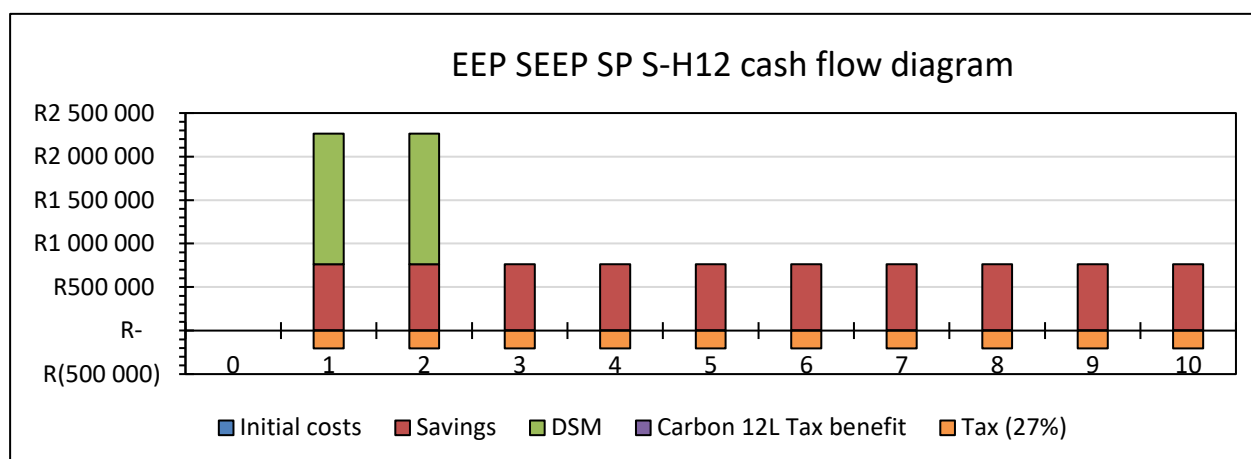
(Source: Own compilation)

Figure 30: EEP Sc-CH11 cash flow diagram



(Source: Own compilation)

Figure 31: EEP Sc-CH12 cash flow diagram



(Source: Own compilation)

Under 100% internal funding (Sc-CH1), the project starts with a large once-off capital outflow in year 0, followed by moderate and fairly stable positive operating inflows from tariff arbitrage cost savings and DSM allowances in years 1 and 2. However, the annual surpluses are too small relative to the initial investment for the discounted cash flows to turn positive within the ten-year lifespan, which is consistent with the negative NPVs and profitability indices reported for EEP C. In Sc-CH7, concessional debt at prime minus 3% reduces the immediate equity outlay but introduces a stream of loan repayments that absorbs a significant portion of the operating surplus. The tax shield on interest is beneficial; however, the combined effect still results in the discounted payback extending beyond the project's life. Leasing (Sc-CH10) removes the upfront capex from the mine's balance sheet and replaces it with level lease rentals. These rentals are fully tax-deductible, but the lease margin shifts value to the lessor, resulting in weak net inflows and weak NPVs that are more negative than those under the best concessional debt option.

In the performance contract case (Sc-CH11), the mine funds the full initial cost but retains only a fraction of the savings after the ESCO's performance fee. The diagrams show visibly smaller net inflows than in Sc-CH1, reflecting the fact that performance contracting is the least favourable of the self-financed structures for this marginal project. By contrast, the shared-savings model (Sc-CH12) shows no year 0 outflow from the mine's perspective; all visible cash flows are operating, with the ESCO covering the capital cost and recovering it from half of the realised savings. This produces lower annual inflows than internal or debt financing would deliver if the project were strongly profitable; however, it is the only structure that generates a positive NPV for the mine under the current cost and tariff assumptions. However, this model would likely not be a viable option for an ESCO due to the significant initial cost and relatively low annual savings in comparison.

Overall, the cash flow patterns for EEP C underline that, at present prices, arbitrage-only BESS is just below the feasibility threshold for mines. While financing innovations can redistribute risk and reduce capital burden, they cannot fully compensate for the underlying economics that remain slightly unfavourable.

4.2.3.3 Simulation results

The simulation results for Project C are presented in Table 14, Appendix C: Simulation Results. The BESS energy arbitrage project stands in stark contrast to the two preceding EEPs. Whereas the heat-pump upgrade and compressed-air control projects both generated strong positive NPVs under almost all self-financed structures, Project C is not financially feasible for the mining companies under any of the internal, debt, leasing or performance-contracting models tested. Across all five mining groups and Financing Models 1–11, the NPVs remain negative, discounted payback periods exceed the project life, and discounted IRRs are either negative or not computable. Only the ESCO shared-savings structures (Model 12) deliver a positive NPV for the mines, and this occurs only because the ESCO provides all upfront capital. These results confirm that, under current cost and tariff assumptions, an arbitrage-only BESS on Megaflex is close to, but not yet across, the feasibility threshold from the perspective of mining companies.

Despite this generally weak picture, there is still a clear ranking of scenarios. For all five companies, the least bad outcomes are consistently produced by Financing Model 6, which includes a concessional debt mix of 80% debt at prime minus three percentage points and 20% internal capital. Scenarios Sc-CH6, Sc-CS6, Sc-CA6, Sc-CI6, and Sc-CE6 all yield the smallest negative NPVs (around –R0.33 to –R0.39 million) and the highest discounted ROIs among the self-financed options, even though the discounted payback period still exceeds the project life and the PI remains below 1. In contrast, performance contracting (Model 11) is the worst performer across all mining groups: Sc-CH11, Sc-CS11, Sc-CA11, Sc-CI11, and Sc-CE11 exhibit the most negative NPVs (approximately –R4 to –R5.5 million), the largest absolute value of negative PI, and the longest (discounted) payback period. Leasing (Model 10) also performs poorly, with NPVs ranging between approximately –R1.9 million and –R2.2 million. In other words, within an already marginal project, concessional debt attenuates but does not eliminate value destruction, while performance contracting and leasing amplify it.

The indicators themselves help to explain this outcome. Simple payback periods, where calculable (Models 1, 5, 8, 9, and 11), cluster around 7.8 to 9.75 years, which is close to or beyond what many mines would accept for a cost-saving project even before discounting. Once the WACCs from Table 5 are applied, the discounted cash flows never recover the initial outlay, as the discounted payback periods exceed the project lifespans in all self-financed cases, and the

discounted IRRs are either negative or undefined. The apparently positive accounting metrics (for example, ROIs between 13% and 76%) indicate that undiscounted cumulative savings plus residual value still exceed the initial cost over the technical life; however, the time value of money and high mining hurdle rates erode this advantage when viewed through NPV, Discounted IRR and PI. This is consistent with the modelling principles in Section 3.3.6, which emphasise NPV and discounted indicators as the primary feasibility tests for high-risk, capital-intensive projects.

Differences across financing models largely follow the logic established earlier in this study; however, they are not sufficient to change the NPV from negative to positive. Moving from internal funding (Model 1) to prime-based debt mixes (Models 2–5) slightly improves discounted indicators in some cases but leaves NPVs firmly negative. Introducing concessional interest rates (Models 6–9) delivers the best relative performance, with Model 6 being closest to break-even for every company. However, the incremental benefit of leasing (Model 10), which dominated for EEP B, is reversed here: fixed lease charges and less favourable tax dynamics push NPVs further into negative territory. Performance contracting (Model 11) again shows the weakest results, as the mining company faces higher effective capital costs and shares a portion of the savings with an ESCO, which is particularly detrimental when the underlying project economics are marginal. In short, capital structure still matters, but it can no longer rescue a project that is fundamentally below the corporate hurdle rate.

The ESCO shared-savings model (Financing Model 12) presents an important contrast. Scenarios Sc-CH12, Sc-CS12, Sc-CA12, Sc-CI12 and Sc-CE12 all yield positive NPVs for the mines, ranging from approximately R4.75 million to R5.94 million. From the mining companies' perspective, these structures are attractive because they require no upfront capital and still deliver a meaningful stream of net benefits. However, the key point is that these results do not prove that the project is feasible on a stand-alone basis at current costs; rather, they indicate that there is enough system-wide value in the arbitrage opportunity to support a third-party ESCO, provided that the ESCO can finance the BESS at its own cost of capital and capture a sufficient share of the savings. The mine's positive NPV arises because its 'investment' is limited to contractual commitments, not capex, and the shared savings act as a quasi-free cash inflow.

As with the other projects, company-specific WACCs influence the range of results. For any given financing model, Sibanye-Stillwater and Exxaro tend to have the least negative NPVs and slightly better ratio indicators, whereas Impala generally shows the most negative NPVs and the largest gaps between simple and discounted payback periods, reflecting its higher effective discount rate. This ordering mirrors the patterns identified in the WACC analysis and confirms that higher required returns penalise emerging technologies with long, back-loaded savings streams, such as arbitrage-only storage, even when those technologies are experiencing rapid cost reductions.

Overall, the Project C simulations indicate that, under the current assumptions for BESS capital costs, Megaflex tariff spreads and battery operating life, arbitrage-only storage is not yet financeable as an on-balance-sheet investment for the participating mining companies. Concessional debt (Model 6) brings the project closest to break-even but still results in negative NPVs, while leasing and performance contracting increase the losses. ESCO shared-savings structures (Model 12) can make the project worthwhile for mines by shifting capital and performance risk to a third party, but only by allocating a large portion of the total value to the ESCO. Considering the current achievable savings-to-cost ratio, it would also be difficult for an ESCO to make Model 12 financially feasible from its perspective. Taken together with the literature on falling battery prices and value stacking, these findings suggest that although BESS arbitrage in South African mining is approaching, it has not yet crossed the viability threshold for corporate financing. Modest future reductions in capex, higher peak-off-peak spreads, or the addition of stacked services (such as peak-demand reduction or ancillary service revenues) will likely be required before internal, debt or leasing structures can deliver the kind of positive NPV observed for the more mature EEPs in this study.

5 Chapter 5 – Conclusion and informed recommendations

This chapter synthesises the insights from the systematic literature review and the quantitative simulations to provide informed recommendations on financing models for EEPs in the South African mining sector. It firstly distils key lessons from Chapters 3 and 4 into practical guidance, then reflects on how the research questions and objectives set out in Chapter 1 have been addressed. The chapter concludes with recommendations for future research and closing remarks on the contributions and implications of the study.

5.1 Informed recommendations based on findings

The systematic literature review in Chapter 3 revealed that a wide range of financing sources and capital structures is available for EEPs. These include internal funding, corporate and project debt (at varying interest rates), leasing, and ESCO-based performance-contracting and shared-savings models. It also highlighted the existence of databases that list various financing sources and incentives (AlliedCrowds, c2025; GreenCape, 2024). It also emphasised persistent barriers: competition for internal capital with core production projects, perceived technical and performance risks, a lack of collateral, limited project-preparation capacity, and underuse of available incentives such as Eskom DSM and Section 12L (Barburski & Holda, 2023; Painuly, 2009). Much of the existing work in this field remains conceptual or descriptive, with relatively few studies translating financing mechanisms into project-level cash flow models for mine-site EEPs in the South African context (González-Ruiz *et al.*, 2021).

The quantitative analysis in Chapter 4 extends this literature by applying those financing structures to three representative mine-site EEPs: a hot-water heat-pump retrofit (EEP A), a compressed-air optimisation system (EEP B) and a BESS for tariff arbitrage (EEP C). Across five mining companies with different WACCs, the simulations confirmed that:

- For projects with strong technical and economic fundamentals (EEP A and especially EEP B), all financing models considered are financially feasible; however, the choice of structure significantly impacts how much value is captured by the mine compared to financiers or ESCOs. The quantitative analyses demonstrated that a project under the same circumstances for the same mining company, but with different financing models, can lead to significant differences in NPV. Two different financing models for the compressed-air control system on Impala exhibited a difference in NPV exceeding R18 000 000, as shown in Table 13.

- For projects with marginal economics at current costs and tariffs (EEP C), none of the tested financing structures alone is sufficient to elevate the project to a high positive NPV under the assumed conditions, despite DSM support and concessional debt.

Drawing these strands together, the following recommendations are proposed for mining companies, financiers and policymakers.

(a) Prioritise concessional debt and optimised debt-equity mixes for high-return EEPs. For heat-pump and compressed-air projects, concessional energy efficiency loans combined with lower internal equity (Model 6 and related variants) consistently delivered high NPVs and strong discounted IRRs across companies, outperforming pure internal funding and prime rate debt. Leasing and ESCO models remain feasible but sacrifice part of the upside to external parties. For the valve project, however, the leasing structure (Model 10) is the best performer because it converts the large, predictable compressed-air savings into immediate net cash surpluses while spreading the capital cost into a fixed operating charge. In contrast, in most other simulations, the prime minus 3% concessional loans still remain the most value-efficient option for the mines.

Mines should therefore:

- Use internal capital sparingly as equity in projects with clear savings, and actively seek concessional, ring-fenced EEP credit lines from development finance institutions, green banks or commercial lenders with blended finance.
- Set project hurdle rates using company-specific WACCs rather than blanket corporate IRR targets to avoid rejecting financially sound EEPs.

