MANDELA MINING PRECINCT
MINDS FOR MINES

Guideline:
Energy Utilisation

science & innovation
Department: Science and Innovation
REPUBLIC OF SOUTH AFRICA

CSIR

MINERALS COUNCIL SOUTH AFRICA

MANDELA MINING PRECINCT
MINDS FOR MINES

About the Mandela Mining Precinct

The Mandela Mining Precinct is a Public-Private Partnership between the Department of Science and Innovation and the Minerals Council South Africa. The Precinct is jointly hosted by the Council for Scientific and Industrial Research and the Minerals Council. The Mandela Mining Precinct is an initiative aimed at revitalising mining research, development and Innovation in South Africa to ensure the sustainability of the industry. This is achieved through the South African Mining Extraction, Research, Development and Innovation (SAMERDI) strategy. The strategy comprises six research programmes:

1. Longevity of Current Mining;
2. Mechanised Mining Systems;
3. Advanced Orebody Knowledge;
4. Real-Time Information Management Systems;
5. Successful Application of Technologies Centred Around People; and
6. Test Mine.

This guideline was developed under the Mechanised Mining Systems research programme. The programme is aimed at providing sustainable mechanised drill, blast and mechanical rock breaking solutions in advancement towards atomised systems to facilitate achieving zero harm, whilst maintaining and defending desired production rates at minimised costs, within the au and PGM mining industries.

ISBN number: 978-0-7988-5652-2

Contact details enquiries@mandelaminingprecinct.org.za
www.mandelaminingprecinct.org.za

Editors Martin Pretorius (Mandela Mining Precinct) and Xiaohua Xia (University of Pretoria)

Contributing authors Dr Xianming Ye, Centre for New Energy Systems (CNES) at the University of Pretoria; and Peter Klein, Energy Centre at the Council for Scientific and Industrial Research (CSIR)

External Review Roy Murley, Glencore; and Alex Fenn, Sibanye Stillwater

Executive Summary

In the context of rising electricity costs, compounded by nationwide electricity generation constraints, it is important for the industry to explore a diversified energy supply through alternative self-generation technologies such as renewables. This guideline is intended to assist the industry in selecting the most feasible technologies suited to their needs.

Despite the effects of COVID19, 2020 has seen the highest levels of load shedding to date, with 1362 GWh of energy shed. The IRP2019 has identified a short term capacity gap of 2000 MW up to 2022, which must be filled in order to avoid future load shedding. This capacity gap will be further exacerbated if the performance of the existing coal fleet does not recover from current levels. The mining sector can play a leading role in the rapid role out of embedded generation and storage technologies to provide a customer response at scale to this energy crisis. In recent communications the president has indicated that the government is moving to create an enabling environment to allow customers to deploy embedded generation.

An overview of the proposed minimum technical specifications for the major components of a solar PV plant is presented in this guideline, including applicable IEC and SANS standards that should be adhered to, as well as recommendations to ensure plant performance. The guideline also provides an energy planning methodology for conducting a techno-economic optimisation of an alternative energy generator. The approach includes a demand side assessment, generator modelling and a least cost optimisation. A case study is presented in this guideline for the optimisation of a solar PV plant and grid electricity for a representative 30 MW mining profile.

As part of the latest Integrated Resource Plan 2019 (IRP2019) an allocation of 500 MW/yr from 2023 to 2030 has been provided for embedded generation, and an undetermined allocation between 2019 and 2022 to reduce the short term capacity gap.

Despite the potential for cost savings through the deployment of alternative energy technologies, the high levels of upfront costs, present a major hurdle that has to be overcome in the development of projects in the mining sector. This guideline describes some financing approaches that could support mines pursuing an alternative energy investment. The REIPPPP provides the best example of financing mechanisms for the deployment of large scale renewable energy plants. Therefore an overview is provided on how projects in BW1-4 achieved financial close. A description of applicable green finance funds from the DBSA and IDC is also presented.

Table of Contents

List of Figures

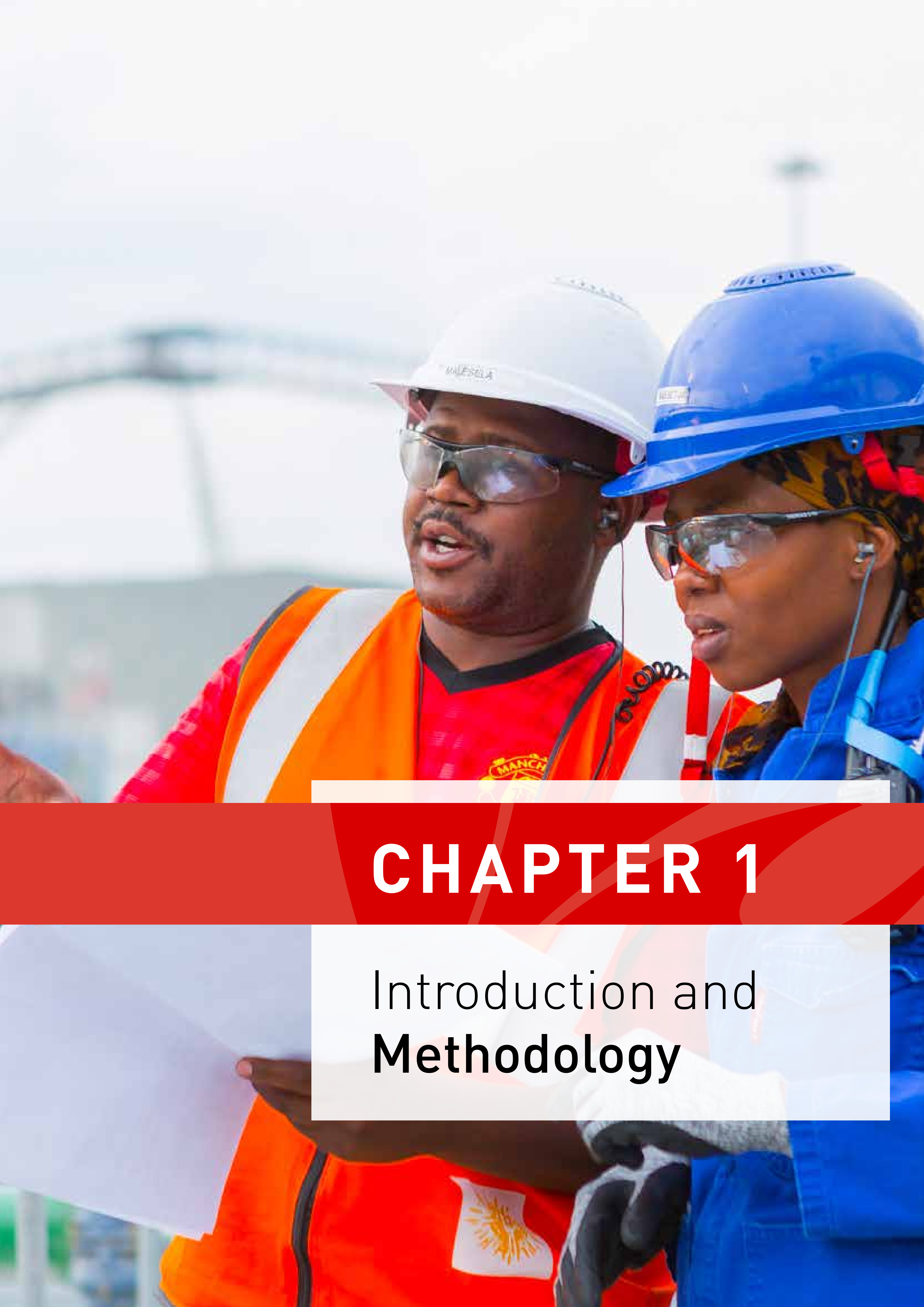
List of Tables

List of Abbreviations

CNES	:	Centre of New Energy Systems
CSIR	:	Council for Scientific and Industrial Research
PV	:	Photovoltaic
P2P	:	peer to peer
EE	:	Energy efficiency
DSM	:	Demand side management
POET	:	Performance, operation, equipment, and technology
CSIR	:	Council for Scientific and Industrial Research
DBSA	:	Development Bank of South Africa
DFI	:	Development Finance Institution
DNI	:	Direct Normal Irradiance
GHI	:	Global Horizontal Irradiance (GHI)
GIZ	:	Deutsche Gesellschaft für Internationale Zusammenarbeit
IDC	:	Industrial Development Corporation
IRP	:	Integrated Resource Plan
EPC	:	Engineering, Procurement and Construction
O&M	:	Operation and Maintenance
PID	:	Potential Induced Degradation
PR	:	Performance Ratio
PV	:	Photovoltaic
REIPPPP	:	Renewable Energy Independent Power Producer Procurement Programme
PVGIS	:	Photovoltaic Geographical Information System (PVGIS).
RFP	:	Request for Proposal
TMY	:	Typical Meteorological Year

SCOPE

This guideline provides energy efficiency development and recommended energy efficiency interventions to improve plant wide energy efficiency across the gold and platinum mining sectors. A large focus is placed on effective solutions related to alternative energy sources, optimised energy supply strategy and structures, and efficient energy utilisation. The planned energy efficiency activities will be guided by a POET framework.



CHAPTER 1

Introduction and **Methodology**

1.1 INTRODUCTION TO POET

The POET philosophy classifies energy efficiency into four components, namely:

1. **Performance efficiency**
   This is a measure of energy efficiency, which is determined by external but deterministic system indicators such as production, cost, energy sources, environmental impact and technical indicators amongst others.

2. **Operation efficiency**
   The operational efficiency is evaluated by considering the proper coordination of the various system components. It has the following indicators: physical coordination indicators (sizing and matching); time coordination indicator (time control) and human coordination.

3. **Equipment efficiency**
   This is a measure of the energy output of isolated individual energy equipment with respect to given technology design specifications. Equipment efficiency is evaluated by considering the following indicators: capacity; specifications and standards; constraints; and maintenance.

4. **Technology efficiency**
   This is the measure of efficiency of energy conversion, processing, transmission and usage characterised by its novelty and optimality. Technology efficiency is often evaluated by the following indicators: feasibility; life-cycle cost and return on investment; and coefficients in the conversing/processing/transmitting rate.

The POET framework is a useful and comprehensive guideline to identify energy savings opportunities as well as to design effective energy efficiency solutions. This POET philosophy is originally established by the Director of the Centre of New Energy Systems (CNES) – Prof. Xiaohua Xia, which has been internationally accepted to be effective in improving the energy efficiency of buildings and industrial processes. In addition, the POET framework is a well-established framework to guide the energy audit process, which has also been widely applied to designed energy efficiency specifications in industrial plants in South Africa.

1.2 ADVANTAGEOUS FEATURES OF POET

An Energy efficiency (EE) proposal refers to the process of determining the best interventions that could be implemented to improve efficiency of an existing facility in terms of energy consumption reduction and energy cost decrease in the most cost-effective way. This usually follows directly after the energy audit, information gathered through which can be used as the primary inputs for the EE proposal development. CNES has developed a unified methodology for energy efficiency proposals covering the comprehensive scope of energy systems. This methodology is also based on the POET classification of energy efficiency. In particular, Figure 1 depicts how the POET framework can be used to identify energy efficiency improvement opportunities and therefore to come up with EE proposals. The POET efficiencies are further categorised into sub-groups including efficiencies that are affected directly by technical impacts, time impacts and behaviour impacts, respectively. With the help of this categorisation, one can identify a basket of interventions that can be implemented to improve the overall efficiency of an energy system. Generally, this process can be divided into three steps:

1 Baselining and targeting

Usually, the EE proposal requires information gathered through an energy audit. A system model will be built making use of the information obtained. This model is used to determine the baseline energy consumption of the system under investigation. Once the baseline is built, one then moves to identify savings potentials by comparing the baseline to the average consumption of similar processes. Thus, setting a target for improvement.

2 Determining the inventory for improvement

After the target is set, one then looks into the technology, equipment, operation and performance efficiencies to identify the inventory of possible improvements. For example, a process operating with poorly maintained old equipment can easily be improved by either replacing the equipment with better counterparts or proper maintenance of the existing equipment. Therefore, the two interventions, namely, equipment retrofit and maintenance, make up the items of the inventory of improvements.

3 Option optimisation which are detailed in the following

After obtaining the full inventory for improvement, a decision making assistant system is required to determine which of the inventory items should be implemented because the energy efficiency improvement projects are usually subject to financial constraints. In order to determine the best options of the inventory for implementation, the optimal combination must be selected following a holistic approach. This is done following the energy optimisation method, which when used for decision making support, solve the problem of finding the optimal combination of the inventory items such that costs are minimised; the benefits in terms of energy savings and financial returns are maximised, and the physical, operational, and financial constraints, such as budget limit, are honoured.

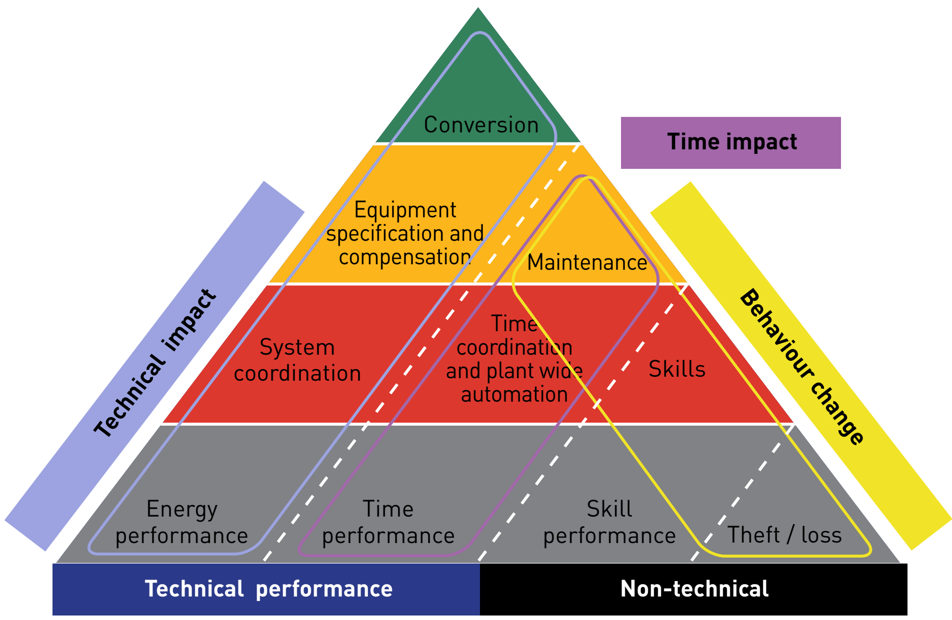


Figure 1: The POET framework for energy efficiency planning

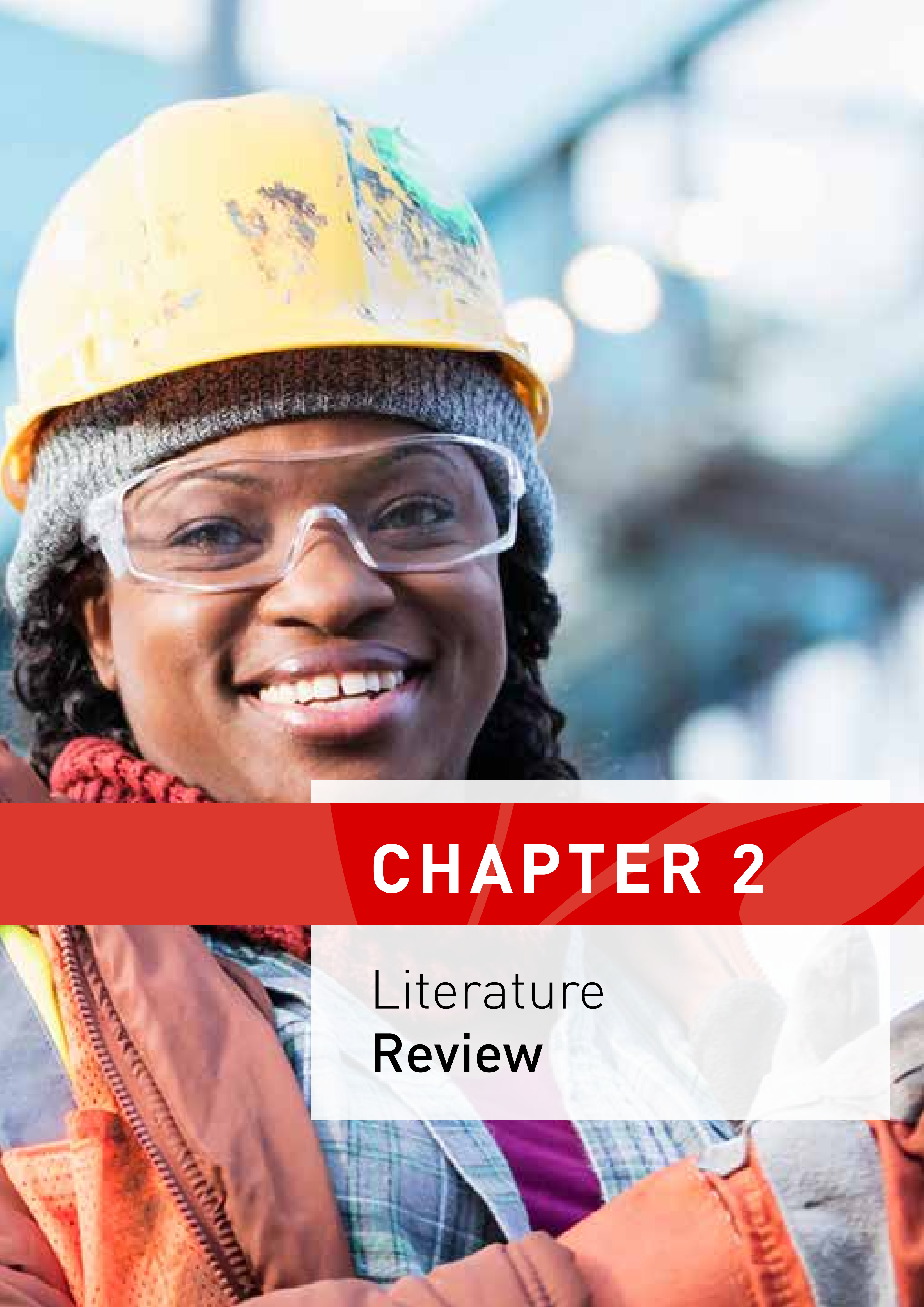
1.3 APPLICABILITY OF POET

Given that the aim is to identify the most suitable energy efficiency solutions from the supply side, this guideline starts by looking at the energy sources, the energy supply infrastructure such as energy storage systems, and the demand side such as the mining energy systems. In Table 1, we use examples such as the solar energy from the energy supply, battery energy storage system of the energy supply infrastructure, and the belt conveyor system at the demand side to illustrate how to apply the POET framework to identify potential energy efficiency solutions. While these indications are brief, detailed analyses are presented in later sections of this guideline.

Table 1: Apply POET to assess the energy efficiency features of an energy system

CATEGORY	TECHNOLOGY	EQUIPMENT	OPERATION	PERFORMANCE
Supply side – solar energy	Options: solar PV, solar thermal	Solar panel, solar collector (best design of technical specifications)	Weather conditions such as solar irradiance, temperature, etc. Maximum power point tracking, dust management, etc.	Levelised cost for solar power generation, kWh/m2
Energy supply – Battery	Options: Li-ion battery, lead acid battery, among others	Size, shape, weight of the battery	Charge/discharge control, state of health, temperature management, fault management, etc.	Life span, capacity fade, etc.
Energy utlisation - Belt conveyor	Single drive or multiple drive	Length, height, number of motor drives, etc.	Running empty? Speed regulation and control?	kWh/ton

In recent years, the POET energy efficiency framework has also been widely adopted to guide the research developments for various energy systems, such as electrical vehicle charge stations, strategies for improved energy conservation on a military installation, optimal metering plan in an energy efficiency project for a ferrochrome plant, and modelling, control and optimisation of a dual circuit induced draft cooling water system. Thus the POET framework is selected as the most applicable guideline approach for this project.