(b) Use leasing and ESCO/shared-savings models strategically to overcome binding constraints. Although these structures may not always be the financially dominant options, they play a critical role when balance sheet capacity, borrowing headroom or technical capability is the main barrier. The simulations show that:

- Leasing can be attractive for projects such as EEP B, where savings are large and stable, provided lease pricing is competitive; however, lease margins can materially erode NPV for more marginal projects such as EEP C.
- Performance-contracting and shared-savings arrangements reduce the need for internal expertise and capital, and can unlock projects that would otherwise not proceed; however, they lower the share of savings retained by the mine (Arndt, 2005).

Mines should therefore:

- Reserve leasing and ESCO/shared-savings models for situations where internal capital, debt capacity, or in-house technical capacity is constrained, or where risk transfer is a priority.
- Negotiate ESCO contracts carefully, aligning performance fees with measurable savings and ensuring that contract terms do not unduly extend payback or reduce the PI below internal thresholds.

(c) Recognise that financing cannot fully compensate for weak fundamentals in capital-intensive projects. The BESS arbitrage project (EEP C) illustrates that when the underlying economics are only slightly positive at an undiscounted level and the project life is limited, financing optimisation alone cannot transform a marginal project into a highly attractive one. Across all five companies and all financing models simulated, NPVs remain modest or negative and discounted payback periods exceed the 10-year lifespan in many scenarios, even when concessional debt and DSM incentives are included.

Recent evidence from *Watts in Store (Part 2, South Africa)* shows that lower battery costs are making energy arbitrage viable for some private sector projects. However, the report highlights that combining multiple value streams, such as arbitrage with ancillary services or peak-demand reduction, significantly improves project economics (Halsey *et al.*, 2024). The source further notes, citing international evidence, that a BESS model may be unprofitable if it can derive revenue only from one or a very limited set of grid services (Halsey *et al.*, 2024).

Accordingly:

- Mines should treat arbitrage-only BESS projects with caution under current tariff spreads and cost assumptions, prioritising EEPs with clearer savings such as heat pumps and compressed-air optimisation.
- Where BESS is pursued for strategic reasons (such as energy security and the integration of renewables), mines and financiers should focus on value stacking (e.g., peak-demand reduction and ancillary services) and on securing deeper concessional support, guarantees, or grants, rather than relying solely on tariff arbitrage savings.

(d) Integrate incentives and tax considerations into the project design stage. The modelling confirms that incentives such as Eskom DSM payments and Section 12L tax deductions (where applicable) materially improve project economics, while shortening the payback period and increasing the NPV and PI. Incentives are, however, project specific: the BESS project

qualifies for DSM but not 12L, while efficiency-driven projects benefit from both energy and carbon-related support.

Mines should therefore:

- Design EEPs explicitly to qualify for available incentives and factor these into financial models from the outset.
- Engage early with Eskom and SARS, either directly or through advisors/ESCOs, to confirm eligibility and the timing of payments, thereby reducing uncertainty and improving bankability.

(e) Strengthen project-preparation capacity and standardised modelling. The literature review highlighted the limited lender-grade, project-level analysis for mine-site EEPs in South Africa. Chapter 4 demonstrated that bankability assessments are sensitive to assumptions about WACC, tariff paths, coverage ratios and tax. To improve consistency and transparency:

- Mining companies should adopt standardised cash flow modelling templates for EEPs that incorporate company-specific WACCs, debt service coverage ratio/loan life coverage ratio tests, tax and incentive treatment, and clear sensitivity analysis.
- Financiers and ESCOs should collaborate with mines to establish shared modelling standards, reducing information asymmetries and transaction costs and enabling quicker, better-informed financing decisions.

Taken together, these recommendations suggest that the ‘most effective’ financing models are not a single structure but rather context-specific combinations of internal equity, concessional debt, and, when necessary, leasing or ESCO arrangements, chosen in line with project fundamentals, company constraints, and available incentives.

(f) Cash flow patterns and their implications for liquidity. The cash flow analyses in Sections 4.2.1.2, 4.2.2.2, and 4.2.3.3 show that financing decisions not only change the overall NPV and IRR of EEPs but also affect the timing, volatility, and risk profile of annual cash flows. Internally funded projects typically exhibit a large once-off outflow followed by significant positive savings, whereas concessional debt and leasing structures replace part of the upfront burden with a stream of repayments or lease fees. In some scenarios, this results in very attractive long-term value but weak or even negative net cash flow in the early years, especially once DSM, 12L, and other incentives are no longer available. For capital-constrained mines that must fund multiple “competing” projects from internal budgets, these differences in cash flow timing are as important as the headline returns.

- Firstly, based on these results, mines should treat detailed cash flow profiles as a core decision criterion, alongside NPV, IRR and payback. First, EEPs should be screened for their impact on liquidity by tracking annual and cumulative cash flows and applying minimum thresholds, such as avoiding extended periods of negative net cash flow after implementation.
- Secondly, financing models should be selected to align outflows as closely as possible with realised savings and incentives. In practice, this means favouring structures where debt service or lease fees can be covered by DSM, 12L and verified energy cost savings, thereby keeping projects effectively 'self-funding' on a cash basis.
- Thirdly, cash flow sensitivity tests should be standard practice, including stress-testing for tariff escalation, production levels, savings realisation and incentive eligibility. Embedding these cash flow principles into capital allocation processes would enable mines to implement more EEPs without undermining short-term liquidity, while still capturing the long-term financial and environmental benefits identified in this study.

5.2 Addressing research objectives

In terms of the research objectives, the primary objective was to evaluate how alternative financing sources and capital structures influence the financial feasibility and bankability of EEPs, and to identify those that most effectively support implementation under realistic South African conditions. This has been achieved through a combined literature review and quantitative modelling framework, which demonstrates the financial consequences of financing choices for different project and company contexts. The results of the different financing models of EEPs are evaluated and discussed in Chapter 4 and are used to inform the recommendations provided in Section 5.1.

- For economically strong projects such as the heat-pump retrofit and compressed-air control (EEPs A and B), optimised debt-equity mixes using concessional EEP loans usually offer the best balance of high NPV, attractive IRR and manageable risk, while prime rate debt and internal funding remain feasible but less efficient.
- Leasing appears to be a targeted rather than a universal solution. It is most compelling where savings are high, stable, and easily measurable, or where short-term liquidity is critical, as in the compressed-air pressure-control valve system. In this case, the lease option (Model 10) turns compressed-air savings into immediate positive net cash flow while keeping the balance sheet light. Across the wider set of simulations, however, below-prime rate concessional loans generally still deliver superior value to the mine.

- ESCO/shared-savings structures provide alternative routes where internal capital and expertise are constrained, but they generally yield lower NPVs for the mine.

For marginal projects such as the BESS arbitrage case (EEP C), none of the modelled financing structures alone provide a compelling NPV at the assumed tariffs and costs, implying that financing optimisation cannot fully compensate for weak project economics and that additional revenue streams or stronger incentives are required.

These findings collectively identify the financing models and capital structures that most effectively enhance feasibility and bankability in the tested South African mining context, thereby answering the primary research question and addressing the primary objective.

The secondary objectives formulated in Section 1.6.2 were also achieved as follows:

- The first secondary objective was to identify, classify and describe the financing sources and structures currently available for EEPs in the South African mining sector, including internal funding, debt instruments, leasing arrangements and ESCO/performance-contracting models. This objective was primarily met in Chapter 3, which synthesised academic and practitioner literature on project finance, energy efficiency finance and mining capital structures, and then organised the relevant instruments into a clear typology. Internal funding, commercial and concessional debt, leasing structures and ESCO/performance-contracting arrangements were described in terms of their risk allocation, balance sheet treatment, typical pricing and applicability to EEPs in mining. These structures were operationalised as concrete financing models for use in the simulations.
- The second secondary objective was to develop and apply a quantitative financial modelling framework that simulates representative EEPs across multiple mining companies and financing models, using South African electricity tariffs, incentives and company-specific WACCs as inputs. This was achieved through the construction of a lender-grade cash flow model, described in Chapter 2 and implemented in Chapter 4, which incorporated Megaflex tariffs, DSM and 12L incentives, corporate tax and project-specific assumptions. The framework was applied to three representative EEP types (heat pump, compressed air and valve projects) across five mining groups, and to twelve financing models per project-company combination, using empirically derived WACCs and realistic financing terms.
- The third secondary objective was to compare the financial performance and cash flow characteristics of alternative financing models using indicators such as NPV, IRR, MIRR,

payback period, discounted payback period, ROI and PI for each project and company context. This objective was met in Chapter 4, where each of the 180 simulations was evaluated using the full indicator set and summarised in comparative tables and cash flow diagrams. The analysis highlighted how the same underlying project produces materially different NPVs, discounted IRRs, payback periods and profitability indices under internal funding, concessional loans, prime rate debt, leasing and ESCO structures, and how these patterns vary across companies with different WACCs and cost of capital.

- The fourth secondary objective was to derive evidence-based, decision-oriented recommendations on the selection and structuring of financing models that address identified financial barriers, enhance project bankability and support increased uptake of EEPs in the South African mining sector. This objective was fulfilled in Section 5.1, which integrates the insights from the systematic literature review with the comparative simulation results to formulate practical guidance for mining decision-makers and financiers. The chapter sets out the financing models that are most suitable for different EEP types and risk profiles, explains how concessional energy efficiency loans and well-structured leasing or ESCO arrangements can overcome capital and risk constraints, and concludes with recommendations for mines, lenders and policymakers aimed at scaling up the bankable deployment of EEPs in the sector.

5.3 Recommendations for future research

While this study has made progress in linking financing structures to project-level feasibility for mine-site EEPs in South Africa, it also highlights several areas where further research would be valuable:

- **Broader portfolio and multi-project analysis.** The quantitative analysis focused on three representative EEPs at the project level. Future work could extend the modelling framework to portfolios of projects within a mine or across a group of mines, examining how the diversification of technologies, lifespans and savings profiles affects financing strategy, risk and capital allocation. This could include portfolio-level optimisation of internal versus external capital for EEPs relative to core production projects.
- **A deeper exploration of risk, uncertainty and dynamic conditions.** The simulations applied deterministic assumptions for tariffs, savings and costs over the project life. Future research could introduce stochastic modelling of electricity tariffs, inflation, carbon prices and project performance, including Monte Carlo analysis and real-options approaches, to better capture downside risk and the value of managerial flexibility in EEP investments.

- **Expanded the technology scope and value stacking, especially for storage.** The BESS case highlighted the sensitivity of arbitrage-only projects to cost and tariff assumptions. Future studies could model BESS projects that stack multiple value streams (such as arbitrage, peak-demand reduction, embedded renewables integration and ancillary services) and compare these with pure efficiency projects, both technically and financially. Similar modelling could be conducted for other emerging technologies (such as demand-response, ventilation optimisation and digital energy management systems).
- **Alternative financing instruments and innovative structures.** The financing models considered in this study focused on internal funding, conventional debt, concessional loans, leasing and ESCO arrangements. Further research could examine green bonds, sustainability-linked loans, on-bill financing, energy service securitisation, and blended finance structures that combine public and private capital, assessing their feasibility and cost in the South African mining context.
- **Behavioural, organisational and governance dimensions.** Although this study acknowledged barriers such as internal competition for capital and risk perceptions, it did not model organisational decision-making processes in detail. Future work could explore how governance structures, incentive schemes for mine managers, ESG reporting requirements and board-level risk preferences influence EEP financing decisions, potentially using qualitative or mixed methods alongside financial modelling.
- **Policy impact and regulatory design.** Finally, there is scope for research that explicitly models the impact of alternative policy designs, such as changes to DSM programmes, tax incentives, carbon pricing or guarantee schemes, on the bankability of EEPs and on the choice of financing structures. This could provide valuable input to policymakers seeking to scale EEP adoption in the mining sector and beyond.

5.4 Concluding remarks

This study set out to analyse how financing models and capital structures influence the financial feasibility and bankability of EEPs in the South African mining sector, and to identify which models most effectively support their implementation. By combining a systematic literature review with detailed quantitative simulations of three representative EEPs across multiple mining companies and financing structures, it has been shown that financing choices matter: they can materially affect value capture and risk allocation, and can, in some cases, determine whether a project proceeds at all.

For projects with strong savings and modest capital requirements, such as heat pumps and compressed-air optimisation, a range of financing options is available and economically attractive, with concessional debt and optimised debt-equity mixes offering particularly strong results. For more capital-intensive and emerging technologies such as BESS arbitrage, the analysis suggests that financing structures alone cannot fully compensate for borderline economics under current conditions; instead, strategic value stacking, deeper concessional support and careful project design are required. Across all cases, the study underscores the importance of integrating South African-specific tariffs, incentives and company WACCs into project-level financial models.

Beyond its specific numerical findings, the study contributes a structured, replicable framework for evaluating EEP financing models in high-risk, capital-intensive industries. It connects conceptual insights about financing instruments and barriers to lender-grade cash flow analysis tailored to mine-site projects, and translates the results into practical guidance for mining companies, financiers and policymakers. In doing so, it supports more informed, evidence-based decisions on how to finance energy efficiency in the South African mining sector, with potential benefits for operational cost control, environmental performance and long-term competitiveness.

By clarifying where financing structures can unlock value and where they cannot substitute for sound project fundamentals, the study reinforces a simple yet important message: effective EEP financing in mining depends on careful alignment between technology choice, project economics, capital structure and policy context. Building on this foundation through further research and practical application can help accelerate the uptake of EEPs, contributing to a more sustainable and resilient mining industry in South Africa.