CHAPTER 2

Literature **Review**

2.1 INTRODUCTION

A detailed literature review has been conducted in three major areas namely, renewable energy resources, energy supply infrastructure, and energy utilisation. More precisely, the renewable energy resources include the solar energy that is mainly supported by the solar photovoltaic (PV) and solar thermal systems, wind energy and the biomass. The energy supply infrastructure covers the power supply security due to main grid power failures, peer-to-peer energy sharing innovations among networked microgrids, energy storage systems to enhance power supply reliability and security, and reduction of power losses during the power supply. While this is an abridged version of the literature review, the full document can be obtained from the Mandela Mining Precinct.

2.1.1 RENEWABLE ENERGY RESOURCES

This section provides an overview of the primary renewable energy technologies that are applicable to the mining sector, including solar (PV and thermal), wind and biomass. The information is presented according to the POET framework, and summarised in Table 2.

Table 2: Summary of renewable energy in terms of POET

SOLAR PV	• Amorphous silicon • Crystalline silicon • Chalcogenide • Dye-Sensitized • Hybrid • III-V • Organic PV • Perovskite	Solar modules • Standard, bifacial, concentrating (CPV), PVT Power electronics • MPPT, • Inverter • Transformer Mounting structures • Fixed tilt • Single axis tracker • Dual axis tracker • Motors, drives, controllers Monitoring • Irradiance sensor • Power/energy monitoring	• Irradiance • Weather conditions • Temperature • Automation and control • Tracking • Cleaning • Emergency stow and shutdown for high wind periods (trackers only). • Planned maintenance: modules, cabling, junction boxes, structures, • Unplanned maintenance	• Levelised Cost of Electricity • Performance Ratio • O&M costs • Power and energy output • Capacity factor • Cash flows from energy savings/ sales

SOLAR THERMAL	Non concentrating • Flat plate • Evacuated tube Concentrating • Linear Fresnel • Parabolic trough • Central receiver • Parabolic dish	• Solar collectors/ receivers • Mirrors • Heat transfer fluid • Thermal energy storage • Heat engine (CSP only) • Mounting structures, including single and dual axis trackers • Auxiliary equipment, including pumps, piping, valves, insulation, sensors	• Irradiance • Weather conditions • Temperature • Automation and control • Tracking • Cleaning • Emergency stow and shutdown	• Levelised Cost of Heat/ Electricity • O&M costs • Power and energy output • Capacity factor

2.1.2 ENERGY SUPPLY INFRASTRUCTURE

The energy that is consumed by the end-users is the transformation of the primary energy into more useable forms of final energy. There is a different example of this transformation such as coal to electricity in power stations, crude oil to liquid fuels in oil refineries, coal to liquid fuels, and natural gas to liquid fuels. Transformation of coal to electricity, supply 59% of the South African energy. The rest of the energy supply followed by 20% renewables and 16% crude oil. Natural gas contributed 3% while nuclear contributed 2% to the total primary supply in 2015. South Africa supplies approximately 40% of Africa's electricity and has until recently been one of the four cheapest electricity producers in the world. The electricity division in South Africa is dominated by the national utility Eskom, a primary electricity supplier and generates around 90% of the electricity used in the country. In this section of the report, we identify the power delivery losses and also energy supply opportunity with peer-to-peer energy sharing.

Energy utilization

The mining industry is a well-established and resourceful sector of South Africa's economy and plays a key role in the country's economy. It is also one of the main consumers of energy in the country, particularly electricity. Of all the energy supplied in 2015, the industry used 60% of electricity, 38% of the petroleum products, 2% of coal and an insignificant amount of gas as depicted in Figure 2. The total energy used by the sector is approximately 184 742 terajoules, with electricity consumption of 110 272 terajoules.

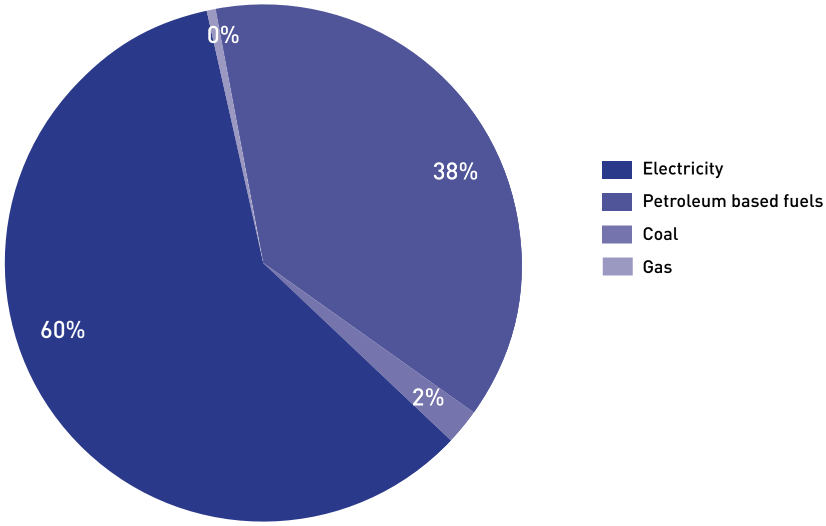


Figure 2: Energy consumption in South African mining (2015)

The consumption of the entire mining sector was estimated in 2010 to account for about 15% of Eskom's annual output. Within the sector, the gold mining subsector was the largest consumer, accounting for 47% of the industry's electricity. Platinum mining was second, consuming 33%, and all other mines together shared the remaining 20%.

While in the past the prevalence of energy efficiency initiatives in the mining sector was closely correlated to energy prices, the picture today has changed significantly. Indeed, in recent years, however, concerns about climate change, the carbon footprint of products, the related internalising of associated costs, and, in some cases, decline in ore grade are also driving decisions related to energy consumption and efficiency in the minerals sector. In addition, because of the multiple benefits offered by energy efficiency improvements (see Figure 3), many also relevant to the mining industry, public authorities increasingly tend to promote the implementation of energy conservation measures across their domestic economies.

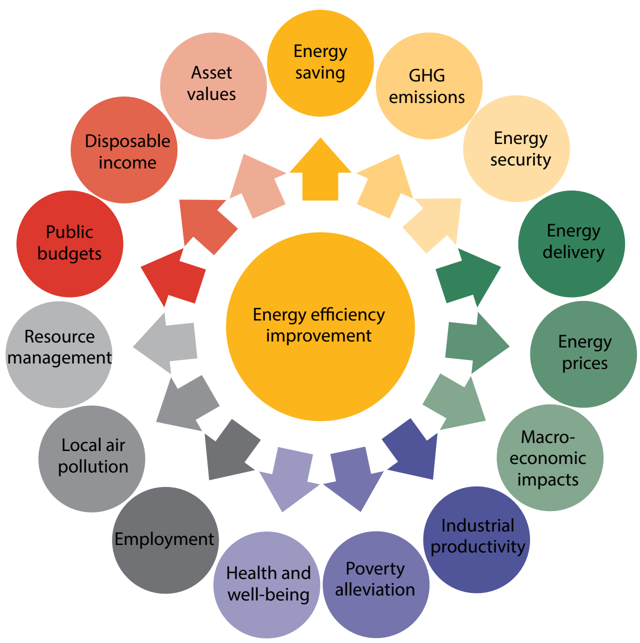


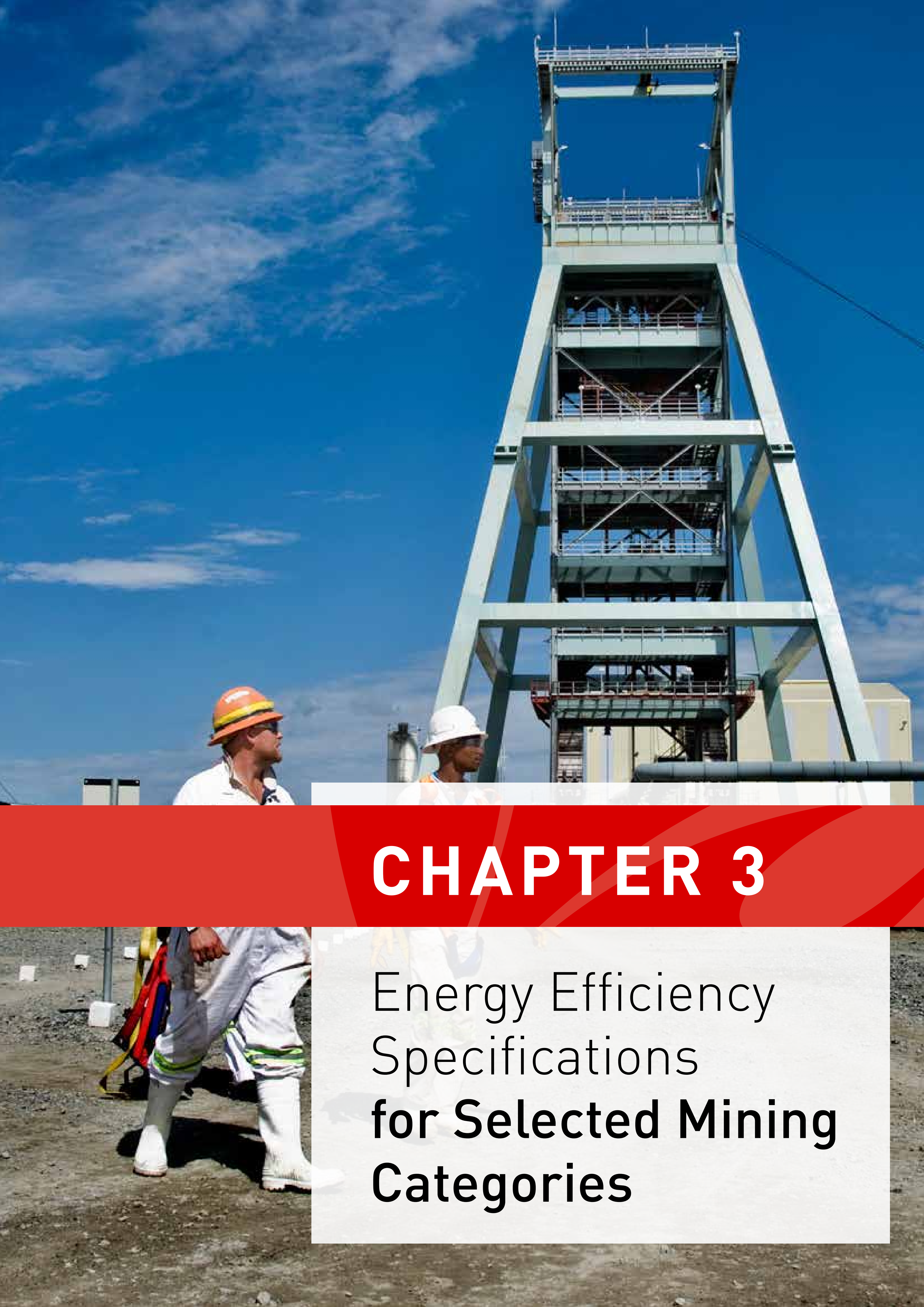
Figure 3: The multiple benefits of energy efficiency improvements

To illustrate the potential savings at stake, a 2007 energy bandwidth study that analysed energy use and the potential for energy savings of key processes in the U.S. mining sector established a potential to reduce the energy consumption by 54%, including 33% from the implementation of best practices across the entire industry and 21% through further research and development efforts. Table 3 below details the potential for energy efficiency improvement in the top 10 energy-intensive processes.

Table 3: Efficiencies of equipment types in mining (neglecting electricity losses)

MINING AREA	EQUIPMENT	METAL MINING			MINERAL MINING			COAL MINING		
		Current practice efficiency[1]	Best practice efficiency[2]	Maximum attainable efficiency[3]	Current practice efficiency[1]	Best practice efficiency[2]	Maximum attainable efficiency[3]	Current practice efficiency[1]	Best practice efficiency[2]	Maximum attainable efficiency[3]
EXTRACTION	Drilling	47%	57%	80%	22%	27%	53%	47%	59%	81%
	Blasting	23%	30%	56%	23%	30%	56%	23%	30%	56%
	Ventilation	75%	82%	93%	75%	82%	93%	75%	83%	92%
	Dewatering (pumps)	75%	83%	88%	75%	83%	88%			
MATERIALS HANDLING	Digging	63%	75%	84%	30%	45%	63%	53%	66%	78%
	Diesel equipment	30%	45%	63%	30%	45%	63%	30%	45%	63%
	Electric equipment									
	Conveyor (motor)	85%	95%	98%	85%	95%	98%	85%	95%	98%
	Load Haul Dump							85%	95%	98%
	Pumps	75%	83%	88%	75%	83%	88%			
BENEFICIATION AND PROCESSING	Comminution									
	Crushing	50%	80%	92%	50%	80%	92%	50%	80%	92%
	Grinding	1%	1%	3%	1%			1%		
	Separations									
	Centrifuge							27%	41%	86%
	Flotation	64%	79%	86%	64%	79%	87%	64%	79%	86%

[1] Average efficiency by U.S. mines for performing a given process in 2007
[2] Efficiency by U.S. site mines with above energy efficiency in 2007
[3] Efficiency that would be achieved after R&D achieves substantial improvements in the energy efficiency of mining processes



CHAPTER 3

Energy Efficiency Specifications **for Selected Mining Categories**

3.1 TECHNICAL SPECIFICATIONS OF A SOLAR PV PLANT

3.1.1 INTRODUCTION

The typical project development process for a solar PV plant is shown in Figure 4. The proposed procurement philosophy by CSIR, is to provide only minimum technical specifications of the solar PV plant in the Request for Proposal (RFP), and instead put in place performance guarantees with the EPC contractor to ensure that the system design and performance is satisfactory. The EPC contractor is then tied to an initial 3-year performance and O&M contract, with financial penalties for underperformance based on the Performance Ratio (PR) agreed upon. The designing of the solar plant, including modules, trackers (if any), mounting structure, balance of system and inverters is left to the EPC contractor. The team evaluating the bids, therefore must be able to assess the technical plausibility of the overall design. If this capability is not available in-house, then expert opinion should be sought in the bid evaluation process.

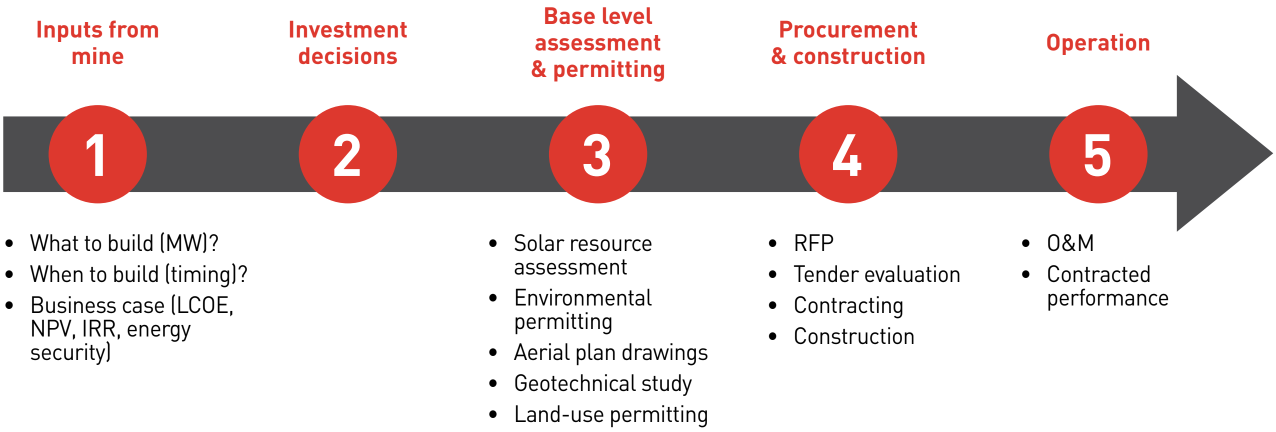


Figure 4: Steps involved in a solar PV plant procurement

This section provides a description of the proposed minimum technical specifications for a solar PV plant in order to ensure robust operation and achieve the expected energy yields over the plant lifetime. These specifications have been developed by the CSIR Energy Centre in partnership with the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), for a solar PV procurement guideline for municipalities that is under development. Permission to share these recommended technical specifications has been kindly granted by the GIZ.

3.1.2 PHOTOVOLTAIC MODULES

It is recommended to not specify the type and number of modules to be utilised, and instead leave these design decisions to the EPC contractor based on a minimum specified installed DC capacity. All plant equipment should comply with the minimum local content regulations of the Department of Trade, Industry and Competition.

A. International Standards - IEC 61215 and IEC 61730

Detailed specification sheets and certificates of compliance to these standards are to be provided as part of project documentation. In addition, all the modules should be PID free certified and have positive output tolerance.

Recommendations:

1. In order ensure the quality of modules utilised, it is recommended that a comprehensive IV flash test report for each PV module procured shall be provided at least two (2) weeks prior to the commencement of construction works.
2. Modules should carry a minimum defect warranty of 10 years and a linear 25 or 30 year performance guarantee of 80%. The warranties offered by the module manufacturer should be fully transferable to the mine and other terms and conditions clearly defined.
3. The sales agreement with the module manufacturer shall clearly define the claiming procedure of defective modules, the required additional specific independent party involvement and any other conditions that might influence the honouring of the warranties and guarantees.
4. The PV module installation manual must be provided as part of the as-built documentation. The manual shall contain all the necessary requirements and specifications for proper module installations according to the manufacturer.

3.1.3 PV MOUNTING STRUCTURE – GROUND MOUNTED (FIXED TILT AND TRACKING)

A. International Standards - IEC 62727 (trackers)

B. Local Standards - SANS 1200 (civils works).

Recommendations:

1. The mounting structure should have a minimum 10 year warranty but shall be designed for a minimum lifetime of 25 years. Special attention should be paid to warranty conditions against corrosion. Corrosion prevention must consider site and soil specific parameters.
2. The mounting of modules onto the mounting structure shall be in accordance with the requirements of the module manufacturer as described in the instruction manual. If not, a written approval from the module manufacturer shall be provided by the EPC.
3. If modules are clamped onto the mounting structure, at least 4 clamping points should be used. The minimal torque for screwing the modules as stated in the instruction manual shall be respected.
4. If the ground does not support driven posts, the anchoring types such as helical piles and ground screws may be used. The system should be designed to be adjustable for any sort of differences in land contours. The ground mounted systems need not always penetrate into the earth. Arrays can be ballasted on the ground just as they are on flat roofs.
5. The EPC contractor shall determine a minimum inclination angle of the modules in order to assure the self-cleaning effect by the rain. The sheds are to be designed so that the shadow angle is to stay below winter solstice.
6. The trackers may be of any type, and designed in accordance with IEC 62727 and should have been used in commercial projects demonstrating availability of at least 98% during 1 year of operation.
7. The trackers shall feature at least one inclination sensor per actuator and the bearing mechanism shall be accessible and serviceable.
8. Civils works shall be in accordance with SANS 1200.

3.1.4 INVERTERS - TECHNICAL REQUIREMENTS

The selection of inverters shall be based on the design and functional requirements, including the integration requirements of the PV system and the compatibility to the selected PV modules for the installations. Central or string inverters should be used in the project.

A. International Standards - IEC 62109 and IEC 62116

These standards specify the minimum safety requirements and anti-islanding protection required by the inverters.

B. Local Standards - NRS 097-2-1:2017, amendment July 2020.

The inverters must adhere to the South African grid code.