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APPENDIX A: DISCUSSION AND OVERVIEW OF THE EIGHTEEN MOST RELEVANT STUDIES

From the 82 studies and sources that were evaluated against the defined criteria, 18 were identified as the most relevant. These are discussed below to highlight their significance and to extract insights applicable to this study.

Study 1 (Yun *et al.*, 2009)

Title: Capital structure optimisation for build-operate-transfer (BOT) projects using a stochastic and multi-objective approach.

Authors: S. Yun, S.H. Han, H. Kim, and J.H. Ock.

Relevant criteria:

- **EEPs in capital-intensive sectors:** Although not directly about mining EEPs, the study examines capital structure in large-scale, capital-intensive infrastructure projects, offering transferable insights for mining projects.
- **Financing structures and capital allocation:** The study develops a model to optimise debt-to-equity ratios, directly addressing financing structure considerations.
- **Financial feasibility assessment and optimisation of EEPs or similar projects:** Monte Carlo simulations and multi-objective optimisation techniques were applied to assess IRR and debt service coverage ratio (DSCR), focusing on feasibility optimisation.

Overview: This study developed a capital structure optimisation model for privately financed infrastructure projects using the build-operate-transfer (BOT) model. The model balances profitability for operators and risk management for creditors by determining an optimal equity-to-debt ratio. Monte Carlo simulations and a multi-objective genetic algorithm were used to capture uncertainty in demand forecasts, operational costs, and revenues. The model provides a structured method for identifying optimal capital structures under variable financial conditions.

Results: The model optimised capital structures with a balance between IRR and DSCR. Simulations showed that an equity share between 20% and 26.6% maximised profitability while ensuring debt serviceability. The findings confirmed that capital structure optimisation significantly improves project viability.

Relevance: The study demonstrates how financial feasibility can be enhanced through structured optimisation of capital structures. While the BOT context differs from mining EEPs, the principles

of optimising debt-to-equity ratios and balancing profitability with risk provide valuable insights that could be adapted to South African mining EEP financing.

Gained from study:

- Introduces a structured optimisation approach to capital allocation.
- Shows the usefulness of Monte Carlo simulations for risk analysis in financing decisions.
- Highlights the importance of balancing profitability and risk when structuring project finance.

Shortcomings and recommendations:

- The focus on BOT infrastructure projects means direct application to EEPs in mining requires adaptation.
- Risk profiles differ between infrastructure and mining EEPs, limiting direct transferability.
- Future research should adapt the optimisation model to mining energy projects and test alternative financing mechanisms such as green bonds or EPC contracts.
- This study focused on optimisation of the capital structure regarding IRR and DSCR; further research can be conducted to optimise for other variables.

Study 2 (Painuly, 2009)

Title: Financing energy efficiency: lessons from experiences in India and China.

Authors: J.P. Painuly

Relevant criteria:

- **Financing sources and instruments relevant to EEPs:** The study evaluates mechanisms such as commercial banking windows, ESCO financing, guarantee funds, and specialised loan schemes.
- **Financing structures and capital allocation:** It considers how project finance and guarantee facilities can mitigate risk and improve access to credit.
- **Contextual and sustainability considerations relevant to EEPs:** The analysis is embedded in the broader policy and market contexts of India and China, highlighting regulatory support, institutional behaviour, and government-industry collaboration.

Overview: This study examines the financial barriers to energy efficiency projects, focusing on limited access to finance, high transaction costs, and perceived risks. It evaluates solutions such as commercial banking windows, guarantee funds, and ESCO models through a UNEP-World Bank project. This paper reports on the lessons learned from the experience of a three-country

United Nations Environment Programme/World Bank Energy Efficiency Project (involving China, India and Brazil) that was set up to address the previously mentioned financial barriers.

Results:

- Identified financial barriers and developed strategies to address them.
- Supported commercial banking windows and ESCO financing.
- Led to the creation of specialised energy efficiency loan schemes in India.
- Promoted guarantee funds and an on-lending facility in China that positively benefited new EEP's.
- Raised awareness among financial institutions about the viability of such projects, helping them to be perceived as more "bankable."

Relevance: This study is relevant to the topic as it helped to identify possible barriers of entry for EEPs and possible methods that could be used to mitigate them. The project succeeded in creating awareness and a better understanding among the financial institutions in both India and China on the potential of energy efficiency and the need to make financing available for these projects. Although the setting is outside South Africa, the lessons provide a roadmap for developing financial mechanisms and awareness campaigns that could strengthen mining EEP financing locally.

Gained from study:

- Insights into financial barriers in energy efficiency projects.
- The role of banks and government incentives in EEP financing.
- Showed how banking windows, ESCO models, and guarantees reduce risk and unlock credit.
- Insights into what is required to make EEPs more bankable.

Shortcomings and recommendations: The focus is geographically limited to India and China, which reduces direct applicability to South Africa. Future research should apply these insights to emerging markets such as South Africa, with a focus on private-sector models and mining-specific risks.

Study 3 (Rezessy & Bertoldi, 2010)

Title: Financing energy efficiency: forging the link between financing and project implementation

Authors: S. Rezessy & P. Bertoldi

Relevant criteria:

- **Financing sources and instruments relevant to EEPs:** The study provides an in-depth review of debt, equity, subordinated debt, project finance, leasing, guarantees, vendor finance, and on-bill financing as they apply to energy efficiency.
- **Financing structures and capital allocation:** It analyses models such as third-party finance, ESCO-led structures, and special purpose vehicles, showing how risk and capital are allocated.
- **Contextual and sustainability considerations relevant to EEPs:** It situates financing mechanisms within EU policy, regulatory frameworks, and Structural/Cohesion Funds, linking financing to sustainability and carbon markets.

Overview: This report, prepared by the European Commission's Joint Research Centre, investigates barriers to financing energy efficiency projects in the EU and outlines a wide range of financial instruments to address them. The authors categorise financing options into debt, equity, mezzanine finance, project finance, and supplementary mechanisms such as guarantees, public programmes, and carbon finance. Attention is also given to contextual barriers such as information gaps, high transaction costs, legal limitations, and the lack of project pipelines.

Results: The study documents numerous financing models, including end-user borrowing, ESCO borrowing, and SPVs, highlighting how project cash flows can be used as collateral in limited-recourse structures. It shows that debt financing combined with guarantees can expand access to affordable credit, while leasing and forfeiting provide alternative means of overcoming collateral limitations. Innovative practices such as on-bill financing, vendor credit, and energy-efficient mortgages are described, alongside EU-level support mechanisms such as Structural Funds and the EIB. The report also provides concrete examples, such as municipal bonds in Bulgaria for street lighting upgrades, eco-mortgages in France, and guarantee schemes like the Bulgarian Energy Efficiency Fund (BEEF).

Relevance: The study offers a comprehensive review of financial instruments that can be adapted for EEPs in the South African mining sector. Lessons on project finance, guarantees, and risk-sharing mechanisms are particularly relevant for overcoming institutional reluctance in emerging markets. While the focus is on Europe, the structural insights and innovative schemes have clear

transferability to South Africa's policy environment, especially under carbon tax and demand-side management schemes.

Gained from study:

- Detailed catalogue of financing instruments applicable to EEPs.
- Clear examples of how risk-sharing, guarantees, and SPVs make projects bankable.
- Highlights the importance of project pipelines and technical assistance to create investable opportunities.

Shortcomings and recommendations: While the study provides extensive coverage of financing instruments, it focuses mainly on European Union mechanisms, which may not be fully transferable to the mining sector in different regions. Future research should explore industry-specific financial frameworks for EEPs in mining.

Study 4 (Chavalala & Nhamo, 2014)

Title: Clean and energy efficient technology as a green economy transition mechanism in South African gold mining: Case of Kusasaletu

Authors: B. Chavalala & G. Nhamo

Relevant criteria:

- **EEPs in capital-intensive sectors:** The study directly addresses energy efficiency in deep-level South African gold mining, one of the most capital- and energy-intensive sectors.
- **Financial feasibility assessment and optimisation of EEPs or similar projects:** It evaluates operational savings, cost implications, and financial performance linked to energy-efficient technology adoption.
- **Contextual and sustainability considerations relevant to EEPs:** The analysis is embedded in South African policy and regulatory contexts, including carbon tax proposals, Eskom's DSM programme, and global sustainability pressures.

Overview: This study examines Harmony Gold's Kusasaletu mine, which faced rising costs and environmental pressures due to deepening operations. As electricity use escalated with depth (ventilation, cooling, pumping, and drilling), the mine adopted clean and energy-efficient technologies from 2009 onwards. Data from 2004 to 2012 were analysed under "Business as

Usual" (BAU) and "Business Unusual" (BU) scenarios to compare trends in energy consumption, GHG emissions, and financial performance.

Results: The findings show significant reductions in both energy use and greenhouse gas emissions under the BU scenario. Between 2009 and 2012, Kusasaletu reduced electricity consumption by nearly 582 000 MWh and avoided around 616 000 tonnes of CO₂ emissions compared to the BAU trajectory. Financially, the adoption of energy-efficient technologies initially required high capital expenditure (e.g., R430 million in 2010, R380 million in 2011), but this was offset by operational cost savings and improved profitability. Profits rose by 33% in 2011 and by a further 48% in 2012, supported by co-funded DSM projects with Eskom.

Relevance: The Kusasaletu case demonstrates the direct financial and environmental benefits of EEP adoption in mining. It highlights how policy drivers such as carbon tax, regulatory compliance, and voluntary participation in disclosure initiatives can shape investment decisions. For South Africa's mining sector, the study shows that although upfront costs are high, the long-term financial feasibility of EEPs is strengthened through reduced operational costs, enhanced competitiveness, and reputational gains.

Gained from study:

- This study provided insights into the trade-off between high initial capital expenditure and long-term operational savings from energy efficiency technologies and projects.
- Empirical evidence from the mining sector on cost and emissions reductions through energy efficiency.
- Demonstrates alignment between green economy policies, operational savings, and profitability.
- Provides a South African case study that strengthens the contextual relevance of EEP financing analysis.

Shortcomings and recommendations: While the study effectively documents the technological and environmental benefits, it does not analyse the specific financing mechanisms that enabled the transition. Future work should integrate financial structuring (e.g., green bonds, EPC models) with technology adoption to provide a fuller picture of financing feasibility in mining EEPs.

Study 5 (Sarkar & Singh, 2010)

Title: Financing energy efficiency in developing countries-lessons learned and remaining challenges

Authors: A. Sarkar & J. Singh

Relevant criteria:

- **Financing sources and instruments relevant to EEPs:** The study surveys a wide spectrum of financing instruments, including utility DSM programmes, ESCO models, dedicated credit lines, revolving funds, guarantees, subsidies, and carbon finance.
- **Financing structures and capital allocation:** It highlights how institutional arrangements, performance contracting, and risk-sharing mechanisms allocate capital and influence project feasibility.
- **Contextual and sustainability considerations relevant to EEPs :** The analysis is rooted in developing-country contexts, stressing institutional capacity, regulatory frameworks, and behavioural barriers to financing EE

Overview: The paper reviews decades of World Bank and development partner experience in financing energy efficiency across developing countries. It identifies significant energy-saving potential, with estimates of 30–40% efficiency gains still unrealised, largely due to institutional barriers, transaction costs, and risk perceptions. The study assesses programmatic models such as demand-side management (DSM), ESCO development, guarantee funds, market transformation initiatives, and subsidy schemes. It emphasises that institutional challenges, rather than capital shortages, are the main obstacles in mobilising financing.

Results: This study identifies key financial barriers that hinder energy efficiency (EE) investments in developing countries. The study also evaluates various financing models, including utility demand-side management (DSM), energy service companies (ESCOs), and specialised funds. It found that while DSM programs help manage electricity demand, their long-term viability is hindered by weak regulatory support. It also found that while ESCOs facilitate EE investments by securing external funding and managing energy performance contracts, they face challenges such as limited credit access and high transaction costs. The study identified that specialised credit lines and market transformation initiatives, like bulk procurement programs, have improved EE adoption but require strong policy backing. The findings highlight the need for integrated financing mechanisms and regulatory alignment to scale up EE investments effectively.

Relevance: The insights from this study are valuable for understanding the obstacles and opportunities in financing energy efficiency projects. While not specific to mining, the lessons learned regarding overcoming high upfront costs and navigating institutional barriers can inform the development of optimised financing models for EEPs in capital-intensive sectors. This study also discusses Eskom DSM initiatives, which makes it very relevant to this study's context, as these DSM incentives will be considered where applicable in the quantitative analyses.

Gained from study:

- Shows that financing barriers in EEPs are mostly institutional and structural, not technical.
- Practical recommendations on how to tailor financing instruments to local market conditions.
- Demonstrates the effectiveness of ESCOs, DSM, and guarantees when adapted to local contexts.
- Highlights the role of concessional finance, carbon funds, and blended finance in mobilising investment at scale.

Shortcomings and recommendations: The study notes that many financing approaches have yielded only short-term successes because of inadequate regulatory frameworks and insufficient market adaptation. It calls for greater inter-institutional coordination, sustained government support, and further research into adaptable, long-term financing mechanisms that could bridge the current financing gap. Research that will contribute to making these types of projects more financially rewarding for facilities, is required to increase long-term success.