Recommendations:

1. The inverter supplier must approve the stringing chosen for the project.
2. Inverters should include at least one MPP tracker, a display showing the faults and the performances, an advanced system to allow power control and efficiency (maximum efficiency must be at least 97%, excluding transformer), remote monitoring and control capabilities, isolation fault detection, anti-islanding protection feature, ability to start and stop function automatically, variable power factor setting, and an external DC switch.
3. IP protection class of at least 54 is required for outdoor mounting and 21 is required for indoor mounting of the inverters.
4. The ratio of the input DC power to output AC power may not exceed 120% at STC
5. The MPP voltages of the strings must lie in the MPP voltage range of the inverter for temperatures between 0-70°C. The maximum inverter input voltage shall also not exceed at -10°C.
6. Inverters shall have a minimum warranty of 10 years. The contract sales agreement with the inverter manufacturer shall clearly define the claiming procedure of defect inverters or parts. The warranties offered by the inverter manufacturer shall be transferable to the mine. Other terms and conditions for warranties transferability must be clearly defined.

3.1.5 BALANCE OF PLANT - PROTECTION AND CONTROL DEVICES

A. International Standards - IEC 60947 and IEC 62271

B. Local Standards - SANS 60947 and SANS 62271

Recommendations:

1. The degree of protection must comply with the applicable standards associated with PV and electrical works in general.
2. Over-current and over-voltage protection devices are required on the DC and AC sides. All switchgears used in any of the switchboards must comply with SANS (IEC) 60947 and SANS (IEC) 62271. The protection and control design and methodology should be proposed by EPC contractor during the tender bidding stage and the mine should review its adequacy.
3. The design shall include any necessary disconnect switches to ensure anti-islanding requirements are met for the jurisdiction having authority.

3.1.6 BALANCE OF PLANT - LIGHTNING PROTECTION AND EARTHING

A. **International Standards** - IEC 62305

B. **Local Standards** - SANS 10313

Recommendations:

1. The EPC contractor must conduct a risk mitigation study of lightning damage in accordance to SANS 10313 and IEC 62305 and implement sufficient Lightning Protection System (LPS).
2. Earthing shall comply with SANS 10142 Parts 1 (LV) and 2 (MV), SANS 10292 and SANS 10199.
3. A neutral earthing design is recommended. All structures, enclosures, PV modules and cabinets shall be earthed appropriately.

3.1.7 BALANCE OF PLANT –AC AND DC CABLING

A. **International Standards** - IEC 60502, TÜV 2 Pfg 1169 or any other equivalent standards, CEI 20-40, CEI 20-67, CEI 64-8 and CEI 82-25.

B. **Local Standards** - SANS 1339, SANS 1507, SANS 1507 SANS 97.

Recommendations:

General

1. All cables shall be installed in accordance with manufacturer's specifications and shall meet all the design aspects considered during cable sizing calculations.
2. The combined cable DC and AC losses should not exceed 3%.
3. DC cables must comply with SANS 1507 / TÜV 2 Pfg 1169 or any other equivalent standards.
4. AC cable construction shall be according to SANS 97 or 1339, SANS 1507 and IEC 60502.
5. Cables should be installed in conduits and hooded cable trays. The cable return path should follow the same way to avoid induction loops.
6. DC cables should be dimensioned according to CEI 20-40 and CEI 20-67. Norm CEI 64-8 must be followed to prevent short-circuit-induced current. Norm CEI 82-25 must be followed for arrangement of cables and cables trays.

3.1.8 BALANCE OF PLANT - METEOROLOGICAL STATION AND MONITORING

A. **International Standards** - IEC 61724.

B. **Local Standards-** SANS 474/NRS 057.

Recommendations:

1. Installation of a meteorological station, including: horizontal secondary-standard pyranometer, secondary-standard pyranometer in plane, ambient temperature sensor, module temperature sensor, anemometer, rain gauge, soiling sensor, pressure (optional) and humidity (optional).

2. All instruments should be supplied with valid calibration certificates and should be re-calibrated (or replaced with calibrated units every two years) for the duration of the O&M period.
3. The monitoring system should be designed in accordance to IEC 61724. A logging tariff meter should be installed at the delivery point compliant with SANS 474/NRS 057.
4. The monitoring system should be designed and implemented in such a way to have a lifetime of 25 years. The monitoring system is expected to continuously measure and record meteorological data, electrical parameters and status of the PV plant components. Updated conglomerated data is to be available online at least every 15 minutes.

3.2 ENERGY EFFICIENCY FOR BELT CONVEYOR SYSTEMS

3.2.1 INTRODUCTION

This section illustrates the design of energy efficiency (EE) specifications for belt conveyor systems to showcase the applicability and pertinence of this practice to energy-consuming mining equipment. These EE specifications aim to provide guidance on new conveyor belt system design and EE improvements on an existing conveyor belt system.

The feasibility of using energy efficiency technologies

Energy Saving Idlers, Direct Torque Control (DTC)-based Variable Speed Drives (VSDs), efficient belts or optimal component design such as wider diameter idlers, wider belt width, etc. shall be evaluated in relation to the investment cost incurred to achieve energy savings and resulting cost savings. An easy and quick decision-making indicator is the payback period.

The EE specifications of conveyor belt systems are provided in terms of the technology, equipment, operation, and performance (POET) framework. They are classified, when possible, in groups of world's best practices, international and national standards, and the industry averages. The current working conditions, energy consumption patterns and type of conveyor belt systems used at the mines need to be identified to calculate the industry averages of some specifications. The relative information of involved belt conveyor systems is composed by incorporating best practice, national, international EE standards and specifications that ensures both safe and efficient operation.

3.2.2 CONVEYOR BELT SYSTEM TECHNOLOGY

3.2.2.1 Conveyor belt optimal profile

A. International Standard-CEMA

1. Horizontal path when space permits and there is no need for material lifting.
2. Horizontal and ascending path:
    a. When space permits, a concave vertical curve and the belt strength (tensions) permits one belt.
    b. When space does not permit, a vertical curve, but the belt strength permits one belt.
    c. When space does not permit, a vertical curve and the belt strength requires two belts.

3. Ascending and horizontal path:
    a. When space permits, a convex vertical curve and the belt strength permits one belt.
    b. When space does not permit, a vertical curve and the belt strength requires two belts.
4. Horizontal and descending path, when space permits, a concave vertical curve and the belt strength (tensions) permits one belt.
5. Descending and horizontal path, when space permits, a convex vertical curve and the belt strength permits one belt.
6. Compound path with declines, horizontal portions, vertical curves, and inclines: for long and overland conveyor when the space permits vertical curves (concave and convex curves) and the belt strength permits one belt.

Recommendations

International Standard (CEMA) shall be used due to availability by checking space limitation and the belt strength practicability.

3.2.2.2 Energy-efficient electrical motor drive

B. International Standard-IEC 60034-30-1

1. For low voltage AC-squirrel cage induction motors with rated voltage between 50 and 1000V, rated power output between 0.12 and 1000kW and rated frequency at 50Hz:
    a. High efficiency motors-IE2: 59.1% (0.12kW) to 95.1% (1000kW).
    b. Premium efficiency motors-IE3: 64.8% (0.12kW) to 96.0% (1000kW).
    c. Super-premium efficiency motors-IE4: 69.8% (0.12kW) to 96.7% (1000kW).
2. For medium and high voltage AC electrical motors (Voltage →1kV): N/A

C. National Standard-SANS 60034-30-1 [12] same as IEC 60034-30-1.

D. Industry Standard: N/A

Recommendations

1. For low voltage AC electrical motors (Nominal voltage ↖1000V and Motor power rating ↖1000kW), National Standard shall be used for high energy efficiency and complies with Local Standard by using premium efficiency motors-IE3.
2. The use of Super-premium efficiency squirrel cage induction motor-IE4 shall be evaluated in terms of investment cost and energy saving (or payback period) opportunity.
3. For medium and high voltage AC motors (nominal voltage →1000V) and power rating →1000kW, standard efficiency AC squirrel cage induction motors shall be used as their efficiency is already high, ranging between 95 to 98%.

3.2.2.3 Energy-efficient belt

A. Best available practice

1. Belt bottom cover: Aromatic polyamide (Aramid) additive and ingredients such as Sulfron are added to the rubber compound in order to improve the visco-elasticity property of the belt by increasing the elasticity of the rubber. This will reduce the overall flexure resistance of the conveyors since the more elastic the rubber behaves, the lower the indentation rolling resistance.
2. Belt carcass: Aromatic polyamide (Aramid)-based carcass such as Twaron is used. This will lead to a lower weight belt with very high strength, high elongation, and excellent high-temperature properties. The reduced weight of the belt will improve the conveyor energy efficiency by decreasing the overall rolling resistance.
3. Up to 40% and 60% energy savings in full-load and non-load conditions, respectively, can be achieved when compared to the standard belt

B. International Standard-CEMA

1. Belt covers: Ethylene propylene-based polymer (EPDM) rubber.
2. Belt carcasses (fibre reinforcement): Aromatic polyamide (aramid).

Recommendations

1. For surface conveyor belt systems, best available practice shall be used for high energy efficiency.
2. For underground conveyor belt systems, best available practice shall be used only with SABS approval.

3.2.2.4 Energy-efficient electrical drive controller

A. Best available practice

DTC (Direct torque control)-based VSD (variable speed drive) with flux optimization for load matching. The use of DTC drive with flux optimization leads to an increased energy saving as well as more accurate speed and torque control across a wider speed range compared to the standard AC drives (VSDs).

B. International Standard-CEMA

VSD based on PWM (Pulse width modulation) for load matching.

C. Industry Standard: N/A

Recommendations

1. For surface applications with dynamic loads (loads with high and frequent variations), best available practice shall be used for high energy efficiency.
2. For underground applications, DTC-based VSD shall be used with mine approval due to dirty environment.

3.2.3 CONVEYOR BELT SYSTEM SPECIFICATIONS AND MAINTENANCE

3.2.3.1 Belt speed

A. Best available practice: up to 8m/s.

B. International Standard-CEMA: 0.254 – 5.08m/s.

C. Mining Standard: N/A.

Recommendations

1. For a given conveyor capacity, International Standard shall be used by choosing an optimal reduced speed combined with an optimal wide belt width provided that the optimal choice of these two parameters (reduced belt speed and wide belt width) is cost effective. Conveyor capacity obtained as result of reduced belt speed and wide belt width leads to energy consumption reduction.
2. For a given conveyor capacity, a cost-effective choice of reduced belt speed and wide belt width corresponds to the minimum point of the difference between the belt width investment cost and yielded energy cost saving for the given belt lifetime. A quick and simple indicator for the cost effectiveness of the choice of the belt speed and belt width is the payback period.

3.2.3.2 Belt width

A. Best available practice: 500-3200mm

B. International Standard:

1. 450-2400mm-CEMA,
2. Up to 2400mm-DIN 22101:2002

C. Industry Standard: N/A

Recommendations

1. For a given conveyor capacity, best available practice shall be used by choosing an optimal wide belt width combined with an optimal reduced belt speed provided that the optimal choice of these two parameters (wide belt width and reduced belt speed) is cost effective. Conveyor capacity obtained as a result of wide belt width and reduced belt speed leads to energy consumption reduction.
2. or a given conveyor capacity, a cost-effective choice of wide belt width and reduced belt width corresponds to the minimum point of the difference between the belt width investment cost and yielded energy cost saving for the given belt lifetime. A quick and simple indicator for the cost effectiveness of the choice of the belt width and belt speed is the payback period.

3.2.3.3 Carrying idler diameter

A. Best available practice: up to 219mm.

B. International Standard-CEMA: 101.6-177.8mm.

C. Industry Standard: N/A.

Recommendations

Best available practice shall be used to reduce the total rolling resistance. The bigger the carrying idler diameter the lower the indentation rolling resistance, hence the higher the energy consumption reduction. Particular attention should, however, be given to the gradual increase of the running resistance of carrying idlers with the diameters and the belt width.

3.2.3.4 Carrying idler troughing angle

A. Best available practice: ↗35°.

B. International Standard-CEMA: 20°, 35° and 45°.

C. Industry Standard: N/A.

Recommendations

Best available practice shall be used for high energy efficiency by using carrying idler troughing angle not less than 35° provided spillage does not occur.

3.2.4 CONVEYOR BELT SYSTEM OPERATION

3.2.4.1 Allowable operating region

A. Best available practice

1. Belt conveyor should be designed to operate at approximately 90 - 100% of the nameplate (full) capacity. This means that the conveyor load factor or filling degree ↗90%.
2. Electrical motor should be designed to operate at least 75% of the nameplate power rating. This means the motor load factor ↗75%.
3. For multiple-drive: The load sharing/proportioning/distribution should be optimised in such a way to avoid overload of one motor, e.g., equal percentage power output by each motor.

B. Industry Standard: N/A

Recommendations

Best available practice shall be used for high energy efficiency and safe operation (for multi-drive conveyor belts) by maintaining:

1. Conveyor load factor of 90%, leaving a clearance of 10% to avoid material spillages.
2. Conveyor load factor of 65% for conveyor belt trippers (to avoid material spillages):
    a. Without swivelled training troughing idlers near the head pulley of the tripper carriage.
    b. Without self-aligning idlers at tripper end portion.
    c. With an old tripper belt carcass on the carry side.
3. Conveyor load factor of 90% when conveyor belt trippers are provided with self-aligning idlers at tripper end portion, with swivelled training troughing idlers near the head puller of the tripper carriage and with tripper belt carcass in good conditions.
4. Motor load factor of not less than 75%.
5. Equal load sharing for multi-drive conveyors.

3.2.4.2 Skills level

A. **International Standard-CEMA:** Well-trained personnel.

Recommendations

International Standard to maintain good high-level operation efficiency.

In this section, information on supercapacitor systems is provided in terms of the POET framework. Since there are no clear rules and information in South Africa for what can be called supercapacitor, in this section we used the International standards to determine what can be the best available technologies and practices.

3.3 ENERGY EFFICIENCY SPECIFICATIONS FOR SUPERCAPACITORS

3.3.1 SUPERCAPACITOR TECHNOLOGY

Supercapacitor (SC) technology can be classified into two, namely; electrical double-layer capacitors (EDLCs) and faradaic capacitors based on their mode of energy storage and the materials used for their fabrication. The EDLCs mainly focus on the use of different allotropes of carbon materials as electrodes, while faradaic capacitor materials include metal oxide and hydroxide conductive polymers and functionalised carbon that have the electrochemical signature of a capacitive electrode.

To ascertain what type of technology is used in each system, Material Safety Data Sheet (MSDS) certification of the system will be the best available starting point. In EDLC technology, activated carbon or some allotropes of carbon materials should be in the electrode material section of the system. The presence of any battery material such as Lithium, Cobalt, and Titanium in MSDS certification, can be a sign of it being a battery system rather than a SC.

Recommendations

The best SC technology in plant and mining is possibly EDLC if one does a search for safety and long cycle life. Alternatively, faradaic capacitor or hybrid electrochemical capacitor (HEC) can be a good option for a high energy application with a lower cycle life.

3.3.2 SUPERCAPACITOR EQUIPMENT SPECIFICATIONS

Supercapacitors create a new standard of energy-use optimisation. They are suitable for applications ranging from wind turbines and mass transit, to hybrid cars, consumer electronics and industrial equipment. Available in a wide range of sizes, capacitance and modular configurations, Supercapacitors can cost-effectively supplement and extend battery life, or in some cases, replace batteries altogether. The best source of the information for the specification of each SC system can be found in the product datasheet. These datasheets typically contain the following information:

- Capacity: Murata's SCs have high capacitance values ranging from several hundreds of millifarads to hundreds of farads. Normally the reported capacitance measure at 25°C.
- Voltage: For a single cell of SCs, voltages can be from 1.2 V to 5.5 V. They can discharge to 0 V and chargeback again to the full voltage.

- Energy and power of SC: SCs typically have higher energy density than other capacitors and higher power density than various batteries. The specific energy of the SC ranges from 1Wh/kg to 30Wh/kg, 10–50 times less than Li-ion battery. Before typical application of SC operated below 10 V at power levels below 1W. Current SC applications operate at voltages approaching 1000 V at power levels above 100 kW.
- Dimension: You can find the SC in different sizes for a different types of applications
- Cost: The cost per Wh of SC is more than 20 times higher than that of Li-ion batteries. However, the cost can be reduced through new technologies and mass production of supercapacitor batteries.

Table 4: Some system specifications for a supercapacitor cell from different companies

COMPANY	MAXWELL	VINATECH	NIPPON CHEMI-CON	YUNASKO	CAP-XX	SKELETONTEC	YEONG LONG ELECTRONICS
Capacity (F)	1 - 3400	1 - 800	50 - 1400	400 - 3000	0.17 - 3000	Up to 3200	0.5 - 400
Voltage (V)	2.3 - 3	2.3 - 3	2.5	2.7	2.5 – 2.75	2.85	2.7
Specific Energy (Wh/kg)	Up to 8.57	Up to 12	Up to 4.3	Up to 6.2	-	5.1 - 6.8	Up to 5.4
Specific power (W/kg)	Up to 18	Up to 3	-	Up to 41	- (5.5KW)	21 - 80	-
Mass (g)	1.1 - 520	1.1 - 96	18 - 810	85 - 490	Up to 551	Up to 530	Up to 75
Operating temperature	-40~85°C	-40~85°C	-40~85°C	-40~65°C	-40~85°C	-40~65°C	-40~65°C
Service life	Up to 1,000,000 duty cycles or 10-year DC life	Up to 500,000 cycle life	-	Up to 1,000,000 cycle life	-	Up to 1,000,000 cycle life	500,000 cycles life

Recommendations

Best available practice shall be used subject to the power, capacity, and life cycle that is needed in the plant and mining area.

3.3.3 SUPERCAPACITOR OPERATION

Supercapacitors show a linear shape during charge-discharge and they can reach 0 voltage without losing any capacity - the voltage will not be regained thereafter. However, by adding faradic material to the system, the energy density of SCs improve. Therefore, the moment that the charge-discharge shape of the system deviates from a straight line, we should call it a hybrid electrochemical capacitor (HEC). The naming of the system is important because, supercapacitors and HECs have both similar and different properties, therefore they must be designated properly. Compared to SCs, HECs cycle life is shorter and the system is unsusceptible to reaching zero voltage (Although they can reach zero voltage, but it has a negative impact on their cycle life). See Figure 5 below.

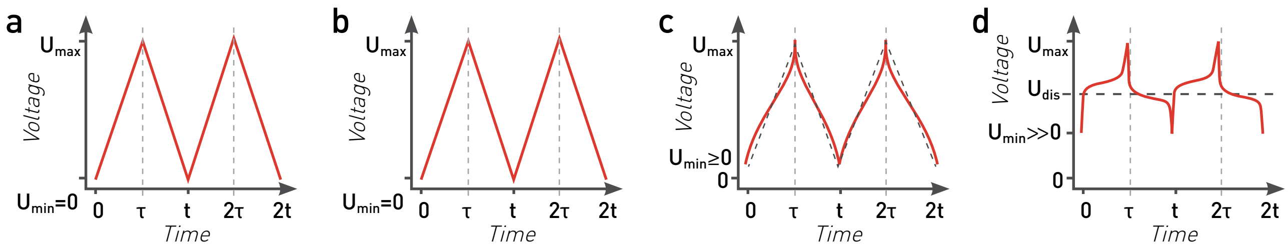


Figure 5: Charge-discharge shape of (a) EDLC, (b) PC, (c) HEC and (d) Battery

For most applications, a single cell at low voltage is not very useful and multiple cells are required to be placed in series. Since there is a tolerance difference between manufactured cells in capacitance, resistance and leakage current there will be an imbalance in the cell voltages of a series stack. It is important to ensure that the individual voltages of any single cell do not exceed its maximum recommended working voltage as this could result in electrolyte decomposition, gas generation, ESR increase and ultimately reduced life. This can be done with cell balancing.

Sizing SCs for your application is another important part in the operation part. In order to size the appropriate SC system for any application, it will need to determine the system variables needed. Using this information, we can calculate the appropriate size and number of cells needed. In order to obtain a complete solution, the following parameters will need to be defined:

- Maximum Charged Voltage (Vmax), if different from Working Voltage then also (Vw)
- Minimum Voltage (Vmin)
- Required Power (W) or Current (I)
- Duration of Discharge (td)
- Duty Cycle
- Required Life
- Average Operating Temperature

The last three parameters are used to determine the life degradation factor to use.