Study 6 (Huang & Li, 2011)

Title: Relationship lending in financing small and medium-sized energy management companies

Authors: Z. Huang & G. Li

Relevant criteria:

- **Financing sources and instruments relevant to EEPs:** Analyses relationship lending as an alternative financing mechanism to overcome barriers in energy efficiency project funding.
- **Financing structures and capital allocation:** Explores a long-term lending pattern with variable interest rates tailored to EMC characteristics.

- **Contextual and sustainability considerations relevant to EEPs:** Frames findings within China's policy and institutional context, but with lessons relevant for emerging markets such as South Africa.

Overview: The study investigates the persistent financing barriers that limit the growth of small and medium-sized EMCs in China. Banks have traditionally been reluctant to lend to EMCs because energy efficiency projects are seen as risky, lack tangible collateral, and have long payback horizons. To address this, the authors apply game theory to test the applicability of relationship lending in EMC financing. The analysis demonstrates that long-term relationships between EMCs and banks can reduce information asymmetry, mitigate risks, and create incentives for banks to provide ongoing credit under more favourable terms

Results: The study verified the applicability of relationship lending to EMCs in China and illustrated that it enables banks to gather required information over time, reducing uncertainty and improving credit availability for EMCs. By establishing long-term relationships, banks can offer lower interest rates and customised loan structures, mitigating the perceived risks of energy efficiency investments.

Relevance: Although focused on China, the study's insights are relevant for South Africa's mining sector, where ESCOs face similar barriers to credit. Establishing structured, trust-based relationships between EMCs/ESCOs and banks could improve financing flows to energy efficiency projects. For the mining industry, where high capital intensity and risk perceptions deter investment, relationship lending could serve as a complementary model alongside performance-based contracts and blended finance mechanisms.

Gained from study: This study provided insights, including the role of long-term banking relationships in reducing credit risk, the benefits of tailored loan structures for energy efficiency projects, and the strategic advantage of inside banks in financing EMCs. The study demonstrates that information asymmetry can be leveraged to create more favourable lending conditions for EMCs, promoting the growth of the energy efficiency sector.

Shortcomings and recommendations: The study is limited to China, with institutional and regulatory contexts that differ from South Africa. It is theoretical and model-driven, with limited empirical testing on actual financial performance. Further research is needed to adapt relationship lending models for African banks, potentially supported by credit guarantees, development finance institutions, or blended public-private funds.

Study 7 (Aslam *et al.*, 2023)

Title: Green financing guidelines for CPEC energy projects

Authors: H. Aslam, M. Sherani & Z. Zahid

Relevant criteria:

- **Financing sources and instruments relevant to EEPs:** The report highlights innovative mechanisms such as green bonds, asset fractionalisation, blended finance, and equity/debt structures for large-scale energy projects
- **Financing structures and capital allocation:** It proposes institutional frameworks (Joint Working Groups, SECP oversight) to allocate risks and returns more effectively across stakeholders
- **Contextual and sustainability considerations relevant to EEPs:** The study emphasises regulatory reform, ESG reporting, mandatory environmental disclosures, and risk diversification in emerging markets, particularly under climate vulnerability.

Overview: The Sustainable Development Policy Institute's guidelines were developed to steer financing of energy projects under the China-Pakistan Economic Corridor (CPEC) towards sustainable pathways. With Pakistan committing to reduce CO₂ emissions by 50% by 2030 and China pledging a 65% reduction in CO₂/GDP intensity, the report stresses the role of green finance in mobilising capital for clean infrastructure. It recommends creating institutional mechanisms (e.g., Joint Working Groups under the CPEC framework), mandating Environmental Information Disclosures (EIDs), and integrating ESG performance into financing decisions

Results: Key tools proposed include a "traffic light" evaluation system (green, yellow, red) to classify projects by environmental impact, mandatory ESG disclosures for listed firms, and SECP-led reforms to promote green shares, green mortgages, and sustainable stock exchange practices. Innovative instruments such as asset fractionalisation and the introduction of international leasing companies are suggested to broaden capital availability. The guidelines highlight case examples, such as Pakistan's first distributed solar project financed through a subsidised GCF-accredited facility, which improved accessibility of rooftop solar solutions.

Relevance: Although centred on Pakistan's CPEC framework, the study provides valuable lessons for South Africa's mining sector. Its emphasis on ESG disclosure, blended finance, and innovative tools like asset fractionalisation directly addresses barriers faced by EEPs in emerging markets. South Africa could adopt similar green financing guidelines tailored to its mining sector, linking them to carbon tax incentives, DSM programmes, and international green finance flows.

The structured traffic-light approach to project classification could also enhance investor confidence in high-risk, capital-intensive mining EEPs.

Gained from study: Key insights include the importance of structured finance mechanisms, the role of public-private partnerships in mobilising funds, and the impact of regulatory requirements on project financing. The study also underscores the necessity of incorporating climate risk assessments in investment decisions.

Shortcomings and recommendations:

- The study is policy-focused and not empirically tested in South Africa's context.
- It prioritises large-scale infrastructure, with limited focus on smaller, distributed EEPs.
- Application to mining requires adaptation, especially in aligning guidelines with South Africa's regulatory instruments (carbon tax, Eskom DSM, POPIA compliance).

Study 8 (Lee & Zhong, 2015)

Title: Financing and risk management of renewable energy projects with a hybrid bond

Authors: C.W. Lee & J. Zhong

Relevant criteria:

- **Financing sources and instruments relevant to EEPs:** Introduces a hybrid bond as a novel instrument to finance renewable energy projects, pooling assets to securitise future cash flows
- **Financing structures and capital allocation:** Applies portfolio theory, tranching, overcollateralisation, and credit enhancements to manage allocation of risks and returns across bond classes
- **Contextual and sustainability considerations relevant to EEPs:** Examines policy and market risks (feed-in tariffs, subsidies, REC markets) and highlights the need for stable governance frameworks

Overview: This study introduces the concept of a hybrid bond as an innovative financing instrument for renewable energy projects. It examines how such a bond can address key financial and risk-related challenges in energy investments, including market risk, credit risk, liquidity risk, and operational uncertainties. By pooling renewable energy projects into a single bond, the study

proposes a structured finance mechanism that enhances capital accessibility and diversifies investment risks.

Results: The research demonstrates that hybrid bonds can significantly improve the financial viability of renewable energy projects by securitising future revenues. By grouping projects into a single financial instrument, these bonds stabilise cash flows and reduce investors' exposure to volatility. The study also outlines the effectiveness of credit enhancement techniques such as over-collateralisation and structured trenching to make hybrid bonds more attractive to institutional investors.

Relevance: For South Africa's mining sector, the hybrid bond concept offers a model for bundling energy efficiency projects (e.g., compressed air optimisation, load management, renewables integration) into investable securities. Such securitisation could attract institutional investors deterred by high perceived risks of individual projects. The tranching mechanism also allows risk-sharing: senior tranches could appeal to conservative banks, while subordinate tranches suit investors seeking higher returns. By aligning with carbon tax incentives and DSM schemes, South Africa could adapt this financing model to mining-specific EEPs.

Gained from study: Key insights include the role of hybrid bonds in improving liquidity and reducing investment risks through diversified energy project portfolios. This demonstrates securitisation as a tool to overcome high upfront capital barriers.

Shortcomings and recommendations: The study primarily focuses on renewable energy rather than specific applications in energy efficiency projects. Further research is needed to explore how hybrid bonds can be adapted to finance EEPs in sectors with different risk profiles, such as mining.

Study 9 (Barburski & Holda, 2023)

Title: Determinants of the Corporate Financing Structure in the Energy and Mining Sectors: A Comparative Analysis Based on the Example of Selected EU Countries for 2012–2020

Authors: J. Barburski & A. Holda

Relevant criteria:

- **EEPs in capital-intensive sectors:** Mining and energy firms were analysed, sectors characterised by high capital intensity and relevance to efficiency investment.

- **Financing structures and capital allocation:** The study examines how capital structures are shaped by profitability, asset structure, liquidity, company size, and tax shields, using panel data econometric models
- **Contextual and sustainability considerations relevant to EEPs:** Results are framed within EU energy transition policies (Paris Agreement, European Green Deal, Fit-for-55), which influence financing decisions

Overview: This study analyses the determinants influencing corporate financing structures in the energy and mining sectors across selected European Union (EU) countries from 2012 to 2020. It examines how factors such as asset structure, company size, profitability, and tax shields impact financing decisions. The research applies a one-factor linear panel model to assess the relationships between financial structures and economic variables.

Results: The findings indicate that financing structures in both sectors are significantly influenced by profitability and the ratio of current liabilities to current assets. A negative correlation was observed between profitability and debt financing, while company size positively affected leverage in the energy sector. Additionally, asset structure, interest tax shields, and non-interest tax shields played varying roles in shaping financing decisions. The study underscores differences between energy and mining companies, highlighting that mining firms tend to rely more on internal financing due to higher capital investment risks. The mining sector generally exhibited lower leverage (average approximately 36%) compared to energy supply (approximately 51%), highlighting structural differences

Relevance: This study is relevant as it provides empirical insights into how financing structures in capital-intensive industries are shaped by various economic and financial determinants. Understanding these factors is crucial for optimising financing models for EEPs in mining.

Gained from study: Key insights include the influence of asset structure and profitability on corporate debt decisions, the role of tax shields in financing strategies, and the impact of company size on leverage. The study offers a comparative perspective across EU countries, making it useful for policymakers and investors aiming to optimise financing models for EEPs.

Shortcomings and recommendations: **Results are EU-focused and may not fully translate to emerging markets like South Africa.** While the study provides a robust statistical analysis, it does not explore alternative financing mechanisms such as green bonds, public-private partnerships, or blended finance. Future research should assess how these innovative financing models can improve capital accessibility in the mining and energy sectors.

Study 10 (Birch, 2016)

Title: Impact of discount rates on cut-off grades for narrow tabular gold deposits

Authors: C. Birch

Relevant criteria:

- **Financing sources and instruments relevant to EEPs:** This study uses WACC as the determinant of discount rate, showing how access to and cost of finance shape project economics.
- **Financing structures and capital allocation:** This study demonstrates how investor expectations and risk-adjusted capital costs drive decisions on project life, cut-off grades, and reserves.
- **Contextual and sustainability considerations relevant to EEPs:** This study provides a robust example of DCF and NPV-based optimisation in practice, illustrating how different discount rate assumptions alter feasibility outcomes.

Overview: The study developed an Excel-based DCF model linked to ore block listings to optimise cut-off grades for narrow tabular gold deposits in the Witwatersrand Basin. It incorporated cash flows, royalties, and gold tax, and compared results with proprietary mine-optimiser outputs. Cut-off grades were optimised at discount rates of 0%, 9%, and 12%, reflecting realistic ranges for South African mines. The analysis showed how financial assumptions impact mine planning strategies and reserve declarations, with implications for both investors and operational decision-making.

Results: At 0%, the cut-off grade was 6.59 g/t, yielding an NPV of R2.4 billion and a life of mine (LoM) of eight years. At 9%, the cut-off increased to 7.04 g/t, reducing NPV to R1.69 billion and shortening LoM to seven years. At 12%, the cut-off rose further to 7.57 g/t, with an NPV of R1.5 billion and LoM of six years. An alternative variable cut-off strategy, recalculated annually, extended LoM by up to three years and increased ore extraction by 15–34%, but lowered NPVs compared with static optimisation.

Relevance: This study is highly relevant as it illustrates the centrality of financing costs and discount rate assumptions in determining project feasibility, directly linking financial modelling to technical mine planning. For EEPs in the South African mining sector, the findings highlight how high costs of capital can reduce project uptake and shorten operational horizons, even when projects are technically viable. The methodological use of DCF and NPV optimisation provides a transferable framework for evaluating EEP financing models.

Gained from study:

- Demonstrates practical application of DCF and NPV optimisation in mining finance.
- Highlights the sensitivity of feasibility to financing costs and discount rates.
- Provides methodological insights for applying similar models to EEPs.

Shortcomings and recommendations: The study is narrowly focused on gold mining and cut-off optimisation, with limited discussion of alternative financing instruments or sustainability-linked funding. It does not engage with broader policy or ESG considerations, nor with green finance mechanisms applicable to EEPs. Further research should adapt the modelling framework to EEPs in mining, explicitly testing how varied financing structures affect feasibility and uptake under South African conditions.

Study 11 (Nel *et al.*, 2018)

Title: Financial model for energy efficiency projects in the mining industry

Authors: A.J.H. Nel, J.C. Vosloo, M.J. Mathews

Relevant criteria:

- **EEPs in capital-intensive sectors:** This study focuses on South African deep-level mining and demonstrates how energy-efficiency initiatives intersect with production realities and mine systems, it also expands on the NEB of EEPs.
- **Financing sources and instruments relevant to EEPs:** This study develops and tests a comprehensive model that monetises both direct and indirect NEBs to assess project feasibility.
- **Contextual and sustainability considerations relevant to EEPs:** Contextual and sustainability considerations relevant to EEPs: Incorporates tax incentives and carbon pricing into the “other benefits” term, aligning with South African policy instruments.