Finally, mostly SCs rating for -40°C to 60°C operating temperature (sometimes up to 85°C with voltage derating). However, the capacitance reduces at a lower temperature (operating at low-temperature extremes will increase the internal resistance of the cell). The capacitance at -40°C will likely lose some part of its capacitance compared to the value at 25°C.

Recommendations

SCs have unique charge-discharge behaviour compared to batteries that should be considered for any plan of usage. They SC system should have potential to reach to 0 voltage without losing any efficiency. The suitable SC unit with right sizing and cell balancing shall be considered for high power application to improve power quality and reduce operational maintenance.

3.3.4 SUPERCAPACITOR PERFORMANCE

The best source of the information for the performance of SC system can be found in the product datasheet. These datasheets typically contain the following information:

- Cycle life: SC can be cycled at a 1000 C rate to 100% depth-of discharge more than one million times and have a virtually unlimited cycle life.
- Response time: The Charge/Discharge respose time of SC can be between 0.1 to 30 s.
- Self-discharging: SCs tend to have significantly high self-discharge rates. The self-discharge rate is related to the material, voltage and the capacity of the device.
- Efficiency: Efficiency can be evaluated as two different figures. The first would be leakage current/self-discharge when the float is charged. This varies by product and depends on the balancing scheme, specifically for modules. The other would be through cycling defined as round trip efficiency. The typical round-trip efficiency is greater than 98%.
- Heat: While batteries are known to explode due to excessive heating when short-circuited, SC does not heat as much due to their low internal resistance. Shorting a fully charged supercapacitor will cause a quick release of the stored energy which can cause electrical arcing, and might cause damage to the device, but unlike batteries, the generated heat is not a concern.

Recommendations

SC with low round-trip efficiency (lower than 85%) cannot be useful for any mining application. Since SCs do not produce excess heat compared to the battery, they will be useful for the environment that needs to be in a stable temperature without losing any energy.

3.3.5 BEST AVAILABLE PRACTICE FOR SUPERCAPACITOR

It is appropriate to sort usage of energy storage systems into three types: DC, pulse, and bidirectional.
In a DC usage, the energy storage system delivers power and discharged by the application. The depletion rate can vary with time but stored energy continually decreases. One example of a DC energy storage system is the battery in a cellular system in the mining sector. It is periodically charged but while in use, only delivers power. Figure 6 shows a flashlight that has a DC energy storage system that uses several 100-F-size supercapacitors cells to power light emitting diodes. Advantages of using supercapacitors over batteries will be providing the ability to rapidly recharge the system with the highest amps and greatly extending the operating life of the flashlight with no maintenance. In some parts of the mining industry where chemical batteries are used and can pose risks, this type of application can be a safe and useful option.

Figure 6: Flashlight with supercapacitor

In a pulse usage, energy storage system delivers power intermittently, sometimes at very high rates. Power is delivered as a single pulse in some applications while in others power is delivered as a train of repetitive pulses. Simple example of these type of energy storage systems is the Starting-Lighting-Ignition (SLI) battery used in a conventional internal-combustion-engine automobile. Every time this battery cranks an engine, power is delivered to the starter motor in a high-power pulse. The SLI battery also serves a second function, which is to provide DC electrical power for lighting and ignition. The Rockster R1100DE rock crusher shown in Figure 7a has a hybrid power system with diesel generator and supercapacitors. The very high power peaks encountered in this application cover with a supercapacitor unit. The supercapacitors supply power to meet high frequency features in the power profile while the internal combustion engine supplies power to meet low-frequency and DC features. Fuel savings of 30% along with 43% higher rock crushing throughput have been reported in comparison to conventional models, which require a significantly larger-size engine to deliver power peak.

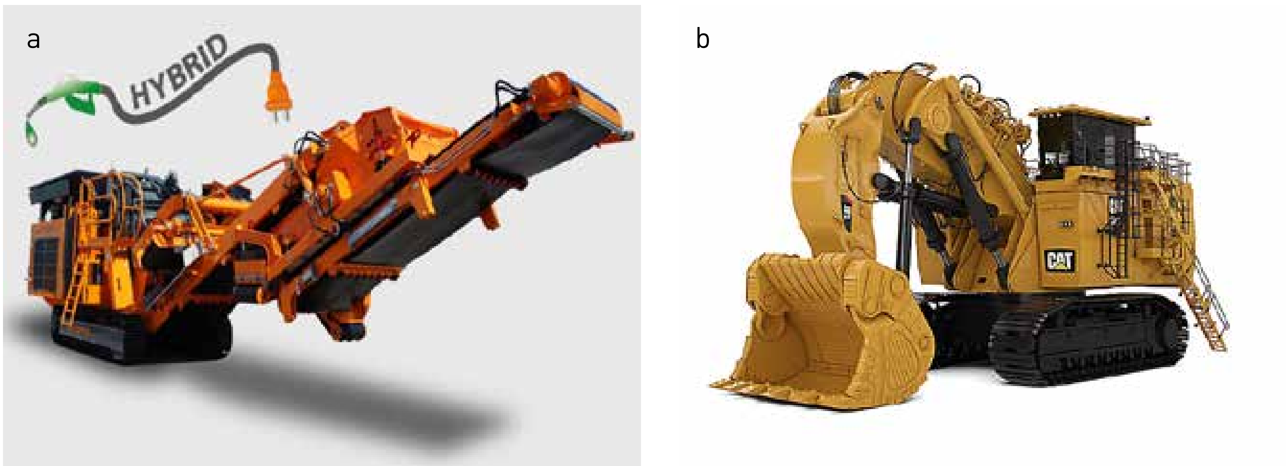
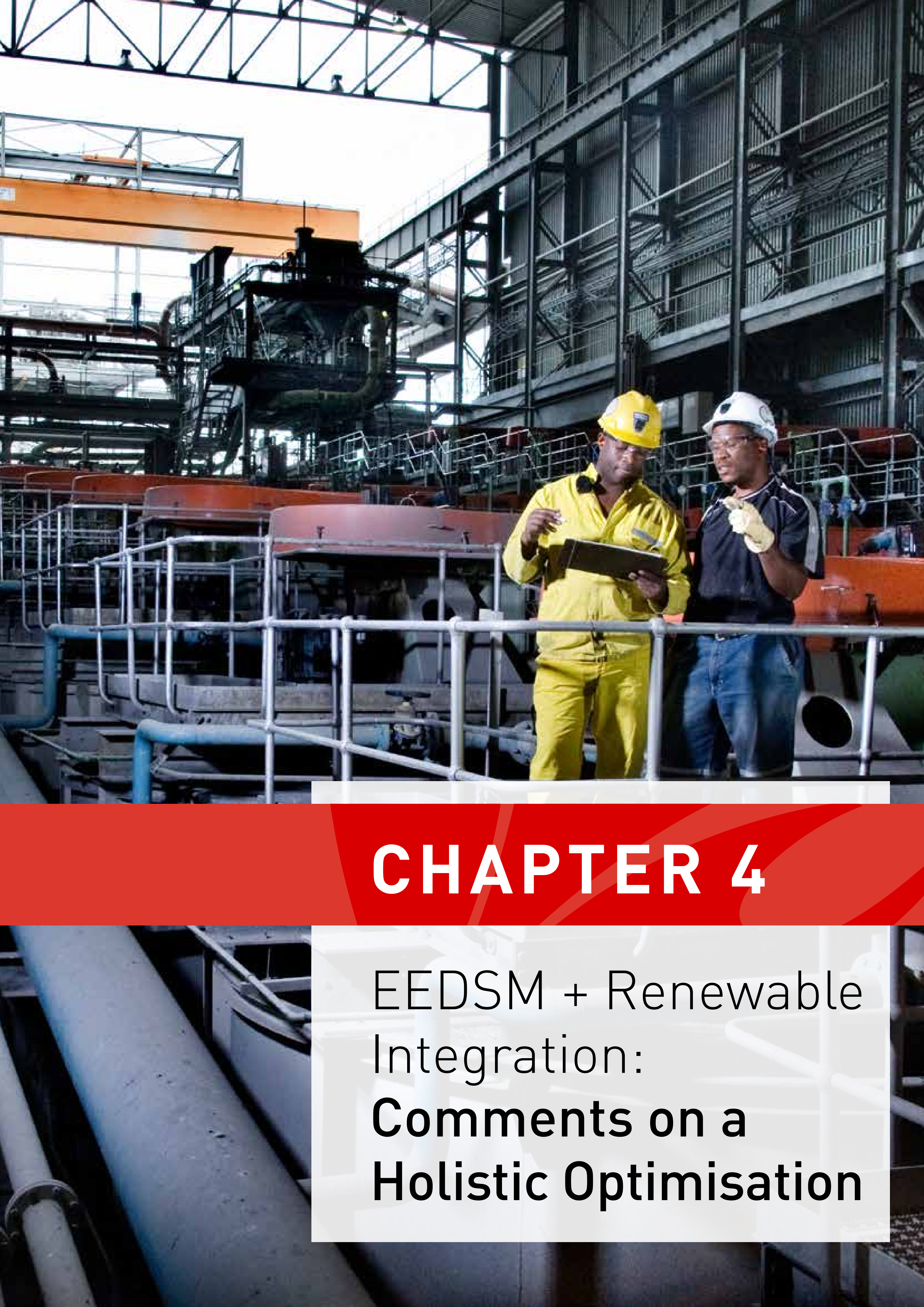


Figure 7: a) R1100DE track-mounted hybrid impact crusher and
b) Caterpillar 6120 H FS 1400-ton hybrid mining shovel

Figure 7b is a photograph of a Caterpillar 6120 H FS 1400-ton mining shovel. It is powered by a hybrid diesel-electric system that has a 48 MJ energy storage system comprised of supercapacitors. The total machine power is approximately 8000 hp, of which 3500 hp is provided by the stored energy with a supercapacitor unit. Regenerative energy storage occurs during swing deceleration and boom-down movements, reportedly leading to fuel savings of 25% over the non-hybrid version. This regenerative braking energy system is perhaps one of the largest ever implemented.



CHAPTER 4

EEDSM + Renewable Integration: **Comments on a Holistic Optimisation**

4.1 **ENERGY MODELLING AND OPTIMIZATION** FOR ALTERNATIVE ENERGY GENERATORS (RENEWABLE)

This section describes a methodology for the system integration modelling of alternative energy generators. A case study is presented for the design of a solar PV plant for onsite electricity generation. The approach that is presented addresses the POET framework through an analysis and optimisation of the performance, equipment and technologies deployed, as well as the optimal operating philosophy for the plant.

4.1.1 Introduction

The proposed methodology for conducting a techno-economic optimisation of an alternative energy generator is presented in Figure 8. The approach includes a demand assessment, generator modelling and a least cost optimisation.

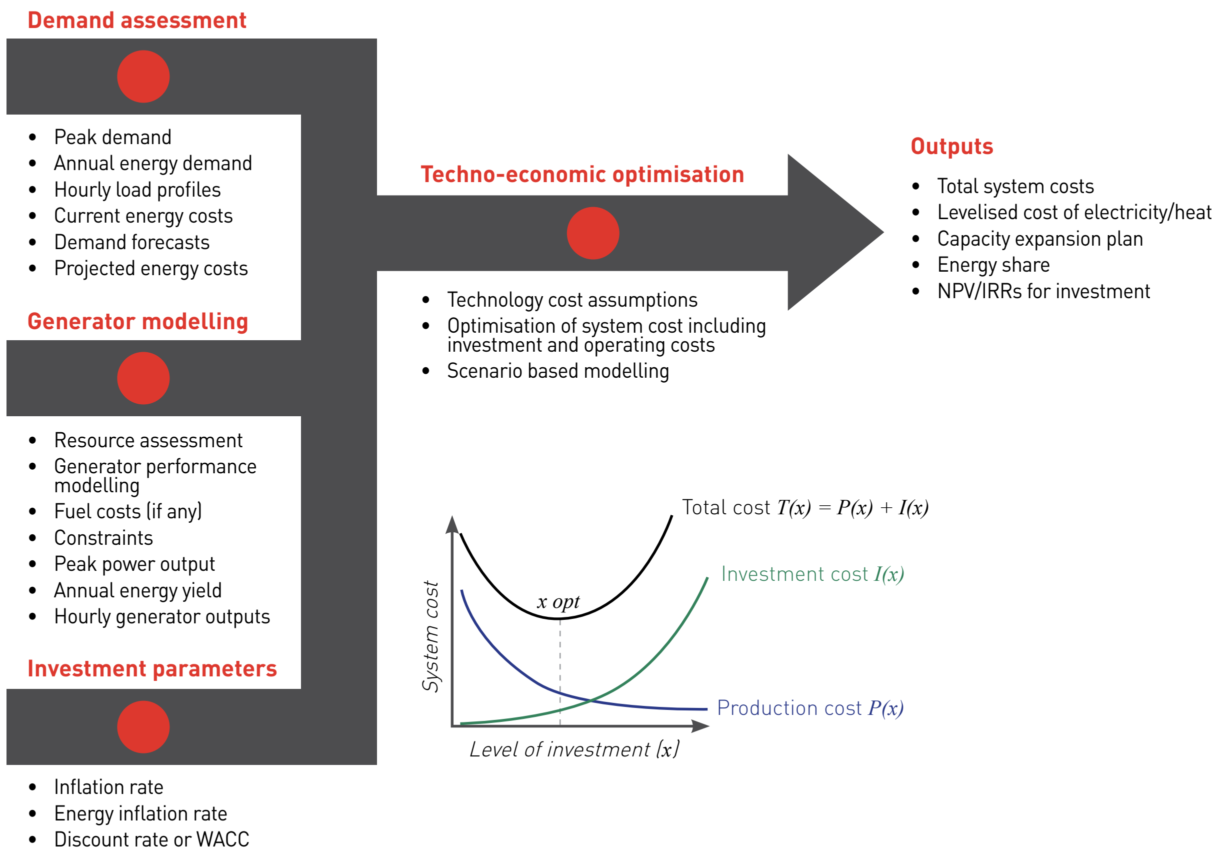


Figure 8: Techno-economic optimisation of an alternative energy generator

4.1.2 Demand assessment

A comprehensive assessment of the current status quo of energy consumption is required as an input to the techno-economic optimisation. Historical energy demand data is essential to correctly size the plant. In the case of large industrial customers such as mines, sub-hourly or hourly electricity data should be provided over a representative 1-year period. Long term trends in reducing/increasing energy demand should also be documented based on historical data over a number of years. The demand data must be combined with the energy charges and peak demand charges that are levied on the mine to establish current costs. Large industrial customers are typically on a Megaflex time of use tariff.

4.1.3 Generator modelling

The modelling of alternative generators varies depending on the technology used. Variable renewable energy technologies such as solar and wind are dependent on the instantaneous availability of the resource, whilst the output of flexible generators such as biomass and gas can be controlled. The case study presented in this work is based on a solar PV plant, but similar principles apply to wind and solar thermal systems. The input to the solar PV generator model is a Typical Meteorological Year (TMY) profile for the selected location that provides hourly data on Global Horizontal Irradiance (GHI), Direct Normal Irradiance (DNI), ambient temperature, wind speed, and humidity. There are various service providers that can provide site specific satellite data and ground measurements as part of a solar assessment (e.g. Geosun Africa). Alternatively, the European Union provides access to solar resource data, which can be downloaded in the form of a Typical Meteorological Year (TMY) from the Photovoltaic Geographical Information System (PVGIS).

A mathematical model is then used to calculate the hourly output power that is generated by a solar PV system as a function of the input TMY weather file data. The industry standard commercial software for such analysis is PVsyst, whilst the System Advisor Model provides an excellent tool that is freely available. If the desired size of the plant is known, the actual energy yield (MWh) and hourly power (MW) profiles can be produced from the model. However, in the case of a techno-economic analysis, the size of the plant is an output from the optimisation. Therefore, it is useful to normalise the output profile of the plant, as an input to the energy planning, such as in Figure 9.

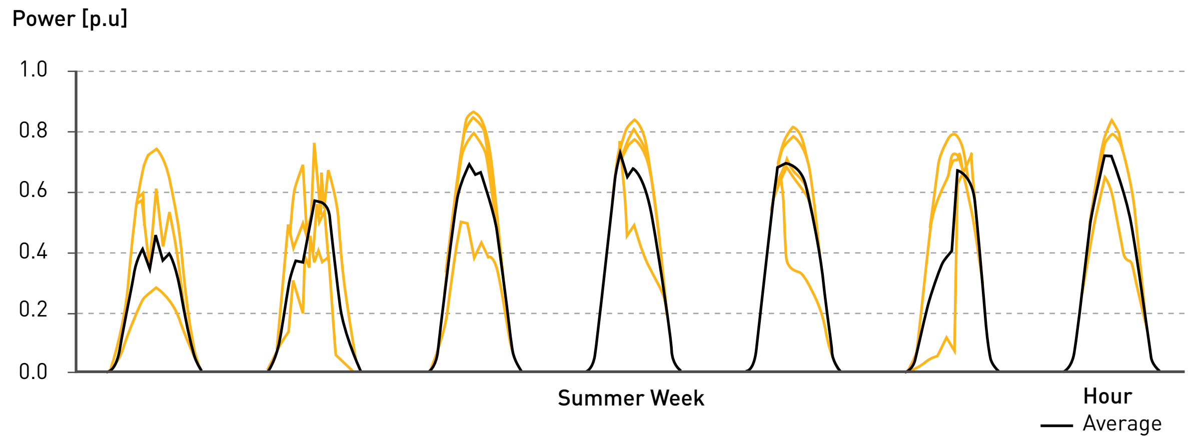


Figure 9: A typical normalized power output profile for a modelled solar PV plant

4.1.4 System sizing and cost optimisation

The objective function for minimisation in the optimisation study is the cost to meet the electricity demand. This will typically involve a combination of grid electricity and embedded generation. Costs are incurred to purchase electricity and fuel, as well as for capex and O&M of on-site generation plants.

The objective function can be written as:

$$min\Big[\sum_{y=1}^{Ny}\sum_{g=1}^{Ng}\frac{(BuildCost_g \times GenBuild_{g,y})}{(1+d)^y} + \sum_{y=1}^{Ny}\frac{(FOM_g \times P^{max}_{g,y})}{(1+d)^y}\,(Units_g + \sum_{i=1}^{y}(GenBuild \times Units_{g,i})) +$$

$$\sum_{t=1}^{Nt}\frac{L_t\,(COUE \times USE_t)}{(1+d)^y}\,(\sum_{g=1}^{Ng}(SMRC_g \times GenLoad_{g,t}))\Big], \qquad (1)$$

where d is the discount rate, FOM is the fixed O&M, $P^{max}_{g,y}$ is the maximum unit capacity, $COUE$ is the cost of unserved energy (USE), $SMRC$ is the short run marginal cost, which includes fuel and variable O&M

costs. The *BuildCost* represents the annualised generator cost, based on the overnight CAPEX and capital recovery factor. This annualised cost is constant each year and provides the same net present cost as the actual cash flow of the investment. The optimisation is subject to the following constraints:

$$\sum_{g=1}^{Ng} GenLoad_{g,y} + USE_t = Load_t \ , \tag{2}$$

$$GenLoad_{g,t} = P_{g,y}^{max} \ (Units_g + \textstyle\sum_{i=1}^{y} \ (GenBuild \times Units_{g,i} \ )), \tag{3}$$

$$\sum_{g=1}^{y} GenBuild_{g,i} = AnnualBuildLimit_{g,y} \ . \tag{4}$$

In the case of multiple generator and storage types (e.g. solar PV, wind, batteries biomass, grid electricity), the least cost optimisation is best solved using specialised software packages such as PLEXOS (high cost but very powerful) or HOMER (affordable but more limited). In the case that the required specialised modelling skills and software are not available within the mining technical team, external consultants should be contracted to assist the mine with developing an optimised energy plan for the future. The costs of a non-optimised system will quickly exceed the upfront planning costs.

4.1.5 Case Study

The following case study was developed for a representative 30 MW mining profile, which is subject to the Eskom Megaflex time of use tariff. The aim of the optimisation is to identify the least cost method of combining on-site solar PV generation and Eskom grid electricity. Understanding the sizing of a solar PV plant is important, however it is also critical to know when to make the investment. As shown in Figure 9, the projected prices of utility scale PV are decreasing in real terms, according to leading research organisations such as NREL, CSIRO and BNEF. Therefore, the timing of the capacity expansion can impact costs, especially when multiple technologies are considered. The results presented in this case study are compared to the business as usual. In the model no value was assigned to excess energy that is generated by the system, however this can of course be included in such an analysis through a feed in tariff. The load profile over a 1 week period is shown in Figure 10.

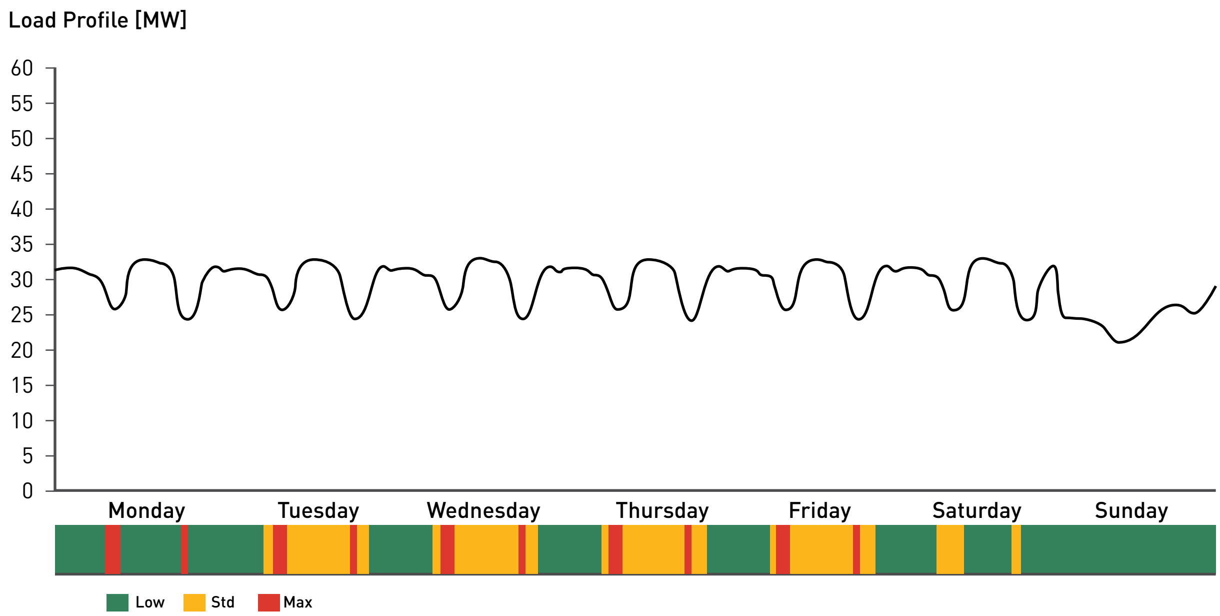


Figure 10: Mining load profile for case study, showing summer ToU tariff periods

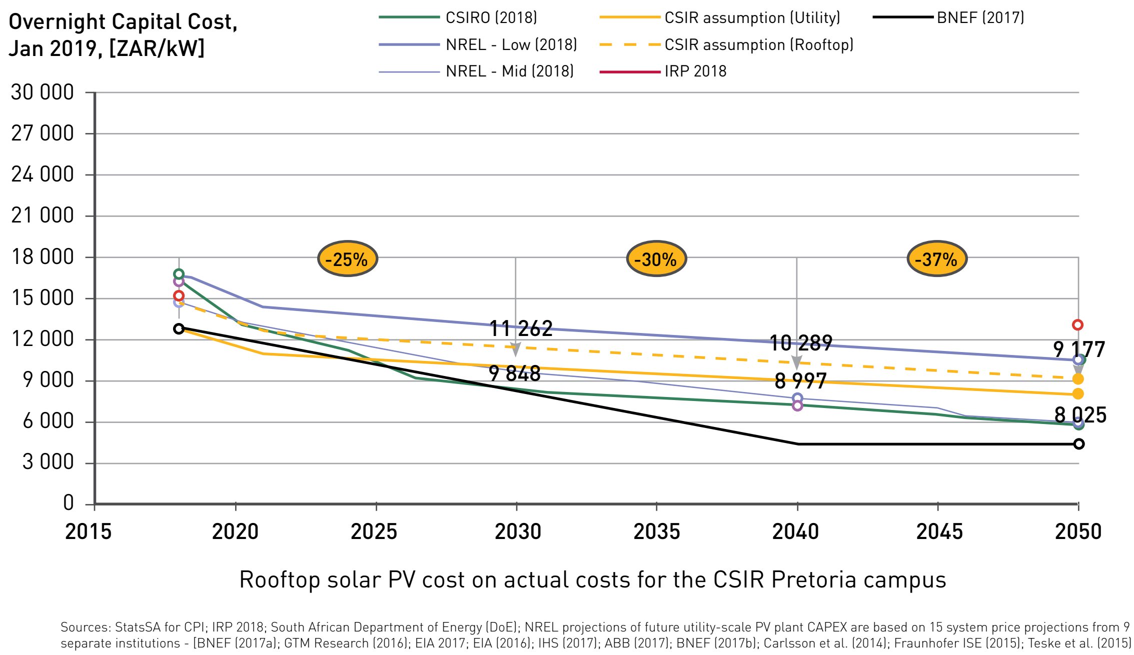


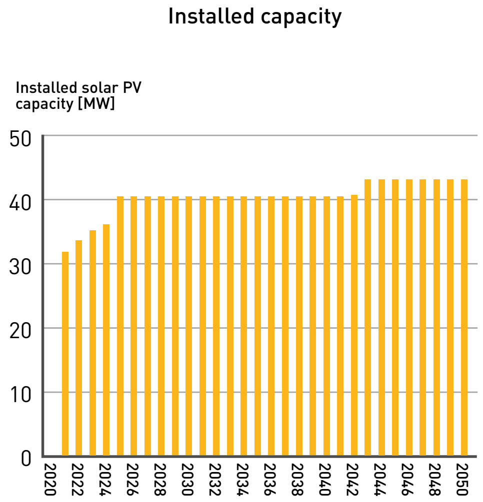
Figure 11: Projected learning curves for solar PV up to 2050

A summary of the key parameters used in the analysis are provided in Table 5. The overnight CAPEX of the system is assumed to decrease from ~R17/W in 2020 to R~12/W by 2040 in this example. The solar resource data is taken for the mining area of Carletonville, which yields an annual capacity factor for the fixed tilt solar PV system of 21.4%. It should be noted that this analysis does not include an increase in the price of electricity in real terms (above inflation), making the solution conservative.

Table 5: Inputs to techno-economic analysis

COSTS	2020 R/KW	PERFORMANCE AND ECONOMIC PARAMETERS	
Capital cost in 2020	16709	Capacity Factor (%)	21.4%
Capital cost in 2025	14949	Reference year	2020
Capital cost in 2030	13047	Real Discount rate	4%
Capital cost in 2040	11819	Weighted average cost of capital	4%
Capital cost in 2050	11404	Economic lifespan	25
Fixed O&M cost	229	Increase in grid tariff (real terms)	0%

The optimisation for the solar PV build out was done in the software PLEXOS. The results in terms of installed capacity of the solar PV plant each year and energy mix is presented in Figure 10. For the 30 MW mining profile that was utilised, the least cost provision of energy results in the construction of 40.6 MW_p of solar PV by 2025, equating to 29% of the energy mix (remaining 61% from the grid). The capacity expansion plan then remains flat up to 2043. At this point the initial solar PV plants have reached their end of lifetime, and are replaced with even cheaper solar PV.



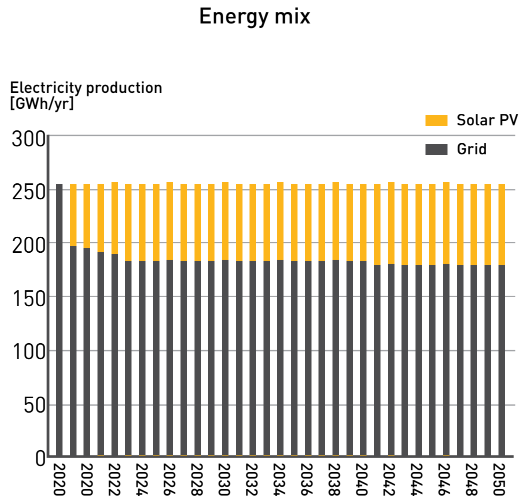


Figure 12: Results of PLEXOS optimisation for a solar PV system in terms of installed capacity and energy mix

The primary reason that only ~30% of the load is met by the solar PV system is due to the fact that no energy storage or feed in tariff was included in this specific model. As shown in Figure 12, the software has optimised the size of the PV plant to avoid significant amounts of curtailed energy, which has no economic value under the model assumptions. Using the PLEXOS software this analysis could be expanded to develop the optimal energy mix for a broad range of generation and storage technologies combined, including a feed in tariff and changes in the price of grid electricity.

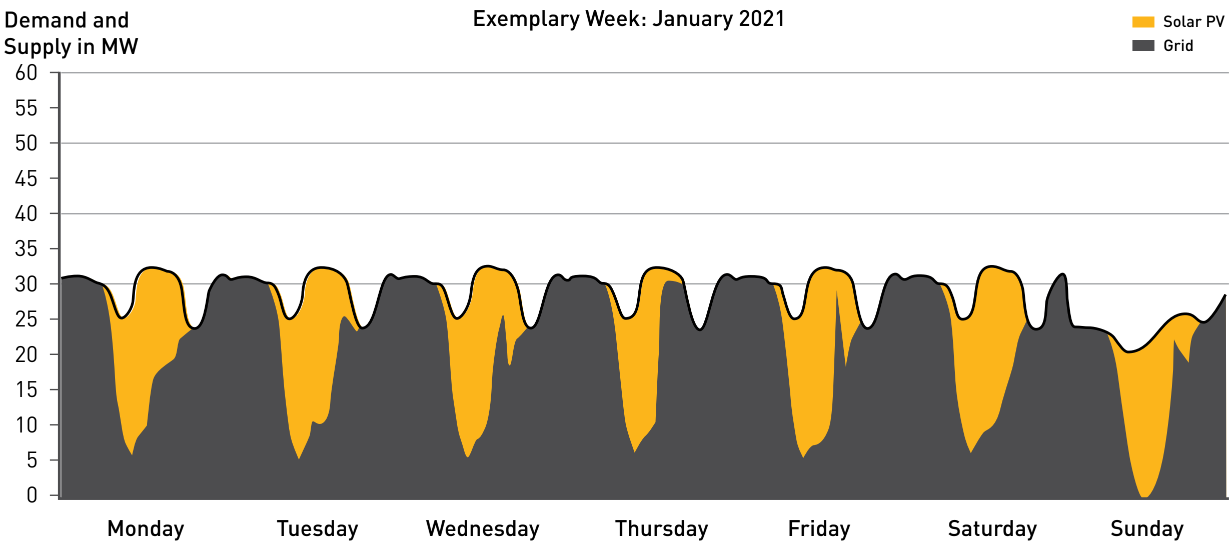


Figure 13: Typical dispatch week for the mine

The annualised and cumulative system costs are presented in Figure 13. The investment in a solar PV system results in an annual cost saving of 4.8% up to 2045. The commisioning of new solar PV capacity in ~2045 at a reduced R11/W significantly increases the annual savings to 11% compared to the business as usual. The cumulative savings over the 30 year period between 2020 and 2050 are R350m (5.6%) under the assumed parameters. Any increases in the Eskom tariff above inflation, would result in further savings and better business case.

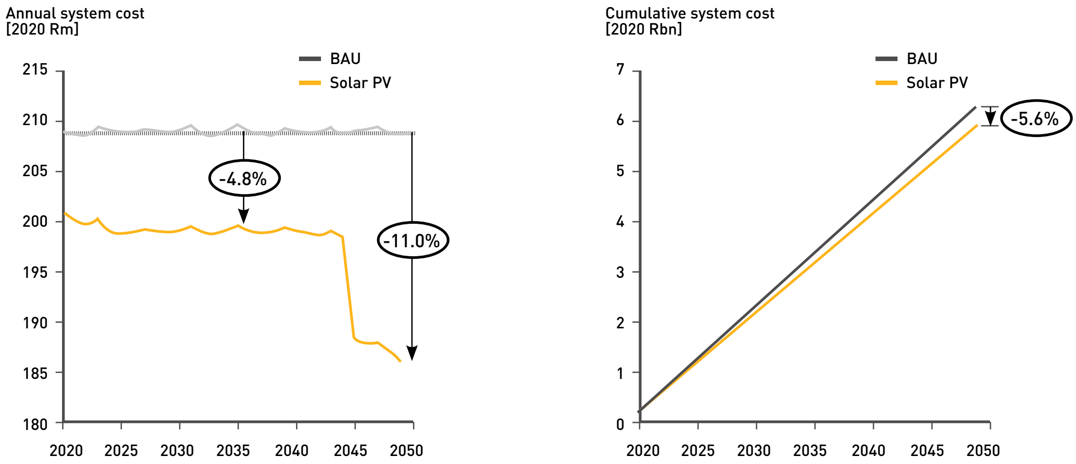


Figure 14: Comparison of business as usual and solar PV systems

This analysis shows the importance of developing an energy mix based on solar PV, combined with other generation sources such as wind/gas or energy storage, in order to meet more than 30% of the mine's load through embedded generation.

4.2 ENERGY MODELLING AND OPTIMISATION FOR DEMAND-SIDE MANAGEMENT

This section describes a methodology for cost optimisation of energy efficiency and demand-side management (EEDSM) interventions. The design of a cost-effective multi-drive belt conveyor system for horizontal and uphill bulk material handling is presented as a case study.

4.2.1 Methodology for performance optimisation of EEDSM initiatives

Figure 15 shows an ordered approach to minimising the cost of EEDSM initiatives. Details of the five steps are as follows:

- Project specifications: Collection and organisation of all the technical, environmental and economic data relevant to the process/system under investigation.
- Techno-economic modelling: Development of the energy model of the process/system and formulation of the performance index to be optimised. In the case of analytical models, the energy model and the performance index are presented in the form of mathematical equations, which are functions of the decision variables.
- Optimisation problem: Formulation of the optimisation problem from the techno-economic models developed earlier, with the performance index as the objective function, and the optimisation constraints derived from the energy model requirements.
- Optimisation process: Solving the aforementioned optimisation problem by means of an appropriate optimisation engine.
- Optimal solution: Numerical results of the best solution found by the optimiser.

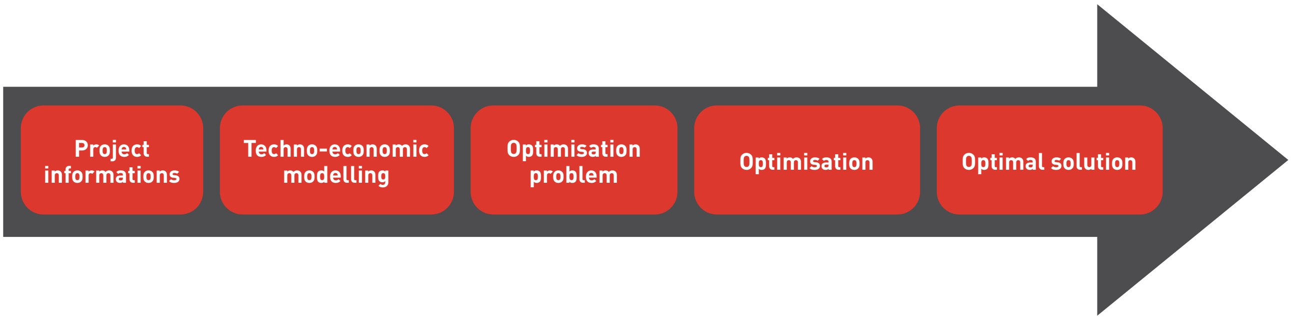


Figure 15: Performance optimisation procedure for EEDSM initiatives

4.2.2 Case study: optimal sizing of belt conveyor systems

In this section, a previous study from is presented to illustrate the application of the above methodology. The example involves the design of a belt conveyor system that achieves the lowest life cycle cost when transferring a bulk material of density equal to 1280 kg/m3 at a mass flowrate of 3500 t/h, over a distance of 2500 m with an inclination of 1 in 100.

4.2.2.1 Bulk material handling requirements

The transport specifications and material properties are summarised in Table 6.

Table 6: Conveyor operation parameters

Parameter	Symbol	Value	Unit
Transport requirements			
Material flow rate	Q	3500	t/h
Horizontal transport distance	L	2500	m
Lift height	H	25	m
Maximum belt sag	h_{rel}	1	%
Material characteristics			
Bulk density	ρ	1280	kg/m^3
Equivalent angle of slope	β	20	o
Dynamic load lump adjustment factor	L_f	1	

The basic economic parameters that apply to the conveyor project are listed in the table below

Table 7: Project economic parameters

Parameter	Symbol	Value	Unit
Income tax rate	t	28	%
Reference inflation rate	r	5.6	%
Debt capital proportion	r_d	0	%
Required return on debt capital	i_d	0	%
Required return on equity funds with 0% of inflation rate	i_e	5	%
Electricity annual escalation rate	r_e	11.2	%
Energy cost at year zero	e_{co}	0.071	USD/kWh
Operating hours per annum	t_a	3600	h
Project lifetime	Z	20	years

Techno-economic modelling

Figure 16 depicts the layout of an uphill multi-drive belt conveyor system considered in this study. It includes drive stations distributed along the carry side (equal 3 in Figure 14), and one additional drive station at the return side. A drive station has two drive pulleys, each driven by dedicated electric motors.

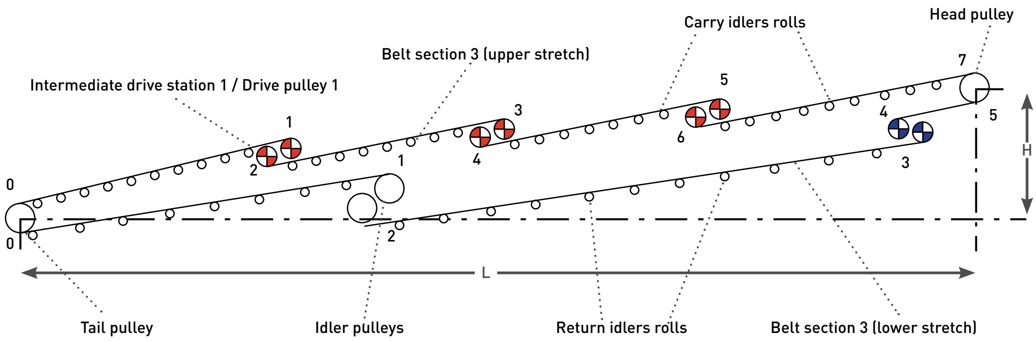


Figure 16: Multiple drive belt conveyor layout

Design constraints

Material transportation requirements

In this section, the modelling of belt conveyor systems is performed in adherence to DIN 22101 and SANS 1313.

Equations (5) and (6) ensure the transfer of the bulk material at the specified flowrate and unloading point:

$$Q = \rho A_{th} v. \tag{5}$$

$$\sum_{k=1,3,\ldots}^{N_0} L_{O,k} - \sum_{i=1}^{N} D_{tr,i} = L/\cos\delta. \tag{6}$$

Here, A_{th}, v, N_0, $L_{0,k}$, $D_{tr,i}$, N, and δ denote, respectively, the theoretical cross section of fill [m^2], belt velocity [m/s], number of belt sections in the upper stretch, length of the belt section k in the upper stretch [m], diameter of drive pulleys, number of drive stations, and inclination angle of the belt [º].