Overview: The paper argues that standard financial appraisals understate industrial EE projects by omitting NEBs. It proposes a mining-specific model that extends beyond energy savings to include maintenance, labour, water, “service delivery” (productivity-linked), and policy-driven benefits. The model evolves from the conventional baseline (energy savings only) to a full specification aggregating energy, maintenance, labour, water, service-delivery benefit, and other benefits.

Results: Applied to a ventilation optimisation at a deep-level mine (“DK”), the incremental analysis shows substantial uplift when NEBs are included. Total benefit rises from approximately US\$0.94 million (energy only) to approximately US\$3.02 million (full model). Payback shortens from 5.2 days (Model A) to 1.6 days (Model F), with ROI 227% and IRR reported at very high levels for the case parameters. The “service delivery” component links improved underground wet-bulb temperatures to productivity; however, the case study did not observe a measured production increase over the period, and the authors note multiple plausible confounders.

Relevance: This study directly tackles a persistent barrier in EEP appraisal: how to recognise and price NEBs in mines. This study offers a practical way to reflect full project value in feasibility screens, highly pertinent to South African mining where short paybacks are often mandated.

Gained from study:

- This study provided insight into EEPs in the South African deep level mining sector and their benefits.
- This study developed a stepwise, auditable method to incorporate NEBs into mine EEP financials.

Shortcomings and recommendations: While the model convincingly shows how NEBs improve project value, it does not test alternative financing structures or link discount rates explicitly to capital structure and lender requirements, limiting its bankability for South African mining EEPs.

Study 12 (International Energy Agency, 2015)

Title: Energy Efficiency Outlook for South Africa – Sizing up the opportunity

Author: B. Magné

Relevant criteria:

- **EEPs in capital-intensive sectors:** The report examines South Africa’s heavy industry and mining as major electricity users and targets for end-use efficiency, and documents utility-scale demand-side programmes (e.g., Eskom IDM).
- **Financing sources and instruments relevant to EEPs:** It details fiscal instruments that influence EEP uptake (electricity levy, prospective carbon tax interaction, Section 12L energy-efficiency savings incentive, and accelerated depreciation for clean energy).

- **Financial feasibility assessment and optimisation of EEPs or similar projects:** While not a project-financing model, it quantifies economy-wide investment needs and costed pathways for efficiency to 2030, supporting screening and prioritisation.
- **Contextual and sustainability considerations relevant to EEPs:** This report sets the South African policy and system context (capacity constraints, price pressures, need for better data/M&V), and links efficiency to security, trade balance and emissions outcomes.

Overview: Produced under the IEA's E4 Programme, the study uses WEO scenario methods to size South Africa's efficiency potential to 2030 across power, industry (incl. mining), transport and buildings. It reviews existing measures, utility programmes and fiscal instruments, and frames efficiency as a response to a constrained electricity system with rising tariffs.

Results: Using an IEA World Energy Model Baseline versus Efficiency scenario to 2030, the study finds that fully exploiting economically viable efficiency measures would cut South Africa's primary energy demand and electricity needs by roughly 15% relative to business as usual. Achieving this scale of savings requires cumulative end use efficiency investment of about US\$46 billion over 2013 to 2030, with around 15% needed by 2020; spending is dominated by transport (about half, mainly efficient vehicles) and buildings (about 38%), while industry's efficiency potential is attainable at comparatively modest cost (about US\$5.1 billion). On the supply side, higher end use efficiency reduces required electricity generation by over 20% by 2030, driving a substantial coal displacement: coal generation falls by about 17% (around 40 TWh) and more than a quarter of coal for power could be avoided in 2030. The report also estimates that improving the coal fleet and moderating demand could avoid burning about 25 million tonnes of coal, defer nearly 10 GW of new capacity, and save around US\$10 billion in coal power investment by 2030. These shifts deliver marked environmental gains, with more than 20% of projected energy related CO₂ emissions potentially avoided under the Efficiency scenario.

Relevance: For South African mining EEPs, the study anchors the macro case for efficiency and points to bankability levers, notably tax incentives, prospective carbon-pricing signals, and tariff trajectories, in a system facing tight capacity. It also highlights the need for better data and monitoring to support credible baselines and verification, which is essential for lenders and ESCO models.

Gained from study:

- Efficiency improves competitiveness but needs cost-reflective energy pricing and a supportive uptake framework (incl. tax incentives such as 12L).
- Strong programme and finance signals exist, e.g., Eskom IDM (savings equal to six 600 MW stations) and IDC-KfW's Green Energy Efficiency Fund providing project finance.

- Industry uses $\sim\frac{1}{3}$ of final energy and could rise $\sim 20\%$ by 2030 without action; mining remains a major electricity user and driver of incremental demand.
- Many EEP options in mining offer 2–5-year paybacks-high-efficiency motors with VSDs/inverter control, LED retrofits, and compressed-air leak reduction (up to $\sim 40\%$ losses)

Shortcomings and recommendations: This report is system-level and policy-focused; it doesn't test financing structures or lender metrics at project level, nor does it specify M&V protocols for monetising savings within debt covenants, both critical to mining EEP bankability.

Study 13 (González-Ruiz *et al.*, 2021)

Title: Towards an Understanding of Project Finance in the Mining Sector in the Sustainability Context: A Scientometric Analysis

Authors: J.D. González-Ruiz, J.C. Mejia-Escobar, G. Franco-Sepúlveda.

Relevant criteria:

- **EEPs in capital-intensive sectors:** This study focuses on mining as a capital-intensive domain and maps financing discourse and gaps relevant to project-level investments.
- **Financing sources and instruments relevant to EEPs:** The paper positions project finance (PF), often coupled with PPPs, as a central technique to mobilise private capital into capital-intensive infrastructure and mining, and points to transition/green bonds aligned to SDGs as emerging mechanisms.
- **Financing structures and capital allocation:** The paper frames project finance (PF) as an SPV-based, non-/limited-recourse structure in which lenders rely on the project's own cash flows rather than the sponsor's balance sheet; leverage is typically high ($\approx 70\text{--}100\%$), so operating cash flows must cover Opex, debt service and equity return. It positions PF alongside PPPs as mainstream mechanisms for capital-intensive assets, and links financing explicitly to sustainable-finance themes (SDGs; transition/green bonds). For EEPs in mining, this is directly relevant: PF/PPP structures can ring-fence project risk, unlock higher debt capacity without burdening corporate gearing, and align funding with sustainability-linked instruments, an attractive route where sponsors face balance-sheet limits or where policy (e.g., SDG-aligned finance) is a determinant of capital cost.
- **Contextual and sustainability considerations relevant to EEPs:** Emphasises SDG alignment and the risk-sharing role of PF/PPPs where public funds are constrained.

Overview: The study argues that PF has become one of the most important techniques for developing infrastructure systems, widely used with PPPs across sectors, including mining, airports, power and water, especially where governments face fiscal limits and seek private capital for greenfield/brownfield assets. PF's appeal lies in risk-sharing and mobilising long-tenor debt for single-asset SPVs, while aligning financing with sustainability goals (e.g., transition bonds, SDGs).

Results: The project finance in mining research field shows steady growth yet fragmented collaboration: few co-authored works, weak inter-country links, and minimal citation linkages, indicating a disjointed research base for PF in mining. PF differs materially from corporate finance: debt is lent to the SPV (non/limited recourse) rather than the sponsor's balance sheet; high leverage ($\approx 70\text{--}100\%$) is common, with lenders relying on project cash flows to cover Opex, debt service, and equity returns. The SPV structure shields sponsors, gives lenders a tangible security package over project assets, and can increase sponsor borrowing capacity with limited impact on corporate metrics. Smaller miners (exploration/prospecting) face greater barriers to corporate debt and therefore gravitate to PF or innovative mechanisms, while larger producers tend to prefer internal funds.

Relevance: For mining-sector EEPs, PF/PPP structures can ring-fence risks, align repayment with metered savings or availability payments, and potentially unlock higher leverage-useful where sponsors face balance-sheet constraints-while transition/green bonds offer SDG-linked pricing signals. The study also underscores that project bankability hinges on cash-flow robustness, covenant headroom, and credible risk allocation-directly pertinent to lender-ready EEP financing.

Gained from study:

- PF vs corporate finance: PF uses an SPV, non/limited recourse, and off-balance-sheet treatment; sponsors can raise debt without materially weakening corporate metrics.
- Leverage & cash-flow focus: Typical PF leverage $\sim 70\text{--}100\%$ with debt service covered from project cash flows (Opex, debt, equity return).
- Policy-linked instruments: PPPs and transition/green bonds aligned to SDGs are relevant routes for sustainable mining investments.
- Heterogeneous access to finance: Large producers prefer internal/corporate funding; smaller/exploration firms face constraints and turn to PF or innovative schemes.

Shortcomings and recommendations: As a scientometric review, the paper does not quantify structure-specific bankability for EEPs (e.g., DSCR/LLCR under PF vs corporate capex vs leasing), nor does it model South African policy instruments within term sheets.

Study 14 (Goosen, 2013)

Title: Efficient monitoring of mine compressed air savings

Authors: P. Goosen

Relevant criteria:

- **EEPs in capital-intensive sectors:** This study shows that in 2012 mines consumed 14.5% of Eskom's electricity and that compressed air equates to ~40% of a mine's demand, making it a prime EEP target. This study provides information on deep level mine compressed air EEPs in the South African mining sector.
- **Financing sources and instruments relevant to EEP's:** This study provides information on Eskom DSM incentives that reward EEPs financially in South Africa. The study provides case studies of where EEPs in combination with DSM initiatives have been implemented in the South African mining sector.
- **Contextual and sustainability considerations relevant to EEPs:** The study provides context on the South African mining sector and its energy consumption as well as compressed air systems that are responsible for a significant portion of the mines energy consumption. It further provides context and information relevant to the government Eskom DSM incentives for EEP adoption.

Overview: Goosen develops and deploys an automated, centralised reporting system for mine compressed-air DSM projects: reliable daily data capture from SCADA/PLC, processing to a central database, auto-generated daily/monthly/group reports, and email distribution to close the feedback loop between ESCo and mine teams. The aim is to sustain DSM savings by speeding insight and corrective action.

Results: The study explains how pressure set-point reduction and better valve/compressor control deliver energy savings; financially, it reiterates the (historic) DSM benchmark funding model and the importance of measured weekday targets vs baseline. Case applications across multiple mines show the system cuts manual effort, shortens feedback delays, and helps maintain target savings that otherwise erode due to control faults, leaks and operational drift.

Relevance: Directly applicable to South African mining EEPs on compressed air: quantifies why these systems are material loads, 21–40%+ of mine electricity. The study also clarifies DSM mechanisms (PC vs EE), and shows that data quality, cadence, and automated reporting are pivotal to turning modelled savings into bankable, sustained outcomes.

Gained from study:

- Compressed air is a high-impact EEP lever in mines. This study provided insight in to mine compressed air systems and pressure control systems that serve as effective EEPs.
- This study provided information on Eskom DSM incentives and their implementation in the South African mining sector and provided a clear distinction between PC (evening peaks) and EE (all-day reduction). The study provided insight in to the financial benefits of aligning with these incentives.

Shortcomings and recommendations: The focus is operational performance and reporting, not financing structure or lender metrics; historic DSM benchmarks are cited and may have changed.

Study 15 (International Energy Agency *et al.*, 2024)

Title: The Future of Heat Pumps in China

Authors: International Energy Agency (IEA) and Tsinghua University Building Energy Research Center (BERC)

Relevant criteria:

- **EEPs in capital-intensive sectors:** This study assesses industrial and district-heating heat-pump deployment, including integration with power-plant/industrial/wastewater/data-centre waste heat, with quantified national potentials.
- **Financial feasibility assessment and optimisation:** This study is relevant because it examines a proven EEP, industrial and building heat pumps, together with quantified financial feasibility (lifecycle/LCOH comparisons, tariff sensitivity) and system factors (waste-heat integration, demand-side response) that inform financing and implementation choices in utility-type loads analogous to mine water-heating duty.
- **Contextual and sustainability** Links efficiency/electrification to emissions cuts and outlines large recoverable waste-heat resources and HP capacity potential by 2030/2050.

Overview: The report maps technology, economics and policy for heat pumps across buildings, light industry and district heating in China to 2050. It quantifies usable temperature ranges, regional tariff dynamics, and waste-heat integration pathways, while outlining scenario-based investment and manufacturing implications (STEPS/APS).

Results: The study finds air-to-air and air-to-water heat pumps are already lifetime-cost competitive in several climates; e.g., in Harbin, air-to-air units match district heating with ~40% lower energy costs, and air-to-water beats electric resistance and gas over the lifecycle. By 2030, lifetime costs for heat pumps are projected at around half those of gas boilers and electric heaters, with coal remaining marginally cheaper unless pledges narrow the gap further; high upfront costs persist but can be offset by incentives. Regionally, electricity-gas price ratios drive competitiveness; electricity can be 2–3× the price of gas in some provinces, shaping optimal cases for HPs and the need for supportive tariffs/DSR. Waste-heat integration potential is material: ~19 EJ available by 2050, with ~650 GW heat-pump capacity technically deployable.

Relevance: This report supports the modelling assumptions for EEP A by providing evidence on heat-pump adoption trends, performance improvements, and cost trajectories. These insights help justify the expected EUL and savings stability used in the South African mining heat-pump case study.