Safety and endurance requirements

Equations (7) and (8) set a minimum belt tension at the tail pulley and the slack side of intermediate drive stations so that the belt sag in the upper stretch is limited above the specified limit:

$$F_0 \geq \frac{g(\rho A_{th} + B\gamma_{belt})l_o}{8h_{rel}}, \tag{7}$$

$$F_0 + \sum_{j=1}^{k} F_{\mathrm{W,o,j}} - 2\sum_{r=1}^{m} \frac{\eta_r P_r}{v} \geq \frac{g(\rho A_{th} + B\gamma_{belt})l_o}{8h_{rel}}, \tag{8}$$

where, F_0, g, B, γ_{belt}, l_0, $F_{w,o,j}$, $\eta_r P_r$, m denote, respectively, the belt tension at each side of the tail pulley [N], gravitational acceleration [m/s^2], belt width [m], specific mass of the belt [kg/m^2], spacing between idler rolls in the upper stretch [m], overall resistance to the belt movement in the section in the upper stretch [N], efficiency of motor-gearbox pair, power output of motor [kW], $m = \frac{[k\text{-}1]}{2}$, $k = 2,4,\ldots,N_0 - 1$ with N_0 the number of belt sections in the upper stretch.

Similarly, the constraint below ensures the maximum belt sag is not exceeded along the lower stretch:

$$F_{TU} \geq \frac{B\gamma_{belt})l_u}{8h_{rel}}, \tag{9}$$

where F_{TU} and l_u denote the belt tension on both sides of the take-up device [N] and spacing between idler rolls in the lower stretch [m].

The nominal breaking strength of the belt related to belt width and the maximum belt tension must satisfy:

$$\frac{k_{t,rel} k_N}{S_0 S_1} \geq \frac{F_{T1,1}}{B} \tag{10}$$

where $k_{t,rel}$, k_N, S_0, S_1 and $F_{T1,1}$ denote, respectively, the relative reference endurance strength of the belt, the nominal breaking strength of the belt related to belt width [N/m], belt safety coefficient related to the splicing conditions, belt safety coefficient related to the expected lifetime and the operation conditions, and tight side tension of the first drive pulley in the first drive station [N].
The next condition ensures that the strength of the longitudinal tensile members in the belt core endures over the expected lifespan of the belt

$$D_{tr,i} \geq c_{Tr}\, d_{Gk}, with\ i = 1, \ldots, N + 1. \tag{11}$$

Here $D_{tr,i}$, c_{Tr} and d_{Gk} denote, respectively, the diameter of the drive pulleys in the i-th drive station [m], drive pulleys constant coefficient related to the type longitudinal tension members of the belt, and thickness of the longitudinal tension members of the belt [m].

The idler rolls in the upper stretch are also subjected to constraint to further prevent risks of premature failure,

$$S_f B_f L_f F_{s,o} \leq F_{max,o}, \tag{12}$$

$$S_f B_f L_f F_{s,u} \leq F_{max,u}, \tag{13}$$

where S_f, B_f, L_f, $F_{s,o}$, $F_{s,u}$, $F_{max,o}$ and $F_{max,u}$ and denote, respectively, the dynamic load coefficient related to belt speed, dynamic load coefficient related to bearing life, dynamic load coefficient related to lump size of the material transferred, static load on the central carry idler roll in a three-idler troughing configuration [N], static load on a flat return idler in the lower stretch [N], maximum load allowable on a central carry idler roll, and maximum load allowed on a return idler roll.

The rotation speed of each idler roll should not exceed the limit of 750 rpm:

$$\frac{60v}{\pi D_0} \geq 750, \tag{14}$$

$$\frac{60v}{\pi D_u} \geq 750, \tag{15}$$

with D_0 and D_u denote the diameters of idler roll in the upper and lower stretch, respectively.

Standardisation requirements

To take advantage of standardisation, the following constraints are introduced:

$$P_i = P_1, \tag{16}$$

$$T_i = T_1, \tag{17}$$

$$D_{tr,i} = D_{tr,1}, \tag{18}$$

$$\alpha_i = \alpha_1, \tag{19}$$

where T_i and α_i denote the rated torque of each gear reducer in the -th drive station and wrap angle of each drive pulley in the -th drive station, respectively.

Life cycle cost

The equivalent annual cost of a belt conveyor system denoted by $A_{conveyor}$ is adopted as performance indicator (cost function). The various costs incurred throughout the belt conveyor lifetime can be classified into capital and operating costs.

The operating costs of a belt conveyor include the energy cost, maintenance cost and labour cost. In the absence of analytical models that express the expenditures for maintenance and labor as functions of the design parameters of belt conveyor systems, this component of $A_{conveyor}$ is limited to the energy costs. The equivalent annual energy cost A_{energy} of a multi-drive belt conveyor with $N + 1$ drive stations, each equipped with a pair of drive pulley-gearbox-motor drive systems (see Figure 16), is given by:

$$A_{energy} = k_1 \, e_0 \, t_a \sum_{i=1}^{N+1} 2P_i / \eta_{mot,i}, \tag{20}$$

where k_1, e_0, t_a and $\eta_{mot,i}$ denote, respectively, the equivalent annual energy cost coefficient, unit cost of energy at the year zero of the project, operating hours per annum, and efficiency of motors of the i-th drive station.

With respect to the capital cost of multi-drive conveyor systems, the belting material, the electric motors, the gear reducers, the carry and return idlers, are considered at this stage.

The annual equivalent cost of the conveyor components are as follows:

$$A_{belt} = k_2\, BK(c_1 + c_2\, k_N^{c3}), \tag{21}$$

$$A_{motor,i} = k_3(c_4 + c_5\, P_i^{c6}), \tag{22}$$

$$A_{gear,i} = k_2\, BK(c_7 + c_8\, T_i^{c9}), \tag{23}$$

$$A_{carryidler} = \xi_o k_5 \sum_{j=1}^{No} \frac{L_{o,j}}{l_o} (c_{10} + c_{11} d_o^{c12} + c_{13}\, D_o^{c14} + c_{15}\, B^{c16}) , \tag{24}$$

$$A_{returnidler} = \xi_u k_6 \sum_{j=1}^{Nu} \frac{L_{u,j}}{l_u} (c_{17} + c_{18} d_o^{c19} + c_{20}\, D_o^{c21} + c_{22}\, B^{c23}) , \tag{25}$$

where K denotes the total length of the belt along the conveyor path, k_2 to k_6 denote the equivalent annual cost coefficients of conveyor components, c_1 to c_{23} denote the initial cost coefficients, ξ_o and ξ_u denote, respectively, the number of carry and return idler rolls per set (ξ_o in a three idler troughing configuration, $\xi_u = 1$ in a flat return configuration).

Accordingly, the equivalent annual cost of a multiple drive belt conveyor with intermediate drive stations is given by:

$$A_{conveyor} = A_{energy} + A_{belt} + 2\sum_{i=1}^{N} (A_{motor,i} + A_{gear,i}) + A_{carryidler}, + A_{returnidler}. \tag{26}$$

Problem formulation

Given a number of intermediate drive stations, the optimisation problem that seeks the design solution with the lowest equivalent annual cost is formulated as follows

$$\min_{x}\ \mathrm{A}_{conveyor}$$

$$\text{subject to } G(X) = 0,$$

$$H(X) \geq 0.$$

Here, denotes the set of design parameters that consists of P_i, T_i, $D_{tr,i}$, α_i, $L_{o,j}$, B, v, lo, l_u, D_o, D_u, d_o, d_u, k_N, and F_{TU}. $\mathrm{A}_{conveyor}$ is given by (26). $G(X)$ consists of the equality constraints, $H(X)$ consists of the inequality constraints, and the lower and upper bound limits of the components of X, detailed in [49].

4.2.2.2 Optimisation and optimal solution

The above mixed integer nonlinear programming (MINLP) was solved using the general-purpose solver MIDACO, which based on an extended evolutionary ant colony optimization algorithm. The optimization results are shown in Figure 15, where SD refers to single drive belt conveyor, STD refers to single tandem drive conveyor, and MD-x refers to multi-drive belt conveyor with x intermediate drive stations. For further details on the simulation results, see [48], [49]the multi-drive technology has gained worldwide popularity in recent years because of the cost saving opportunities as a result of the possible reduction of the belt weight. Until recently, however, limited knowledge on the cost-effective design of such conveyor systems was reported in the literature. Following the findings of a novel contribution on this matter, this paper presents a comparative numerical study for the identification of the most advantageous belt conveyor design for a specific bulk material handling application. Three types of belt conveyor are compared: the single drive belt conveyor, the single-tandem drive belt conveyor and the multi-drive belt conveyor. Subject to the assumption made and the manufacturers supplied information, the study shows that the implementation of the most cost-effective multi-drive conveyor will result in equivalent annual cost savings of about 63,120 $(USD.

The minimum EAC of 63,120 $(USD) is achieved by the belt conveyor equipped with three intermediate drive stations (MD-3) operated at 1.69 m/s with the following specifications: $P_i = 151.1$ kW; $B = 1.8$ m; $T_i = 16.1$ kNm; $k_N = 571.3$ N/mm; $\alpha = 217.7^{\circ}$; $F_{TU} = 87.0$ kN; $D_{tr} = 400$ mm; $D_o = 63$mm; $d_o = 30$mm; $D_u = 63$mm; $d_u = 30$mm; $L_{o,1} = 573.0$ m; $L_{o,k} = 649.7$ m; $L_{o,N+1} = 628.9$ m.

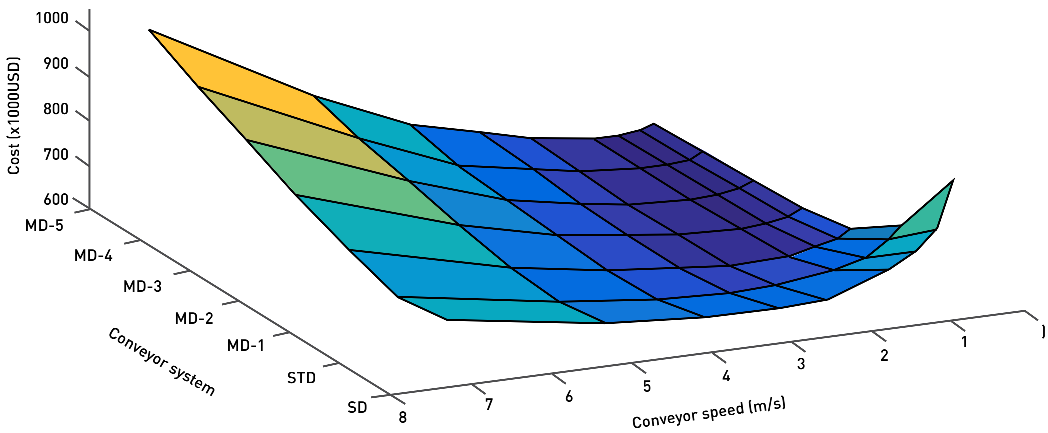


Figure 17: Cost-effective belt conveyor systems.

4.3 BATTERY-SUPERCAPACITOR HYBRID ENERGY STORAGE SYSTEM APPLICATION AND OPTIMISATIONS

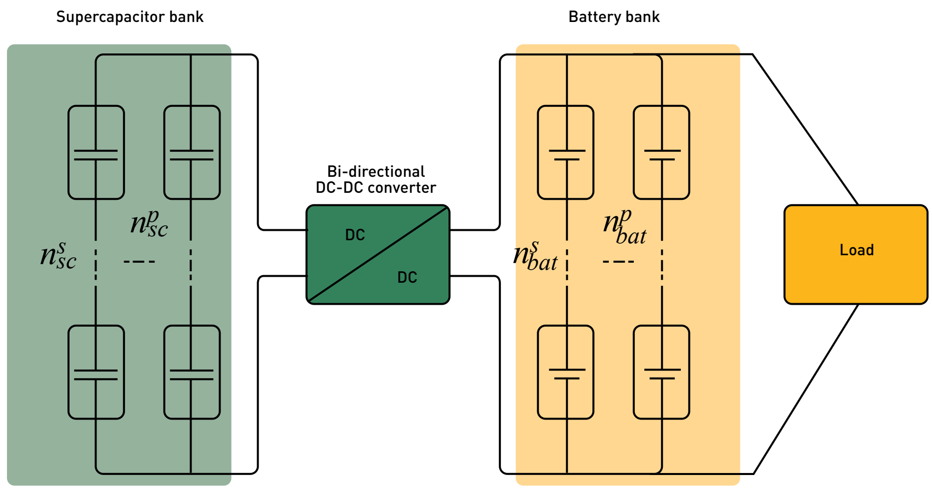


Figure 18: Diagram of the HESS in EV for sizing purpose

With reference to a University of Pretoria study about the usage of the battery-supercapacitor hybrid energy storage system (HESS) in electric vehicle (EV) application, a real-time unified speed control and power flow management system for an EV powered by a battery-supercapacitor HESS was developed following a nonlinear control system technique. This type of application can be used in the mining sector for movement parts (such as the conveyor belt). In view of the coupling between energy management and HESS sizing, a HESS sizing model is developed to optimally determine the size of HESS to serve an EV using the controller designed. The objectives of the controller are to track the set speed of the vehicle with globally exponential stability and to make use of the HESS wisely to reduce battery stress. The design provides a compound controller by exploiting the physical origins of the vehicles' power demand. The controller and HESS sizing system designed are simulated on a standard urban dynamometer driving schedule and a recorded actual city driving cycle for a full-size EV to demonstrate their effectiveness.

A sizing model is also presented to determine the numbers of battery and supercapacitor cells required to power the vehicle. In the sizing process of HESS, one important target is to make sure that the battery used in the vehicle can endure a specified lifespan. In this regard, it is commonly accepted that the battery capacity loss must be within 20% after ten years of operation. To take this into account in the sizing process, a battery degradation model is essential. The battery degradation models that are used is:

$$Q_{loss} = Be^{-E_a/RT} A_h^{\rho} , \tag{27}$$

where Q_{loss} is the percentage of battery capacity loss, B is the pre-exponential factor, E_a is the activation energy from Arrhenius law in J mol^{-1}, A_h is the Ah-throughput, T is the absolute temperature in K, and R = 8:314 J mol^{-1}K^{-1} is the gas constant. ρ = 0:5 is the power law factor. The rest parameters of the capacity loss model were empirically obtained from a large set of testing data.

An optimal sizing model is given with the objective to minimise the weight of the HESS while considering the limit on 20% battery capacity loss over a ten-year period. The HESS sizing is highly dependent on the topology of the HESS. The formulation given here is for a semi-active configuration, which suits the designed energy management system and speed controller. The HESS diagram for which the sizing problem is developed is shown in Figure 18. The sizing problem is then formulated as minimizing the following objective function

$$f(n_{sc}^s, n_{sc}^p, n_{bat}^s, n_{bat}^p) = n_{sc}^s\, n_{sc}^p\, m_{sc}^{cell} + n_{bat}^s\, n_{bat}^p,\, m_{bat}^{cell}, \tag{28}$$

subject to constraints defined in equations below:

$$\begin{aligned}
0.3 n_{sc}^s\, v_{sc}^{cell} &\leq V_{l,min} , \\
n_{sc}^s\, v_{sc}^{cell} &\geq V_{l,max} , \\
V_{h,min} \leq n_{bat}^s\, v_{bat}^{cell} &\geq V_{h,max}, \\
n^s\ n_{sc}^p p_{sc}^{cell} &\geq p_{ev,\,sc} , \\
n_{sc}^s\, n_{sc}^p\, p_{sc}^{cell} + n^s\ \ n_{bat}^p p_{bat}^{cell} &\geq p_{ev,max} , \\
n_{sc}^s\, n_{sc}^p\, e_{sc}^{cell} &\geq e_{ev,sc} - e_{reg} , \\
n_{bat}^s\, n_{bat}^p\, e_{bat}^{cell} &\geq e_{ev,bat} , \\
\mathrm{Q}_{loss,\,10} &\leq 0.2. ,
\end{aligned} \tag{29}$$

In the above formulation, subscripts bat, sc and ev denote variables associated with battery, supercapacitor and EV, respectively. The superscript cell denotes variables for a cell of battery or supercapacitor, n denotes number of cells, and p and e represent power in W and energy in Wh, respectively. In addition, superscripts s and p denote numbers of cells connected in series and parallel, respectively (see Figure 16). $V_{l;min}$ and $V_{l;max}$ are the min and max voltages required by the DC/DC converter at the low voltage side in V. $V_{h;min}$ and $V_{h;max}$ are the lower and upper limits of the voltage at the high voltage side in V.

The controller aims to regulate the speed of the vehicle and at the same time optimally manage power flows in the HESS. Therefore, the controller must be capable of tracking the desired speed of the vehicle while using the hybrid energy storage system in a way that reduces battery stress. Therefore, the main objectives of the real-time compound controller are twofold: 1) speed control: ensuring good speed track performance of the EV and guaranteeing the global asymptotic stability of the speed tracking error; and 2) energy management: relieving battery stress and prolonging battery life by protecting the battery from abrupt power flows/currents.The controller is able to smooth battery power effectively to prolong its lifetime for energy management, and is theoretically proved to be globally stable for speed control with feedback measurements on vehicle speed and road slope.

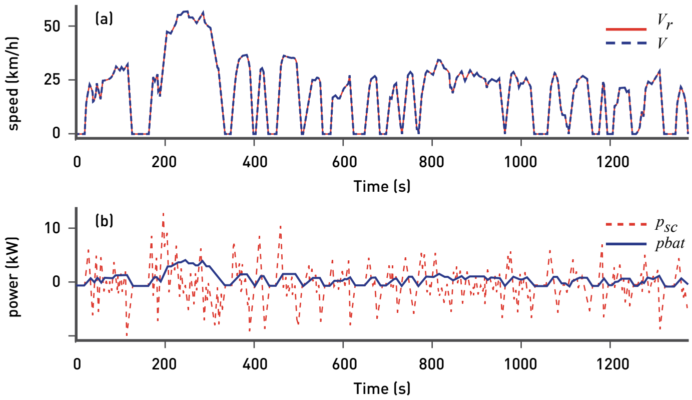


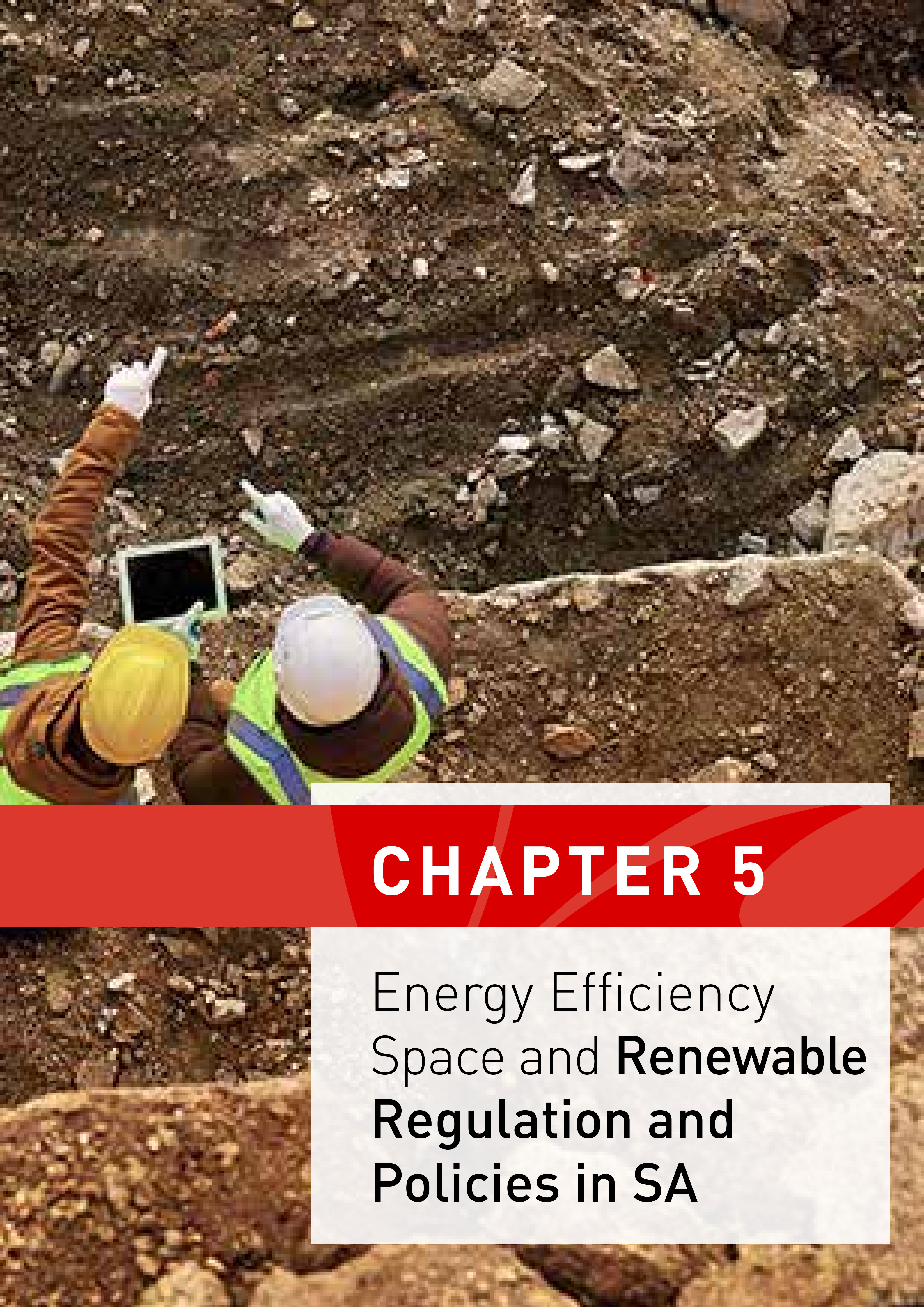
Figure 19: Optimal power split when system speed changes.