Gained from study:

- Provides context and information of the basic workings and principles of heat pumps and their use as EEPs.
- This study provided context regarding EEP heat-pump uptake and barriers
- This study provided information on the savings that can be expected from HP EEP projects

Shortcomings and recommendations: Evidence is China-specific; upstream fuel prices, tariff structures and district-heating context differ from South African mining. Transferability to high-temperature duties is limited. Recompute LCOH using SA tariffs (e.g., Megaflex), mine-site load profiles and local WACC; treat incentives explicitly (tax allowances/ESG-linked finance) and test HP-plus-waste-heat scenarios typical of mine utilities.

Study 16 (Halsey *et al.*, 2024)

Title: Watts in Store Part 2: Creating an enabling environment for the deployment of grid batteries in South Africa

Authors: R. Halsey; R. Bridle; N. Overy; B. Vazi

Relevant criteria:

- **Financing sources and instruments relevant to EEPs:** Sets out Income Tax Act allowances that can be applied or extended to storage (ss11A/11D, 12B, 12L; potential re-activation of 12I) and proposes predictable charging tariffs to stabilise OPEX and support bankability.
- **Financing structures and capital allocation:** Identifies procurement and contracting choices (e.g., fixed charging rates in public tenders) that improve lender comfort and debt sizing.
- **Financial feasibility assessment and optimisation:** Shows why LCOS alone is incomplete and motivates a total-value lens (levelised value of storage) that captures stacked revenues and system benefits.
- **Contextual and sustainability considerations relevant to EEPs Clarifies South Africa-specific drivers:** ToU/wheeling arrangements, evolving regulatory definitions, and system planning signals (IRP/TDP) for BESS scale and location.

Overview: A South Africa-focused synthesis of interviews and literature on grid-connected BESS. The report examines tariff formation for charging and discharging, wheeling and billing arrangements, regulatory treatment of storage, and planning signals (IRP/TDP). It compiles practical instruments, predictable charging rates, clearer service definitions, and tax allowances, to accelerate viable deployment and improve financing outcomes.

Results: BESS economics hinge on tariffs: business cases turn on the spread between charging and discharging prices and where charging energy is sourced (grid, wheeled IPP, or co-located renewables). Public programmes demonstrate a workable hedge via fixed charging rates indexed to inflation, which could be generalised to other use cases. Decision-making should prioritise total value, not LCOS alone, because LCOS varies with utilisation and omits revenues from capacity and ancillary services; a levelised value of storage lens is recommended. System planning indicates rising need for BESS: TDP 2022 signals larger capacity than IRP 2019/IRP 2023 assumptions (with a 4-hour baseline used in current procurements). A policy menu identifies tax allowances and revenue-stacking access as near-term levers to strengthen feasibility.

Relevance: The report is directly applicable to EEP C, as it outlines South African BESS regulatory conditions, revenue-stacking opportunities, and barriers to deployment. This context informs the arbitrage assumptions and risk interpretation used in the BESS financing simulations.

Gained from study:

- Direct support for tariff-led arbitrage logic: model spreads between off-peak charging and peak discharging under Megaflex and wheeling pathways; assess co-located renewables to reduce charging risk.

- Justification to evaluate stacked-revenue cases (arbitrage + demand-charge reduction + services) using a value framework beyond LCOS.
- Concrete SA instruments to encode in financing scenarios: fixed charging-rate structures and storage-eligible tax allowances that improve debt capacity and reduce WACC inputs.

Shortcomings and recommendations: Evidence is predominantly grid-centric and policy-oriented, with limited treatment of behind-the-meter applications at energy-intensive industrial sites. Assumptions for tariffs, charging sources and refurbishment/cycle life are general and not tailored to mining load profiles or Eskom's large-user structures. Financial discussions emphasise public procurements and system planning signals, offering sparse detail on lender terms specific to private industrial projects. The report also highlights the limits of LCOS for decision-making, while quantified, mine-relevant revenue stacks and risk premia remain under-specified.

Study 17 (Xolo et al., 2025)

Title: Energy Services Market Intelligence Report 2025 (Energy Services MIR)

Authors: S. Xolo; U. Terblanche; N. Magoda; S. Khoza; J. Radmore; C. Pienaar; L. Basson; B. Raw; N. Fordyce

Relevant criteria:

- **EEPs in capital-intensive sectors:** Analyses embedded PV and behind-the-meter Li-ion storage in CI&A, an analogous, transferable context for large, energy-intensive users where tariff structures and operational drivers mirror many mine services.
- **Financing sources and instruments relevant to EEPs:** Sets out practical routes, commercial bank debt, leases/rent-to-own, and PPAs, and signposts a national green-finance database useful for sourcing capital.
- **Financing structures and capital allocation:** Distinguishes outright purchase versus third-party ownership, showing how performance and investment risk are allocated in embedded-asset deals (e.g., PPA, lease).
- **Contextual and sustainability considerations relevant to EEPs:** Summarises SA-specific market drivers and municipal embedded-generation enablement that shape bankability and uptake.

Overview: South Africa-focused market intelligence for the commercial, industrial and agricultural (CI&A) segments covering embedded PV and behind-the-meter lithium-ion storage. The report

collates drivers, regulatory enablement, finance modalities and market sizing, including indicative LCOS data and procurement/contract forms used for distributed asset.

Results: A concrete arbitrage case is evidenced for CI&A users on Eskom Megaflex: an off-peak rate of ~R1.07/kWh versus a peak rate of ~R6.52/kWh in high-demand season (<500 V, long-distance zone), with additional gains from peak-shaving and load-shifting. LCOS benchmarking positions Li-ion as the preferred backup technology relative to diesel and advanced lead-acid, with value expanding as services are stacked. CI&A BTM storage demand is expected to stabilise at ~400 MWh p.a. (~R2 billion) with growth to ~2 GWh (~R10 billion) by 2030. Finance availability spans commercial banks and alternative debt providers, with PPAs and leases commonly used where risk transfer is preferred.

Relevance: The Energy Services MIR provides contemporary South African evidence on ESCO market structure, pricing behaviour, and contracting norms. These findings inform the parameter choices and practical feasibility discussion for shared-savings and performance-contracting models in mining EEPs

Gained from study:

- Shows that tariff-aligned arbitrage and peak management are key to BESS economics in South Africa, given large Megaflex time-of-use spreads for CI&A users.
- Provides SA-specific LCOS evidence and market-sizing that sharpen assumptions for stacked-services cases versus backup-only use.
- Confirms multiple financing routes in practice (bank debt, PPAs, leases) and points to an accessible green-finance database relevant to sourcing instruments.

Shortcomings and recommendations: The evidence centres on the CI&A segment rather than mining, and tariff/duty-cycle examples are indicative for generic behind-the-meter users. It does not cover mine-specific operating profiles (high-voltage systems, deep-level shift patterns, coincident peaks), the application of Eskom large-user ToU/wheeling to mines, or the stacked service duties typical of mine BESS (arbitrage, peak management, power-quality support). Financing coverage lists routes (bank debt, PPAs, leases) but omits term-sheet detail relevant to mining EEPs, tenor ranges, covenant/DSCR norms, security packages, refurbishment/degradation provisions, and assessment against South African mining WACC and credit conditions.

Study 18 (Arndt, 2005)

Title: Agreements & Financing (Volume 3)

Authors: D. Arndt (Prepared); P. Costello (Checked); T. Golding (Approved)

Relevant criteria:

- **Financing sources and instruments relevant to EEPs:** Sets out concrete options for performance-contracting finance in South Africa, including client funding, a proposed National Treasury Energy Efficiency Fund (0% interest), Eskom DSM co-funding (100% for load-shifting; 50% for efficiency), and ESCO/financial-institution debt where require.
- **Financing structures and capital allocation:** Compares fixed-fee, shared-savings (ESCO-financed) and guaranteed-performance contracting; clarifies who finances, who bears technical/financial risk, and how savings/repayments are structured.
- **Financial feasibility assessment and optimisation for EEPs:** optimisation for EEPs: Provides worked 10–year financial analyses and a savings comparison across the three models, enabling like-for-like feasibility testing.
- **Contextual and sustainability considerations relevant to EEPs:** Contextual and sustainability considerations relevant to EEPs: Frames roles of DPW/National Treasury/Eskom, contracting processes, and risk-transfer logic shaping bankability in the SA public-sector context.

Overview: South African guidance on energy performance contracting with full contract architecture for three routes, fixed fee, shared savings, and performance contracting-plus implementation workflows, risk analysis, and summary tables. Appendices include template agreements for shared-savings and performance contracts, supporting practical adoption.

Results: The report sets out funding routes for South African EPCs, including client capital, ESCO or third party finance, and concepts linked to Treasury and Eskom, with repayments tied to verified savings. It defines roles and risk transfer across client, consultant and ESCO, with performance guarantees placing technical and shortfall risk on the ESCO. Using a common ten year case, it compares fixed fee, shared savings and performance contracting: fixed fee can yield the largest client saving where maintenance is strong, shared savings delivers benefits without upfront capital but with a smaller share, and performance contracting offers guaranteed outcomes with moderated upside.

Relevance: This guide strengthens the study's treatment of project-finance agreements and risk allocation, which underpin several simulated financing models. Its contracting and covenant considerations are transferable to lender-grade structuring for South African mining EEPs.

Gained from study:

- Practical, SA-specific blueprints for EPC: funding options, agreement stacks, and step-by-step implementation processes.
- Clear risk-transfer mechanics (especially under guaranteed-savings) and the role of third-party verification/consultants in bankability.
- Ready-to-use contract templates (shared-savings, performance) that can be adapted to sector-specific EEPs.

Shortcomings and recommendations: The evidence base is dated (2005) and centred on public-sector buildings rather than mining; it does not reflect post-2010 market shifts (e.g., modern BESS, wheeling PPAs, updated DSM/tax frameworks). Term-sheet specifics (tenor/DSCR/security/degradation provisions) are outlined only at a conceptual level, and ESG framing is minimal, subsequent mining-sector studies should supply current covenant norms and sector-specific duty cycles.

APPENDIX B: ESKOM MEGAFLEX ELECTRICITY TARIFFS

Table 10: Eskom Megaflex mine summer electricity tariffs

	Summer Tariff		
	Weekday	Saturday	Sunday
1	103.15	103.15	103.15
2	103.15	103.15	103.15
3	103.15	103.15	103.15
4	103.15	103.15	103.15
5	103.15	103.15	103.15
6	144.42	103.15	103.15
7	256.86	144.42	103.15
8	256.86	144.42	103.15
9	144.42	144.42	103.15
10	144.42	144.42	103.15
11	144.42	144.42	103.15
12	144.42	103.15	103.15
13	144.42	103.15	103.15
14	144.42	103.15	103.15
15	144.42	103.15	103.15
16	144.42	103.15	103.15
17	144.42	103.15	103.15
18	256.86	144.42	144.42
19	256.86	144.42	144.42
20	256.86	103.15	103.15
21	144.42	103.15	103.15
22	103.15	103.15	103.15
23	103.15	103.15	103.15
24	103.15	103.15	103.15

(Eskom Holdings SOC Ltd, 2025a)

Table 11: Eskom Megaflex mine winter electricity tariffs

Winter Tariff			
	Weekday	Saturday	Sunday
1	103.15	103.15	103.15
2	103.15	103.15	103.15
3	103.15	103.15	103.15
4	103.15	103.15	103.15
5	103.15	103.15	103.15
6	618.91	103.15	103.15
7	618.91	154.72	103.15
8	154.72	154.72	103.15
9	154.72	154.72	103.15
10	154.72	154.72	103.15
11	154.72	154.72	103.15
12	154.72	103.15	103.15
13	154.72	103.15	103.15
14	154.72	103.15	103.15
15	154.72	103.15	103.15
16	154.72	103.15	103.15
17	618.91	103.15	103.15
18	618.91	154.72	154.72
19	618.91	154.72	154.72
20	154.72	103.15	103.15
21	154.72	103.15	103.15
22	103.15	103.15	103.15
23	103.15	103.15	103.15
24	103.15	103.15	103.15

(Eskom Holdings SOC Ltd, 2025a)

APPENDIX C: SIMULATION RESULTS

This appendix provides the tabularised results of the 180 simulations completed for the quantitative analyses in this study:

Table 12: EEP A (water-heating system upgrade with heat pump) financing model simulation results