Simulation results obtained from a simulated optimal power split when system speed changes (Figure 19) show that it achieves less battery power fluctuation and is able to follow the desired speed profile of the vehicle with minimum deviation when measurement noise and modelling uncertainties are taken into account. This is applicable for belt conveyors for mining application. The Figure 17 test is however over a flat route. In order to demonstrate the effectiveness of the designed controller on an actual uneven city road, a driving cycle recorded is used to simulate the performance of the control strategy.

From the results of an actual city driving cycle, it can be seen that the supercapacitor supplies/ absorbs the fast-changing power flows of the vehicle because of acceleration/deceleration and gravitational acceleration. Additionally, the battery bank is continuously discharging and the supercapacitor gets charged during the vehicle's braking period, which is influenced by both the vehicle's speed profile and the slope of the route. This actual city test is over an uneven road, of which the slope influences the resulting power profiles. This type of power profile can be seen in belt conveyors for mining application. The recorded speed profile of the vehicle is also noticeably more dynamic. The data above shows that the battery power is smoothened effectively by the supercapacitor for both the flat route test and an actual road test. Besides, the HESS sizing model presented, selects optimal components for the HESS.

Recommendation:

Supercapacitors have become a widely used energy storage system. Supercapacitor energy storage technology has improved the operating performance of many applications and enabled some new applications. On a stored energy basis, supercapacitors are usually more expensive than other energy storage technologies. However, any application that require long operational life, extremely high cycle life, and high cycle efficiency, supercapacitor will be the lowest-cost solution. In addition, for any application that requires higher power density compared to energy density, one may use a hybrid energy storage system to improve the performance of the system.



CHAPTER 5

Energy Efficiency Space and **Renewable Regulation and Policies in SA**

5.1 SOUTH AFRICA INTEGRATED RESOURCE PLAN 2019

The Integrated Resource Plan 2019 (IRP2019) is the latest version of South Africa's long term electricity capacity expansion plan. This plan specifies the capacity (MW) and the timing of investments in different generation technologies over the planning horizon. The net installed capacity and energy mix from IRP2019 is presented in Figure 18. As South Africa's aging coal fleet is decommissioned, new generation capacity must be procured in order to meet the country's electricity demand. This new capacity consists primarily of a mix of solar PV, wind and gas in the least cost scenario. The annual new build capacities from IRP2019 are presented in Table 8, and include an allocation of 500 MW/yr from 2023 to 2030 for embedded generation (DG in Figure 20), and an undetermined allocation between 2019 and 2022 to reduce the short term capacity gap.

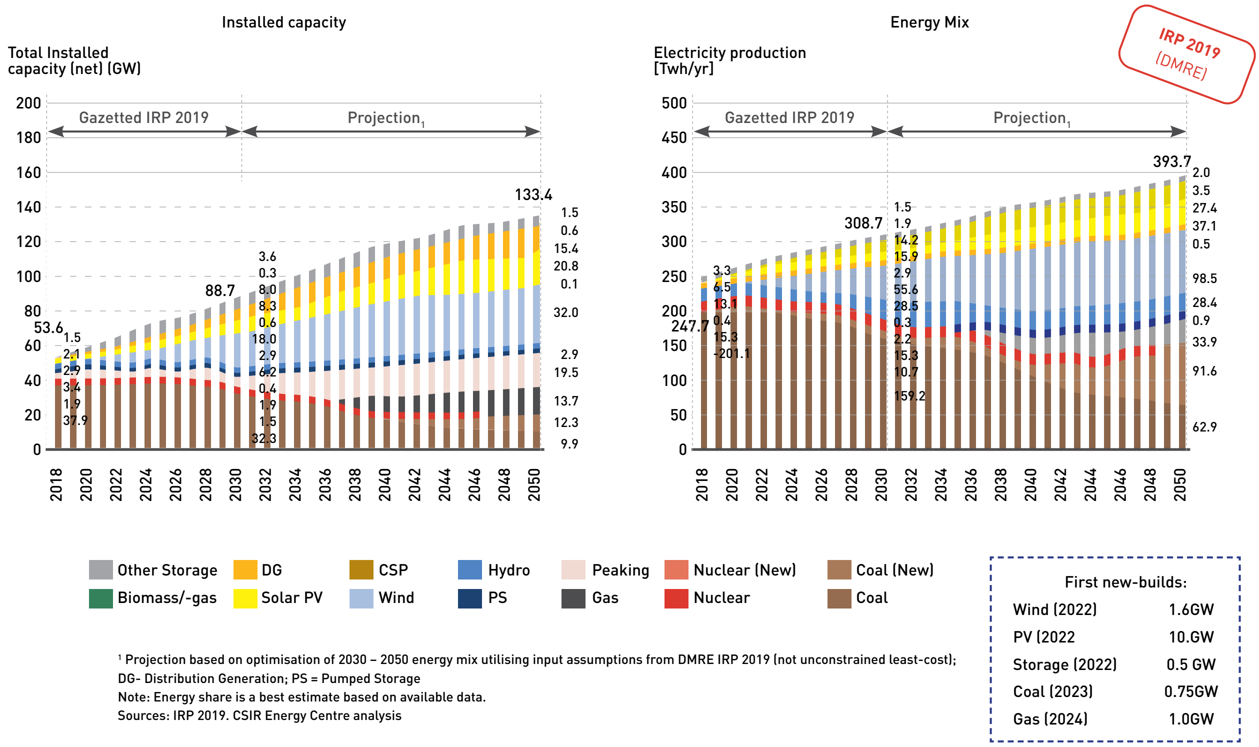


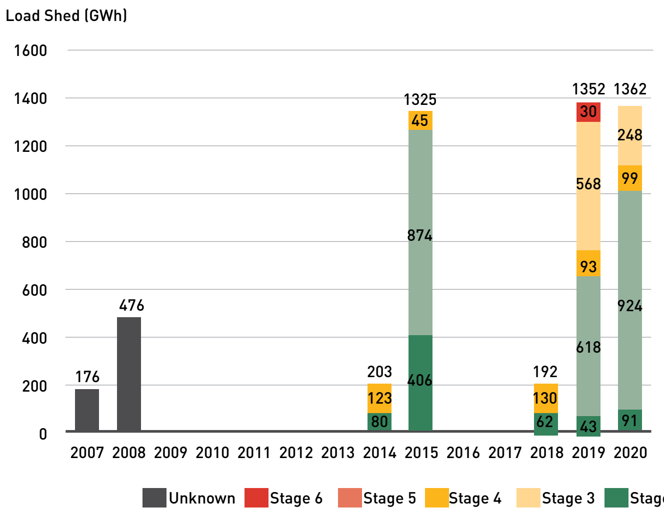
Figure 20: Capacity expansion plan according to CSIR analysis of IRP2019

Table 8: Annual build capacities according to IRP2019

	Coal	Coal (decom	Nuclear	Hydro	Storage	PV	Wind	CSP	Gas/Diesel	Embedded generation
Current	37149		1860	2100	2912	1474	1980	300	3830	499
2019	2155	-2373					224	300		Allocation to the extent of the short term capacity gap
2020	1433	-557				114	300			
2021	1433	-1403				300	818			
2022	711	-844			513	1400	1600			
2023	750	-555				1000	1600			500
2024			1860				1600		1000	500
2025						1000	1600			500
2026		-1219					1600			500

	Coal	Coal (decom	Nuclear	Hydro	Storage	PV	Wind	CSP	Gas/Diesel	Embedded generation
Current	**37149**		**1860**	**2100**	**2912**	**1474**	**1980**	**300**	**3830**	**499**
2027	750	-847					1600		2000	500
2028		-475				1000	1600			500
2029		-1694			1575	1000	1600			500
2030		-1050		2500			1600			500

The deployment of embedded generators by the mining sector can play a key role addressing the short term generation capacity gap (estimated in IRP2019 at 2000 MW) that South Africa is likely to face up to 2024, in order to avoid further load shedding. As presented in Figure 21, 2020 has seen the highest level of load shedding to date with a total of 1362 GWh of energy shed, despite COVID19.

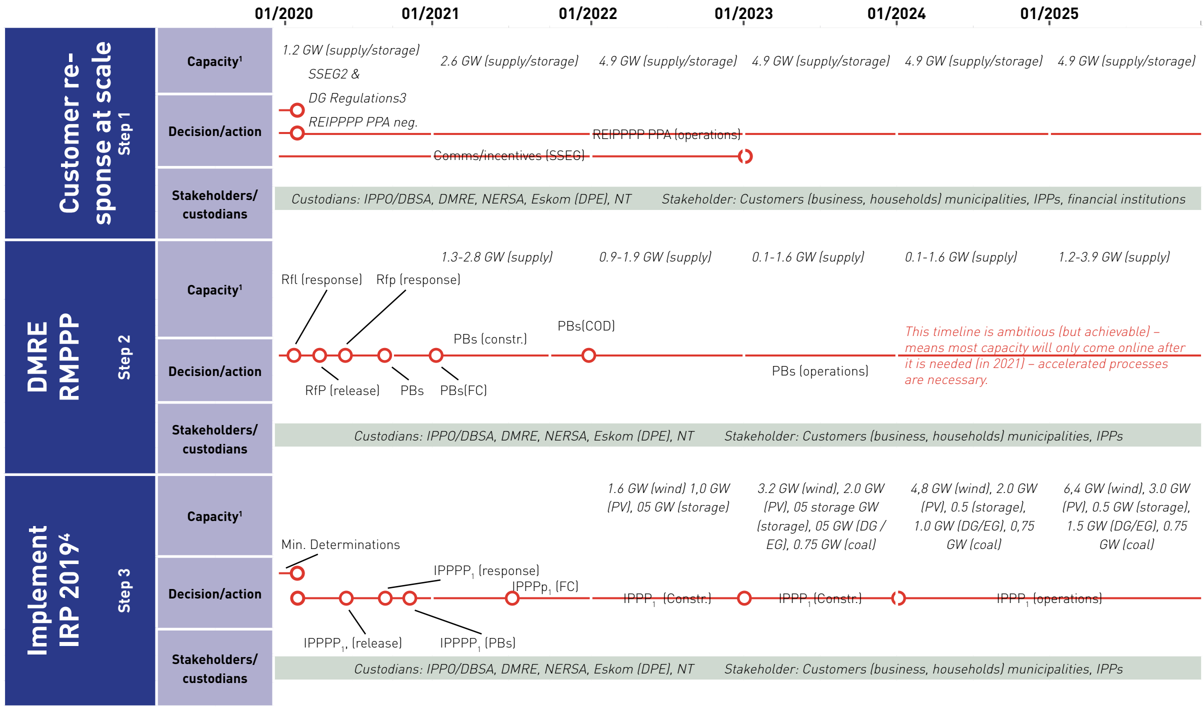


Year	Duration of outages (hours)	Energy Shed (GWh)	Est. econ. Impact (ZAR – bin)
2007	-	176	8-15
2008	-	476	21-42
....	....	....	....
2014	121	203	9- 18
2015	852	1325	58-116
2016	-	-	-
2017	-	-	-
2018	127	192	8-17
2019	530	1352	59 -118
2020 (YTD)	635	1341	58-117

Notes: Load shedding assumed to have taken place for the full hours in which it was implemented. Practically, load shedding (and the stage) may occasionally change end during a particular hour. Total GWh calculated assuming stage 1 – 1ooo MW, Stage 2 = 2000 MW, Stage 3 = 3000 MW, Stage 4 = 4000 MW, Stage 5 = 5000 MW, Stage 6 = 6000 MW; Cost of the economy of load shedding is estimated using COUE (cost of unserved energy) = 87.50 R/kWh
Sources: Eskom Twitter account; Eskom se push (mobile app); Nersa; CSIR analysis

Figure 21: Analysis of load shedding in South Africa

A recently publish CSIR study titled "Setting up for the 2020s," points to the possible size of the capacity gap (in MW) and the energy gap (in GWh) over the next 5 years that must be filled in order to avoid load shedding. The results show that if the performance of the Eskom coal fleet does not recover to 75%, as assumed in IRP2019, the size of the capacity and energy gap will increase significantly up to 2022.
The CSIR has recommended 3 critical actions that need to be accelerated in order to reduce the potential for load shedding over the next 5 years. These actions include a customer response at scale through embedded generation, as well as timeous implementation of the DMRE Risk Mitigation Power Procurement Programme (RMPPP) and the IRP2019. The recommended timelines for the customer response include a ramping up to a proposed 4.9 GW of capacity. The mining sector can clearly play a leading role in the rapid roll-out of embedded generation and storage technologies. In order to intentionally drive a customer response at scale, a framework of enabling regulations are required for embedded generation.



Notes: Timelines are estimated and in no way prescriptive; PBs – Preferred bidders, PPA Power purchase Agreement; RfI Request for information; Rfp Request for Proposal; FC Financial Close, COD – Commercial operation Date; 1Total additional installed capacity; 2 Requires adjusted SSEG regulations (proposed lifting licensing requirement for SSEG & only requiring registration with NERSA – from 1 MW to 10 MW (or more)); 2 SSEG (res) does not require regulatory changes (just communications rollout but could be further incentivised by Eskom/Municipalities);3Will require Ministerial Determination – generators expected → MW (technologies aligned with IRP 2019); 4 Unlikely to get capacity online before 2023 – 2024 (risk misalignment with IRP 2019)

Figure 22: IRP2019 implementation plan.

In a recent opinion article, Cyril Ramaphosa stated the intent of government to facilitate the deployment of embedded generation. The following comments were made with respect to embedded generation

"For facilities that can generate above 1 megawatt, the National Energy Regulator of South Africa is improving its licensing processes to improve turnaround time. So far, five such facilities, with total installed capacity of 25 megawatts, have been licenced. Further work is being undertaken to reform the regulatory environment to ensure that we make fuller use of the great potential in this country for self-generation among commercial and industrial users"

Therefore, there are clear signals that the government is moving to streamline the process to allow large industrial customers to deploy embedded generation moving forward.

5.2 NATIONAL TAX INCENTIVE SCHEMES

The Department of Energy (DoE) and the South African National Energy Development Institute (SANEDI) as the implementing agency have introduced the national section 12I/L/B tax incentive scheme on:

- 12I: Additional investment and training allowances in respect of industrial policy projects
- 12L: Deduction in respect of energy efficiency savings
- 12B: Deduction in respect of certain machinery, plant, implements, utensils and articles used in farming or production of renewable energy

in order to safe guard the country's energy security through energy efficiency mechanisms.

Table 9: Section 12 tax incentives

SECTION 12 TAX INCENTIVE	NAME OF INCENTIVE	SHORT DESCRIPTION
Section 12I	Additional investment and training allowances in respect of industrial policy projects	As of 1 January 2015, greenfield 'industrial policy project' projects above R50 million may deduct an additional investment allowance equal to 55% of the cost of its manufacturing asset, or up to R900 million up until 31 December 2017. However, it has been proposed to extend this to 31 March 2020.
Section 12L	Deduction in respect of energy efficiency savings	As of 1 November 2013, taxpayers are allowed to claim a deduction for most forms of energy efficiency savings that result from activities performed in continuing any trade and in producing income. For assessments between 1 November 2013 and 28 February 2015, the deduction is calculated at 45 cents per kWh; for assessments commencing on or after 1 March 2015, the deduction is calculated at 95 cents per kWh.
Section 12B	Deduction in respect of certain machinery, plant, implements, utensils and articles used in farming or production of renewable energy	Allows taxpayers to claim a capital allowance for qualifying movable assets, owned by the taxpayer and brought into use for the first time for trade purposes in the production of electricity from renewable energy. The rate of the allowance was amended on 1 January 2016 from 50/30/20 basis over three years, to one year (100%).

5.2.1 Section 12I

The 12I tax allowance incentive section is designed to reinforce Greenfield investments as well as Brownfield investments. The Greenfield investments are defined as new industrial projects that utilise only new and unused manufacturing assets, and the Brownfield investments are defined as expansions or upgrades of existing industrial projects. The new incentive offers support for both capital investment and training (The government has introduced the Section 12I tax allowance in to two section incentive programmes for the manufacturing industry namely: The Industrial Policy Project investment and the training allowance incentive).

The objectives of the Section 12I tax allowance are to support:

- Investment in manufacturing assets, to improve the productivity of the South African manufacturing sector; and
- Training of personnel; to improve labor productivity and the skills profile of the labor force.

This incentive is an investment allowance calculated on qualifying assets that may be deducted from taxable income in the financial year. For that reason, to qualify for this tax allowance, the mining sectore must meet the following criteria:

- The minimum investment in Qualifying Assets required is R50 million for a greenfield project and an additional investment of R30 million for a brownfield project.

- Manufacturing assets to be acquired and contracted for on or after the date of approval. 12I
- The investment must be classified under, "Section C: Manufacturing" in version 7 of the Standard Industrial Classification Code (SIC Code) [55]

The Qualifying Assets in the first criteria are defined as new and unused "buildings, plant and machinery" contracted for and acquired after the date of approval of the Section 12I tax allowance and brought into use within 4 years from the date of approval (implementation period).

The Section 12I tax allowance is divided into two statuses, the preferred status and the qualifying status. The Department of Trade and Industry (the Dti) calculates statuses using a point system. (For example, a mining company could fall under Greenfield projects with preferred status). The Dti calculates points based on the following:

- Innovation (1 Point)
- Improved Energy Efficiency: Cleaner Production Technology (2 Points)
- Business Linkages (1 Point)
- Small, Medium and Micro Enterprises (SMME) Procurement (1 Point)
- Skills Development (Training of Employees) (2 Points)
- Located in a Special Economic Zone (SEZ) [56] (1 Point)

The points for a Qualifying Status should be 4,5 or 6 out of 8 points for a Greenfield project and 7 or 8 out of 8 points for a Brownfield project. Points for a Preferred Status should be 7 or 8 out of 8 points for both the Greenfield project and Brownfield project.