Scenario	Payback period (years)	Discounted payback period (years)	Net profit	Net present value	Internal rate of return (p.a.)	Discounted Internal rate of return (p.a.)	Return on investment	Discounted return on investment	Accounting rate of return	Profitability index
Sc-AH1	2.43	3.33	R6 795 266.95	R2 599 111.30	35%	19%	237%	90%	19%	90%
Sc-AH2	0.74	0.83	R5 756 500.70	R3 105 820.74	143%	115%	1 002%	541%	64%	541%
Sc-AH3	0.95	1.06	R5 842 198.91	R3 064 017.22	109%	86%	765%	401%	50%	401%
Sc-AH4	1.25	1.43	R6 016 192.26	R2 979 143.38	75%	55%	524%	259%	36%	259%
Sc-AH5	1.63	1.91	R6 275 883.83	R2 852 466.02	53%	35%	364%	166%	27%	166%
Sc-AH6	0.72	0.81	R6 083 283.36	R3 275 395.89	147%	119%	1 059%	570%	67%	570%
Sc-AH7	0.92	1.04	R6 142 022.01	R3 219 602.41	113%	89%	804%	421%	52%	421%
Sc-AH8	1.23	1.40	R6 261 279.26	R3 106 324.74	77%	57%	545%	270%	37%	270%
Sc-AH9	1.62	1.89	R6 439 275.16	R2 937 253.59	54%	36%	374%	170%	27%	170%
Sc-AH10	1.12	1.24	R4 635 146.95	R2 237 061.79	88%	67%	67%	32%	4%	32%
Sc-AH11	3.03	4.41	R5 001 129.42	R1 618 130.84	27%	13%	174%	56%	16%	56%
Sc-AH12	N/A	N/A	R5 182 423.11	R3 019 160.16	N/A	N/A	N/A	N/A	N/A	N/A
Sc-AS1	2.43	3.12	R6 795 266.95	R3 107 873.28	35%	22%	237%	108%	21%	108%
Sc-AS2	0.74	0.82	R5 756 500.70	R3 430 285.63	143%	120%	1 002%	597%	70%	597%
Sc-AS3	0.95	1.04	R5 842 198.91	R3 403 686.61	109%	89%	765%	445%	55%	445%
Sc-AS4	1.25	1.39	R6 016 192.26	R3 349 682.55	75%	59%	524%	292%	39%	292%
Sc-AS5	1.63	1.86	R6 275 883.83	R3 269 079.46	53%	38%	364%	190%	29%	190%
Sc-AS6	0.72	0.79	R6 083 283.36	R3 618 348.35	147%	124%	1 059%	630%	73%	630%
Sc-AS7	0.92	1.02	R6 142 022.01	R3 576 234.16	113%	92%	804%	468%	57%	468%

Scenario	Payback period (years)	Discounted payback period (years)	Net profit	Net present value	Internal rate of return (p.a.)	Discounted Internal rate of return (p.a.)	Return on investment	Discounted return on investment	Accounting rate of return	Profitability index
Sc-AS8	1.23	1.37	R6 261 279.26	R3 490 729.58	77%	60%	545%	304%	40%	304%
Sc-AS9	1.62	1.84	R6 439 275.16	R3 363 110.82	54%	39%	374%	195%	30%	195%
Sc-AS10	1.12	1.22	R4 635 146.95	R2 519 029.89	88%	70%	67%	37%	5%	37%
Sc-AS11	3.03	4.08	R5 001 129.42	R2 029 198.18	27%	15%	174%	71%	17%	71%
Sc-AS12	N/A	N/A	R5 182 423.11	R3 283 685.52	N/A	N/A	N/A	N/A	N/A	N/A
Sc-AA1	2.43	3.30	R6 795 266.95	R2 659 246.82	35%	20%	237%	93%	19%	93%
Sc-AA2	0.74	0.83	R5 756 500.70	R3 144 235.09	143%	116%	1 002%	547%	65%	547%
Sc-AA3	0.95	1.06	R5 842 198.91	R3 104 223.56	109%	86%	765%	406%	51%	406%
Sc-AA4	1.25	1.42	R6 016 192.26	R3 022 988.02	75%	56%	524%	263%	36%	263%
Sc-AA5	1.63	1.91	R6 275 883.83	R2 901 740.95	53%	36%	364%	168%	27%	168%
Sc-AA6	0.72	0.80	R6 083 283.36	R3 315 984.20	147%	120%	1 059%	577%	68%	577%
Sc-AA7	0.92	1.03	R6 142 022.01	R3 261 803.37	113%	89%	804%	427%	53%	427%
Sc-AA8	1.23	1.40	R6 261 279.26	R3 151 799.85	77%	57%	545%	274%	37%	274%
Sc-AA9	1.62	1.89	R6 439 275.16	R2 987 615.51	54%	37%	374%	173%	27%	173%
Sc-AA10	1.12	1.24	R4 635 146.95	R2 270 245.06	88%	67%	67%	33%	4%	33%
Sc-AA11	3.03	4.37	R5 001 129.42	R1 666 737.99	27%	13%	174%	58%	16%	58%
Sc-AA12	N/A	N/A	R5 182 423.11	R3 050 474.75	N/A	N/A	N/A	N/A	N/A	N/A
Sc-AI1	2.43	3.96	R6 795 266.95	R1 550 201.40	35%	13%	237%	54%	15%	54%
Sc-AI2	0.74	0.88	R5 756 500.70	R2 432 563.18	143%	104%	1 002%	423%	52%	423%
Sc-AI3	0.95	1.11	R5 842 198.91	R2 359 768.33	109%	76%	765%	309%	41%	309%
Sc-AI4	1.25	1.52	R6 016 192.26	R2 211 972.73	75%	47%	524%	193%	29%	193%
Sc-AI5	1.63	2.13	R6 275 883.83	R1 991 382.29	53%	28%	364%	116%	22%	116%
Sc-AI6	0.72	0.85	R6 083 283.36	R2 564 786.06	147%	108%	1 059%	446%	55%	446%
Sc-AI7	0.92	1.09	R6 142 022.01	R2 481 082.83	113%	79%	804%	325%	42%	325%
Sc-AI8	1.23	1.49	R6 261 279.26	R2 311 139.90	77%	49%	545%	201%	30%	201%

Scenario	Payback period (years)	Discounted payback period (years)	Net profit	Net present value	Internal rate of return (p.a.)	Discounted Internal rate of return (p.a.)	Return on investment	Discounted return on investment	Accounting rate of return	Profitability index
Sc-AI9	1.62	2.08	R6 439 275.16	R2 057 493.73	54%	29%	374%	119%	22%	119%
Sc-AI10	1.12	1.31	R4 635 146.95	R1 664 816.60	88%	58%	67%	24%	3%	24%
Sc-AI11	3.03	5.61	R5 001 129.42	R 769 297.11	27%	7%	174%	27%	13%	27%
Sc-AI12	N/A	N/A	R5 182 423.11	R2 470 440.67	N/A	N/A	N/A	N/A	N/A	N/A
Sc-AE1	2.43	3.21	R6 795 266.95	R2 866 339.36	35%	21%	237%	100%	20%	100%
Sc-AE2	0.74	0.83	R5 756 500.70	R3 276 393.24	143%	117%	1 002%	570%	67%	570%
Sc-AE3	0.95	1.05	R5 842 198.91	R3 242 563.79	109%	88%	765%	424%	52%	424%
Sc-AE4	1.25	1.41	R6 016 192.26	R3 173 879.77	75%	57%	524%	276%	38%	276%
Sc-AE5	1.63	1.89	R6 275 883.83	R3 071 366.30	53%	37%	364%	178%	28%	178%
Sc-AE6	0.72	0.80	R6 083 283.36	R3 455 652.58	147%	122%	1 059%	602%	70%	602%
Sc-AE7	0.92	1.03	R6 142 022.01	R3 407 034.24	113%	91%	804%	446%	55%	446%
Sc-AE8	1.23	1.38	R6 261 279.26	R3 308 324.27	77%	59%	545%	288%	39%	288%
Sc-AE9	1.62	1.86	R6 439 275.16	R3 160 995.97	54%	38%	374%	183%	28%	183%
Sc-AE10	1.12	1.23	R4 635 146.95	R2 384 820.74	88%	69%	67%	35%	4%	35%
Sc-AE11	3.03	4.23	R5 001 129.42	R1 834 089.23	27%	14%	174%	64%	16%	64%
Sc-AE12	N/A	N/A	R5 182 423.11	R3 158 214.02	N/A	N/A	N/A	N/A	N/A	N/A

(Source: Own compilation)

Table 13: EEP B (compressed-air instrumentation and control for pressure regulation) financing model simulation results

Scenario	Payback period (years)	Discounted payback period (years)	Net profit	Net present value	Internal rate of return (p.a.)	Discounted Internal rate of return (p.a.)	Return on investment	Discounted return on investment	Accounting rate of return	Profitability index
Sc-BH1	0.39	0.63	R61 155 940.72	R42 535 818.94	263%	222%	1 080%	751%	170%	751%
Sc-BH2	0.08	0.09	R60 197 970.44	R43 209 067.85	1 215%	1 066%	5 314%	3 815%	783%	3 815%
Sc-BH3	0.11	0.12	R60 277 002.99	R43 153 524.82	922%	806%	4 001%	2 864%	593%	2 864%
Sc-BH4	0.16	0.18	R60 437 463.01	R43 040 755.62	623%	541%	2 668%	1 900%	400%	1 900%
Sc-BH5	0.24	0.27	R60 676 955.58	R42 872 443.40	424%	365%	1 786%	1 262%	272%	1 262%
Sc-BH6	0.08	0.09	R60 486 905.81	R43 407 207.37	1 219%	1 069%	5 340%	3 832%	786%	3 832%
Sc-BH7	0.11	0.12	R60 542 101.19	R43 335 317.82	925%	808%	4 019%	2 877%	595%	2 877%
Sc-BH8	0.16	0.18	R60 654 164.54	R43 189 360.26	624%	542%	2 677%	1 906%	401%	1 906%
Sc-BH9	0.24	0.27	R60 821 423.27	R42 971 513.15	425%	365%	1 790%	1 265%	273%	1 265%
Sc-BH10	0.07	0.08	R63 098 542.28	R45 108 250.94	1 379%	1 211%	1 238%	885%	181%	885%
Sc-BH11	0.46	0.52	R49 498 808.90	R34 297 494.92	222%	185%	874%	606%	141%	606%
Sc-BH12	NA	NA	R37 676 672.58	R27 603 570.29	NA	NA	NA	NA	NA	NA
Sc-BS1	0.39	0.63	R61 155 940.72	R45 202 367.57	263%	229%	1 080%	798%	180%	798%
Sc-BS2	0.08	0.09	R60 197 970.44	R45 644 372.56	1 215%	1 090%	5 314%	4 030%	826%	4 030%
Sc-BS3	0.11	0.12	R60 277 002.99	R45 607 907.14	922%	825%	4 001%	3 027%	625%	3 027%
Sc-BS4	0.16	0.18	R60 437 463.01	R45 533 871.31	623%	554%	2 668%	2010%	422%	2010%
Sc-BS5	0.24	0.27	R60 676 955.58	R45 423 370.06	424%	374%	1 786%	1 337%	287%	1 337%
Sc-BS6	0.08	0.09	R60 486 905.81	R45 855 271.58	1 219%	1 094%	5 340%	4 048%	830%	4 048%
Sc-BS7	0.11	0.12	R60 542 101.19	R45 801 407.00	925%	827%	4 019%	3 040%	628%	3 040%
Sc-BS8	0.16	0.18	R60 654 164.54	R45 692 045.58	624%	556%	2 677%	2017%	423%	2017%
Sc-BS9	0.24	0.27	R60 821 423.27	R45 528 819.57	425%	375%	1 790%	1 340%	288%	1 340%
Sc-BS10	0.07	0.08	R 63 098 542.28	R47 680 309.52	1 379%	1 238%	1 238%	935%	191%	935%
Sc-BS11	0.46	0.51	R49 498 808.90	R36 478 380.86	222%	191%	874%	644%	149%	644%
Sc-BS12	NA	NA	R37 676 672.58	R29 055 962.21	NA	NA	NA	NA	NA	NA

Scenario	Payback period (years)	Discounted payback period (years)	Net profit	Net present value	Internal rate of return (p.a.)	Discounted Internal rate of return (p.a.)	Return on investment	Discounted return on investment	Accounting rate of return	Profitability index
Sc-BA1	0.39	0.63	R61 155 940.72	R42 859 110.16	263%	223%	1 080%	757%	171%	757%
Sc-BA2	0.08	0.09	R60 197 970.44	R43 504 372.59	1 215%	1 069%	5 314%	3 841%	788%	3 841%
Sc-BA3	0.11	0.12	R60 277 002.99	R43 451 138.44	922%	808%	4 001%	2 884%	597%	2 884%
Sc-BA4	0.16	0.18	R60 437 463.01	R43 343 056.99	623%	542%	2 668%	1%	403%	1 913%
Sc-BA5	0.24	0.27	R60 676 955.58	R43 181 741.38	424%	366%	1 786%	1 271%	274%	1 271%
Sc-BA6	0.08	0.09	R60 486 905.81	R43 704 054.01	1 219%	1 073%	5 340%	3 858%	792%	3 858%
Sc-BA7	0.11	0.12	R60 542 101.19	R43 634 346.14	925%	811%	4 019%	2 896%	599%	2 896%
Sc-BA8	0.16	0.18	R60 654 164.54	R43 492 818.05	624%	544%	2 677%	1 920%	404%	1 920%
Sc-BA9	0.24	0.27	R60 821 423.27	R43 281 582.09	425%	366%	1 790%	1 274%	275%	1 274%
Sc-BA10	0.07	0.08	R63 098 542.28	R45 420 001.29	1 379%	1 215%	1 238%	891%	182%	891%
Sc-BA11	0.46	0.52	R49 498 808.90	R34 561 987.38	222%	186%	874%	610%	142%	610%
Sc-BA12	NA	NA	R37 676 672.58	R27 779 864.60	NA	NA	NA	NA	NA	NA
Sc-BI1	0.39	0.63	R61 155 940.72	R36 488 063.30	263%	206%	1 080%	644%	149%	644%
Sc-BI2	0.08	0.10	R60 197 970.44	R37 682 101.58	1 215%	1 006%	5 314%	3 327%	685%	3 327%
Sc-BI3	0.11	0.13	R60 277 002.99	R37 583 593.43	922%	759%	4 001%	2 495%	519%	2 495%
Sc-BI4	0.16	0.19	R60 437 463.01	R37 383 592.01	623%	508%	2 668%	1 650%	350%	1 650%
Sc-BI5	0.24	0.29	R60 676 955.58	R37 085 082.44	424%	341%	1 786%	1 091%	238%	1 091%
Sc-BI6	0.08	0.10	R60 486 905.81	R37 851 677.17	1 219%	1 009%	5 340%	3 342%	688%	3 342%
Sc-BI7	0.11	0.13	R60 542 101.19	R37 739 179.02	925%	762%	4 019%	2 505%	521%	2 505%
Sc-BI8	0.16	0.19	R60 654 164.54	R37 510 773.70	624%	509%	2 677%	1 656%	351%	1 656%
Sc-BI9	0.24	0.29	R60 821 423.27	R37 169 870.23	425%	341%	1 790%	1 094%	239%	1 094%
Sc-BI10	0.07	0.09	R63 098 542.28	R39 280 952.18	1 379%	1 144%	1 238%	771%	158%	771%
Sc-BI11	0.46	0.55	R49 498 808.90	R29 345 066.24	222%	170%	874%	518%	124%	518%
Sc-BI12	NA	NA	R37 676 672.58	R24 294 132.06	NA	NA	NA	NA	NA	NA
Sc-BE1	0.39	0.63	R61 155 940.72	R43 955 445.04	263%	226%	1 080%	776%	175%	776%
Sc-BE2	0.08	0.09	R60 197 970.44	R44 505 697.81	1 215%	1 079%	5 314%	3 929%	806%	3 929%

Scenario	Payback period (years)	Discounted payback period (years)	Net profit	Net present value	Internal rate of return (p.a.)	Discounted Internal rate of return (p.a.)	Return on investment	Discounted return on investment	Accounting rate of return	Profitability index
Sc-BE3	0.11	0.12	R60 277 002.99	R44 460 301.95	922%	816%	4 001%	2 951%	610%	2 951%
Sc-BE4	0.16	0.18	R60 437 463.01	R44 368 134.62	623%	548%	2 668%	1 958%	412%	1 958%
Sc-BE5	0.24	0.27	R60 676 955.58	R44 230 571.42	424%	370%	1 786%	1 302%	280%	1 302%
Sc-BE6	0.08	0.09	R60 486 905.81	R44 710 618.58	1 219%	1 083%	5 340%	3 947%	809%	3 947%
Sc-BE7	0.11	0.12	R60 542 101.19	R44 648 316.76	925%	818%	4 019%	2 964%	613%	2 964%
Sc-BE8	0.16	0.18	R60 654 164.54	R44 521 825.19	624%	549%	2 677%	1 965%	413%	1 965%
Sc-BE9	0.24	0.27	R60 821 423.27	R44 333 031.81	425%	370%	1 790%	1 305%	281%	1 305%
Sc-BE10	0.07	0.08	R63 098 542.28	R46 477 374.98	1 379%	1 226%	1 238%	912%	186%	912%
Sc-BE11	0.46	0.51	R49 498 808.90	R35 458 753.58	222%	188%	874%	626%	145%	626%
Sc-BE12	NA	NA	R37 676 672.58	R28 377 277.80	NA	NA	NA	NA	NA	NA

(Source: Own compilation)

Table 14: Project C (BESS for energy arbitrage) financing model simulation results

Scenario	Payback period (years)	Discounted payback period (years)	Net profit	Net present value	Internal rate of return (p.a.)	Discounted Internal rate of return (p.a.)	Return on investment	Discounted return on investment	Accounting rate of return	Profitability index
Sc-CH1	7.80	Exceeds project life	R 2 459 415.28	-R3 090 017.54	4%	-7%	21%	26%	7%	-26%
Sc-CH2	Exceeds project life	Exceeds project life	-R1 771 590.87	-R1 026 135.71	N/A	N/A	76%	44%	6%	-44%
Sc-CH3	Exceeds project life	Exceeds project life	-R1 422 532.86	-R1 196 405.96	N/A	N/A	46%	38%	6%	-38%
Sc-CH4	Exceeds project life	Exceeds project life	-R713 839.33	-R1 542 106.17	-7%	-18%	15%	33%	7%	-33%
Sc-CH5	9.07	Exceeds project life	R343 912.21	-R2 058 076.63	1%	-10%	5%	29%	7%	-29%
Sc-CH6	Exceeds project life	Exceeds project life	-R440 570.10	-R335 437.99	N/A	N/A	19%	14%	9%	-14%
Sc-CH7	Exceeds project life	Exceeds project life	-R201 321.30	-R562 690.80	N/A	N/A	6%	18%	8%	-18%
Sc-CH8	7.92	Exceeds project life	R284 426.25	-R1 024 082.88	2%	-9%	6%	22%	8%	-22%
Sc-CH9	7.82	Exceeds project life	R1 009 422.59	-R1 712 727.76	4%	-8%	14%	24%	8%	-24%
Sc-CH10	Exceeds project life	Exceeds project life	-R2 773 129.75	-R2 123 292.26	N/A	N/A	13%	10%	0%	-10%
Sc-CH11	9.75	Exceeds project life	R227 532.23	-R4 310 344.08	0%	-11%	2%	37%	6%	-37%
Sc-CH12	N/A	N/A	R8 579 707.64	R5 559 166.11	N/A	N/A	N/A	N/A	N/A	N/A
Sc-CS1	7.80	Exceeds project life	R2 459 415.28	-R2 405 116.11	4%	-6%	21%	21%	8%	-21%
Sc-CS2	Exceeds project life	Exceeds project life	-R1 771 590.87	-R1 091 896.10	N/A	N/A	76%	47%	5%	-47%
Sc-CS3	Exceeds project life	Exceeds project life	-R1 422 532.86	-R1 200 236.75	N/A	N/A	46%	39%	6%	-39%
Sc-CS4	Exceeds project life	Exceeds project life	-R713 839.33	-R1 420 201.10	-7%	-16%	15%	30%	7%	-30%
Sc-CS5	9.07	Exceeds project life	R343 912.21	-R1 748 506.11	1%	-8%	5%	25%	8%	-25%
Sc-CS6	Exceeds project life	Exceeds project life	-R440 570.10	-R325 896.52	N/A	N/A	19%	14%	9%	-14%
Sc-CS7	Exceeds project life	Exceeds project life	-R201 321.30	-R497 432.13	N/A	N/A	6%	16%	8%	-16%
Sc-CS8	7.92	Exceeds project life	R284 426.25	-R845 701.41	2%	-8%	6%	18%	8%	-18%
Sc-CS9	7.82	Exceeds project life	R1 009 422.59	-R1 365 506.31	4%	-6%	14%	19%	8%	-19%
Sc-CS10	Exceeds project life	Exceeds project life	-R2 773 129.75	-R2 216 084.68	N/A	N/A	13%	11%	0%	-11%
Sc-CS11	9.75	Exceeds project life	R 227 532.23	-R3 746 973.49	0%	-9%	2%	32%	7%	-32%

Scenario	Payback period (years)	Discounted payback period (years)	Net profit	Net present value	Internal rate of return (p.a.)	Discounted Internal rate of return (p.a.)	Return on investment	Discounted return on investment	Accounting rate of return	Profitability index
Sc-CS12	N/A	N/A	R8 579 707.64	R5 940 240.44	N/A	N/A	N/A	N/A	N/A	N/A
Sc-CA1	7.80	Exceeds project life	R2 459 415.28	-R3 008 801.35	4%	-7%	21%	26%	7%	-26%
Sc-CA2	Exceeds project life	Exceeds project life	-R1 771 590.87	-R1 033 392.19	N/A	N/A	76%	44%	6%	-44%
Sc-CA3	Exceeds project life	Exceeds project life	-R1 422 532.86	-R1 196 363.45	N/A	N/A	46%	38%	6%	-38%
Sc-CA4	Exceeds project life	Exceeds project life	-R713 839.33	-R1 527 244.48	-7%	-18%	15%	33%	7%	-33%
Sc-CA5	9.07	Exceeds project life	R343 912.21	-R2 021 096.77	1%	-10%	5%	29%	7%	-29%
Sc-CA6	Exceeds project life	Exceeds project life	-R440 570.10	-R333 839.69	N/A	N/A	19%	14%	9%	-14%
Sc-CA7	Exceeds project life	Exceeds project life	-R201 321.30	-R554 524.02	N/A	N/A	6%	18%	8%	-18%
Sc-CA8	7.92	Exceeds project life	R284 426.25	-R1 002 580.10	2%	-9%	6%	21%	8%	-21%
Sc-CA9	7.82	Exceeds project life	R 1 009 422.59	-R1 671 320.52	4%	-8%	14%	24%	8%	-24%
Sc-CA10	Exceeds project live	Exceeds project life	-R2 773 129.75	-R2 134 426.45	N/A	N/A	13%	10%	0%	-10%
Sc-CA11	9.75	Exceeds project life	R227 532.23	-R4 243 469.03	0%	-11%	2%	36%	6%	-36%
Sc-CA12	N/A	N/A	R8 579 707.64	R5 604 529.45	N/A	N/A	N/A	N/A	N/A	N/A
Sc-CI1	7.80	Exceeds project life	R2 459 415.28	-R4 520 518.11	4%	-12%	21%	39%	6%	-39%
Sc-CI2	Exceeds project life	Exceeds project life	-R1 771 590.87	-R926 564.15	N/A	N/A	76%	40%	6%	-40%
Sc-CI3	Exceeds project life	Exceeds project life	-R1 422 532.86	-R1 223 065.35	N/A	N/A	46%	39%	6%	-39%
Sc-CI4	Exceeds project life	Exceeds project life	-R713 839.33	-R1 825 052.64	-7%	-22%	15%	39%	6%	-39%
Sc-CI5	9.07	Exceeds project life	R343 912.21	-R2 723 541.13	1%	-15%	5%	39%	6%	-39%
Sc-CI6	Exceeds project life	Exceeds project life	-R440 570.10	-R388 006.18	N/A	N/A	19%	17%	8%	-17%
Sc-CI7	Exceeds project life	Exceeds project life	-R201 321.30	-R728 938.42	N/A	N/A	6%	23%	8%	-23%
Sc-CI8	7.92	Exceeds project life	R284 426.25	-R1 421 134.16	2%	-14%	6%	30%	7%	-30%
Sc-CI9	7.82	Exceeds project life	R1 009 422.59	-R2 454 262.15	4%	-13%	14%	35%	7%	-35%
Sc-CI10	Exceeds project life	Exceeds project life	-R2 773 129.75	-R1 923 837.06	N/A	N/A	13%	9%	0%	-9%
Sc-CI11	9.75	Exceeds project life	R227 532.23	-R5 491 952.58	0%	-16%	2%	47%	5%	-47%

Scenario	Payback period (years)	Discounted payback period (years)	Net profit	Net present value	Internal rate of return (p.a.)	Discounted Internal rate of return (p.a.)	Return on investment	Discounted return on investment	Accounting rate of return	Profitability index
Sc-CI12	N/A	N/A	R8 579 707.64	R4 750 895.70	N/A	N/A	N/A	N/A	N/A	N/A
Sc-CE1	7.80	Exceeds project life	R2 459 415.28	-R2 729 663.39	4%	-6%	21%	23%	8%	-23%
Sc-CE2	Exceeds project life	Exceeds project life	-R1 771 590.87	-R1 059 470.05	N/A	N/A	76%	45%	5%	-45%
Sc-CE3	Exceeds project life	Exceeds project life	-R1 422 532.86	-R1 197 261.00	N/A	N/A	46%	38%	6%	-38%
Sc-CE4	Exceeds project life	Exceeds project life	-R713 839.33	-R1 477 018.39	-7%	-17%	15%	32%	7%	-32%
Sc-CE5	9.07	Exceeds project life	R343 912.21	-R1 894 566.72	1%	-9%	5%	27%	7%	-27%
Sc-CE6	Exceeds project life	Exceeds project life	-R440 570.10	-R329 327.57	N/A	N/A	19%	14%	9%	-14%
Sc-CE7	Exceeds project life	Exceeds project life	-R201 321.30	-R527 355.28	N/A	N/A	6%	17%	8%	-17%
Sc-CE8	7.92	Exceeds project life	R284 426.25	-R929 411.52	2%	-8%	6%	20%	8%	-20%
Sc-CE9	7.82	Exceeds project life	R1 009 422.59	-R1 529 495.48	4%	-7%	14%	22%	8%	-22%
Sc-CE10	Exceeds project life	Exceeds project life	-R2 773 129.75	-R2 172 439.02	N/A	N/A	13%	10%	0%	-10%
Sc-CE11	9.75	Exceeds project life	R227 532.23	-R4 013 768.73	0%	-10%	2%	34%	7%	-34%
Sc-CE12	N/A	N/A	R 8 579 707.64	R 5 760 073.26	N/A	N/A	N/A	N/A	N/A	N/A

(Source: Own compilation)

APPENDIX D: EDITING CERTIFICATE

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