To calculate the tax allowance, first the Dti will send an "its approved letter" which will tell you the exact amount approved for your qualifying assets and secondly SARS will publish notices regarding companies that were approved for the section 12I tax allowance, therefore, there will be no confusion on the exact amount the DTI approves. Investment Allowance can be calculated as below:
For Greenfield investments:

- 55% of Qualifying Assets or a maximum of R900 million investment allowance with a Preferred Status. (100% if located in a Special Economic Zone of "SEZ")
- 35% of Qualifying Assets or a maximum R550 million investment allowance with a Qualifying Status (75% if located in a Special Economic Zone or "SEZ")

For Brownfield investments:

- 55% of Qualifying Assets or a maximum of R550 million investment allowance with a Preferred Status. (100% if located in a Special Economic Zone of "SEZ")
- 35% of Qualifying Assets or a maximum R350 million investment allowance with a Qualifying Status (75% if located in a Special Economic Zone or "SEZ")

Greenfield, Brownfield projects, Preferred Status, and Qualifying Status projects can qualify for the training allowance. The Dti calculates training allowances as the lesser of:

- Actual total training cost or
- R36 000 per full-time employee

Before mining sectors start their Section 12I project, they must apply for the Section 12I tax allowance (this process can take 6 to 12 months to complete). There are many application forms in this process, therefore, the mining company should start the process as soon as possible.

5.2.2 Section 12L

12L Tax Incentives was broadcasted on 9 December 2013 in the Government Gazette No 37136. This tax incentive specifies that the tax allowance must account a person's income based on their energy efficiency savings, in the year of the assessment. The 12L Tax Incentives provides an allowance for businesses to implement energy efficiency savings. When mining sector applying for the 12L deduction, the energy efficiency (EE) savings must be verified and the data must be traceable, accurate, and transparent. This verification needs to be done by an independent SANAS (South African National Accreditation System) accredited measurement and verification (M&V) body.

The 12L tax incentive will be from 45c to 95c per verified kWh (or kWh equivalent) of EE savings that have been signed off by the M&V body and have been approved by the SANEDI 12L evaluation panel for the assessment year in question. Energy savings must be calculated by comparing the measured use of energy before and after the implementation of a certain energy savings measure. The savings must also be determined by making suitable adjustments to account for possible changes in the relevant conditions. When the mining sector applies for the 12L tax allowance, several rules and requirements need to be followed. Among all requirements, "data" is one of the most important aspects of the 12L requirements:

- Data requirements: The baseline and assessment energy data needs to be accurate.
- Calculating EE savings: Accurate data is necessary to construct the correct baseline model, which is then used to calculate the energy savings.
- Limitations and concurrent benefits: Sufficient data management is needed in order to identify, and quantify, any limitations or concurrent benefits that may apply.

Thus, the quality of data is an important factor when claiming the 12L tax allowance.
The verified data on the kWh energy efficiency savings will be used to calculate the entire deductions against taxable income, for example verified kWh * 95c, which will form the basis to calculate the estimated tax revenue forgone. In the case of companies, this will be Verified kWh * 95c * 28% and in the case of unincorporated businesses Verified kWh * 95c * the marginal PIT rate (The marginal rate for unincorporated businesses are the same as for individuals and varies between 18% and 40%). Figure 23 shows one example of a 12L tax incentive. A business could save R260 000 on its annual tax by saving 1 million kilowatt hours of energy.

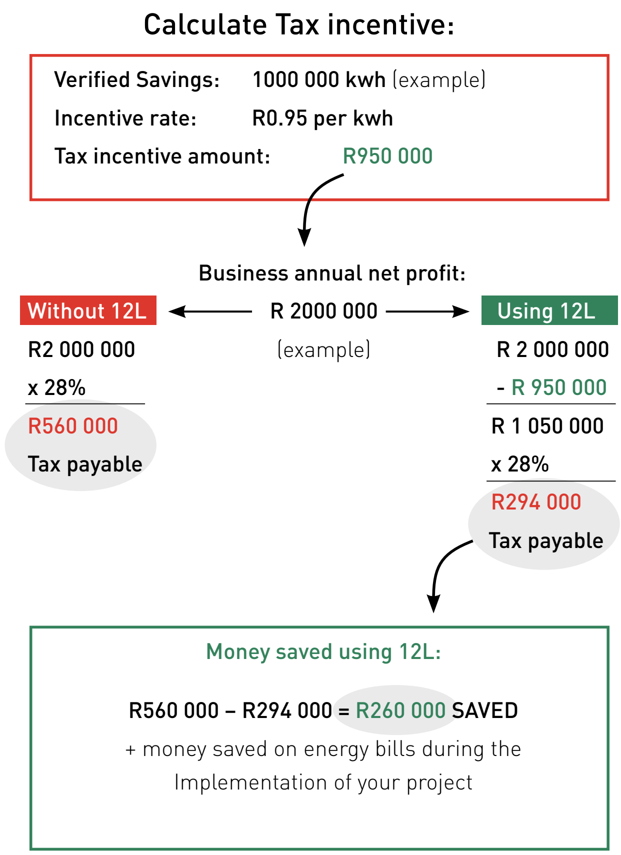


Figure 23: 12L tax incentive example

Time also plays an important role when considering 12L tax incentives. A company that demonstrates EE savings must complete its entire application within a certain timeframe. The tax incentive will be applicable for a period of 12 months of savings (there is some uncertainty on whether the baseline is applicable only within the assessment year or for a calendar years' worth of savings).
In order to claim the tax from SARS, applicants will have to follow the process below:

1. Establish a baseline in terms of energy use;
2. Register with SANEDI (SANEDI will evaluate viability of project at no cost);
3. Once the project is approved it goes through an assessment process. The assessment must be carried out by SANAS accredited M&V body and this is sent back to SANEDI for final sign off (after being signed by M&V body);
4. SANEDI will then issue a tax certificate once assessment is complete;
5. Tax certificate can be sent to SARS for the tax relief.

It is important for the mining sector to carefully consider the viability of this incentive for two main reasons. The first of these is that there is an additional cost burden implied by the M&V body. The Act does not stipulate how these can be carried out and therefore are left at the discretion of that specific M&V body. The other consideration to be made is the financial viability of registering a project under the 12L or against another state led incentive such as the MCEP.

5.2.3 Section 12B

Section 12B of the Income Tax Act provides for a 50/30/20 income tax deduction over three years in respect of any machinery, plant, implement, utensil or article (referred to as a qualifying asset) owned by the taxpayer. The allowance is only available if the asset was or is brought into use for the first time by that taxpayer (the allowance is not limited to new or unused assets).
The asset has to be brought into use for the purposes of the taxpayer's trade in order to generate electricity from the following renewable energy sources:

- Wind power;
- Photovoltaic (PV) solar energy;
- Concentrated solar energy;
- Hydropower (gravitational water forces) to produce electricity of not more than 30 megawatts; and
- Biomass comprising organic wastes, landfill gas or plant material.

The tax deduction also applies to any improvements to the qualifying plant or machinery which is not repairs.

In cases of plant and machinery used in the generation of electricity from photovoltaic solar energy in respect of energy less than 1 megawatt (←1 MW), the taxpayer may write off 100% of the costs of such plant or machinery in the year brought into use. In other words, it allows for a deduction/depreciation on a 100% basis (←1 MW) in the first year or 50%/30%/20% (→1MW) over 3 years in respect to a qualifying asset owned by the taxpayer. The cost of any asset for the purposes of section 12B also includes the direct cost of improvements and foundation. It was furthermore proposed that the taxpayer would incur certain related expenditure as part of the cost of the installation, including the installation planning costs, panel delivery costs and installation safety officer costs. SARS, in this regard, ruled that these costs all formed part of the direct costs of installation and erection of the systems and were therefore deductible in terms of section 12B(3). Taxpayers who instal solar energy systems should therefore carefully consider the tax deductions in terms of section 12B to ensure that all relevant costs are claimed for income tax purposes. The section 12B allowance is also available on foundations or supporting structures that are deemed to be part of the qualifying asset, if:

- The asset is mounted or fixed to any concrete or other supporting structure or foundation;
- The supporting structure or foundation is designed for the asset in such a way that it is an integral part of the asset; and
- The foundation or supporting structure is brought into use on or after 1 January 2013.

In this section, some key points to keep in mind when the mining sector applies for 12B:

- The system must be brought into use for the first time. Thus, a claim cannot be made for a system already used, or claim twice on the same system. This does not stop one from claiming again as you will have a system being brought into first time use again.
- Assets that can be claimed under the generation of electricity from solar energy, include photovoltaic (PV) panels, combiner boxes, inverters, batteries, cabinets, supporting structures, and transmission up to the distribution boards.
- The generation of electricity can be from wind power, photovoltaic solar energy or concentrated solar energy.
- It is advised to obtain a binding ruling from SARS before making an investment as an assurance that the target plant qualifies for the section 12B. (One practical difficulty that arises with the interpretation of section 12B, is which qualifying assets are to be considered when used by a taxpayer in the generation of electricity? Does "generation" simply entail the creation of the electricity (for example, in solar panels of a solar farm) or does it also include the "processing" or "harnessing" of such electricity in a form that can be sold?)

5.3 CARBON TAX AND MINING SECTOR

This section summarizes the methodology used to determine the amount of carbon tax payable and identifies a few technical options that can ease the financial burden caused by this recent tax.

Tax purposes and calculation method

Effective since 1 June 2019, Carbon Tax resorts to a "polluter-pays principle' to reduce greenhouse gas (GHG) emissions. It is intended to price carbon by obliging the polluter to internalise the external costs of emitting GHG and encourage a shift to less carbon-intensive alternatives.
The amount of tax payable by a taxpayer in respect of a tax period is calculated using the following formula [1]:

$$T_{CO2e} = [(E - S)(1 - C) - D(1 - M) + P(1 - J) + F(1 - K)]R, \tag{30}$$

where T_{CO2e} denotes the carbon tax payable expressed in Rands, denotes the GHG emissions related to fuel combustion expressed in tonne of carbon dioxide equivalent (tCO_2e), denotes the sequestered GHG emissions expressed in tCO_2e, denotes the allowances for fuel GHG emissions expressed in percent, denotes the GHG emissions related to diesel and petrol combustion expressed in tCO_2e, denotes the total allowances for diesel and petrol emissions expressed in percent, denotes the GHG emissions related to industrial processes expressed in tCO_2e, denotes the total allowances for industrial process related GHG emissions expressed in percent, denotes the total fugitive GHG emissions expressed in tCO_2e, denotes the total allowances for fugitive GHG emissions expressed in percent, denotes the tax rate expressed in Rands/tCO_2e.

In the first phase that covers the period from 01 June 2019 to 31 December 2022, the tax is levied at a rate equal to R120/tCO_2e, increased by the amount of the consumer price inflation plus two per cent for the preceding tax period as determined by Statistics South Africa. Subsequently, in the second phase, i.e., beyond 31 December 2022, will increase by the amount of the consumer price inflation for the preceding tax year as determined by Statistics South Africa.

The transitional tax-free allowances are structured as follows:

A1: Allowance for fossil fuel combustion emissions: fixed at 60%.

A2: Allowance for industrial process emissions: fixed at 10%.

A3: Allowance for fugitive emissions: fixed at 10%.

A4: Allowance for trade-exposed sectors: up to 10%.

A5: Allowance for companies that outperform their peers: up to 10%.

A6: Allowance for companies that participates in the carbon budget system during or before the tax period: fixed at 5%.

A7: Allowance for companies that resort to carbon offset schemes: up to 10%.

During the first phase, total tax-free allowances can be as high as 95%.

Taxation of fuel combustion emissions

The amount of fuel combustion related GHG emissions liable to carbon tax is given by the first two addition/subtraction factors in Eq. (30), i.e., *(E-S)(1-C)-D(1-M)*. The following relationship is used to determine (total GHG emissions due to fuel combustion):

$$E = A \times B, \qquad (31)$$

where A and B denote the mass of any one type of the fuel expressed in tonne and the GHG emission factor expressed in CO_2e/t, respectively. For a given fuel, the latter is obtained by the relationship:

$$B = (C \times 1 + M \times 23 + N \times 296)D, \qquad (32)$$

where C denotes its CO_2 emission factor expressed in ''CO_2 ($kgCO_2/TJ$)'', M denotes its methane emission factor expressed in ''CH_4 ($kgCH_4/TJ$)'', denotes its Nitrous Oxide emission factor expressed in ''N_2O ($kg\text{-}N_2O/TJ$)'', and its default calorific value expressed in terajoules per tonne (TJ/tonne). Reference values of emission factors and calorific values for the fuels commonly used in industry are provided in [1].

The factor involves the capture and storage of any greenhouse gases before they enter in the atmosphere, resulting in a net reduction in GHG emissions.

The determination of *C* in Eq. (30), takes into consideration the components A1, A4, A5, A6 and A7 of the above tax-free allowance list.

Liquid fuels are taxed duty at source, and already built in for administrative ease. Accordingly, the negative factor *D(1-M)* in Eq. (30) aims to subtract their emissions from the total combustion emissions so that double counting is avoided [2]. Here, is calculated using the same approach as in Eq. (30), while the determination of the allowance factor involved in A1, A6 and A7 from the tax-free allowances listed earlier.

Taxation of industrial process emissions

The amount of industrial process emissions liable to carbon tax is given by the third summation factor in Eq. (30), i.e., *P(1-J)* . The total industrial process emissions is calculated using either Eq. (30) or Eq. (33).

$$P = G \times H, \qquad (33)$$

where G and H denote respectively the mass of each raw material used or product produced expressed in tonne, and the GHG emission factor in CO_2e/t of each raw material used or product produced and determined as follows:

$$H = C \times 1 + M \times 23 + N \times 296 + H \times 11\,900 + T \times 5\,700 + S \times 22\,200. \qquad (34)$$

Considering a raw material or product, denotes the CO_2 emissions expressed in "CO_2/tonne product", M denotes the methane emissions expressed in "CH_4/tonne product", denotes the Nitrous Oxide emissions expressed in "N_2O/tonne product", H denotes the Hexafluoroethane (C_2F_6) emissions expressed in "C_2F_6/ tonne product", T denotes the carbon tetrafluoride (CF_4) emissions expressed in "CF_4/tonne product", and denotes the Sulphur hexafluoride (SF_6) emissions expressed in "SF_6/tonne product". Reference values of , C, M, N, H, T and for various industrial activities, raw materials and products are provided in [1].

The allowance factor *J* related to industrial process GHG emissions considers the components A2, A4, A5, A6 and A7 of the tax-free allowances listed earlier.

Taxation of fugitive emissions

The amount of fugitive GHG emissions liable to carbon tax is given by the last summation term in Eq. (30), i.e., *F*(1-*K*). The total fugitive GHG emissions can be obtained through Eq. (30) or Eq. (35).

$$F = N \times Q, \qquad (35)$$

where denotes the mass expressed in tonne in the case of solid fuels or the volume of each type of fuel expressed in cubic metres in the case of fuels other than solid fuels, and denotes the GHG emission factor expressed in CO2e/t or CO2e/m^3 and determined using the relationship:

$$Q = C \times 1 + M \times 23 + N \times 296, \qquad (36)$$

where denotes the carbon dioxide emissions of a fuel type, denotes the methane emissions of a fuel type, and denotes the Nitrous Oxide emissions of a fuel type. Reference values of , and are for the fuels commonly used in industry are provided in [1].

The allowance factor related to fugitive GHG emissions considers the components A1, A3, A4, A5, A6 and A7 of the tax-free allowances listed earlier.

Technical options to save on carbon tax

Table 10 captures diverse technical approaches that may ease the additional burden caused by the carbon tax.

Table 10: Technical interventions to reduce carbon tax

TECHNICAL OPTION	SCOPE	IMPACT	FEASIBILITY	COMMENTS
Energy efficiency	Implement measures that reduce energy consumption for unchanged output.	In Eq. (30): - Direct decrease of *D*, *P* and *F*. - Indirect increase of *C*, *J* and *K* in the case of an increase in allowance A5.	High	
Renewable energies	Replace fossil fuels by renewable energy sources.	In Eq. (30): - Direct decrease of *E* and *D*.	High	1. Both on- and off-site (via Power Purchase Agreement) options should be considered. 2. Subject to NERSA's regulation and Eskom's constraints.
Fuel shifting	- Replace fuels subject to carbon tax by those indirectly taxed - Shift to fuels with lower carbon footprints.	In Eq. (30): - Direct decrease of *D*, *P* and *F*. - Indirect increase of *C*, *J* and *K* in the case of an increase in allowance A5.	Moderate	Case-by-case approach, paying special attention to aspects such as the calorific value of alternative fuels, supply chain, etc.
Carbon offset	Avoid, reduce, or sequester CO_2e emissions through Clean Development Mechanism (CDM) projects, Gold Standard projects or Verified Carbon Standard (VCS) projects.	In Eq. (30): Increase of *C*, *J* and *K* through the increase in allowance A7.	High	- Tax reduction restricted to up to 10%. - See [3] for details on project eligibility, utilisation period, claiming procedure, etc.
Carbon Capture, Utilisation and Storage (CCUS)	Increase CO_2e sequestration (S)	1. Increase the sequestration component *S* in Eq. (30). 2. Additional savings/ earnings when the captured CO_2 is either used or sold.	Low	1. Unproven track record. 2. Very costly.

5.4 GREEN FINANCING OPPORTUNITIES

The overnight CAPEX costs for a representative solar PV plant sizes is presented in Figure 24. The required financing for large scale plants is significant, ranging between R600m to R800m for a 50MW plant, depending on the projected CAPEX costs over the next 20 years. Therefore, despite the high potential for long term cost savings, the levels of upfront funding required are significant and are a major hurdle to be overcome in the development of projects in the mining sector. This section describes some financing approaches that could support mines pursuing an alternative energy investment.

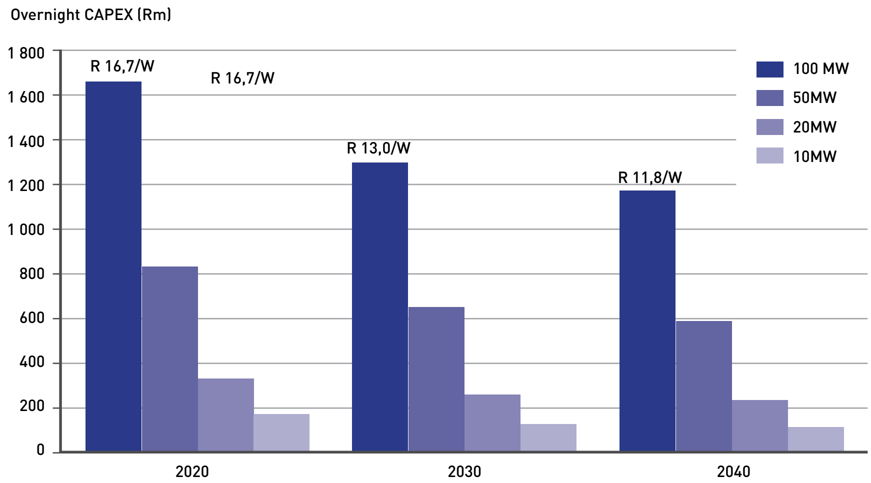


Figure 24: Overnight CAPEX costs of different solar PV capacity plants

An overview of the different forms of finance that are applicable to a project in relation to the project maturity and risk is presented in Figure 25. During the initial stages of a project development, funding must be sought from grants, venture capital, and in-kind contributions from the project developer. As the project matures different forms of finance that are applicable include concessional debt and private equity, with commercial debt applicable towards the end of the project development process. Commercial banks in general fund large-scale low risk projects, whilst Development Finance Institutions (DFIs) fund smaller scale/higher risk projects where there is a developmental return.

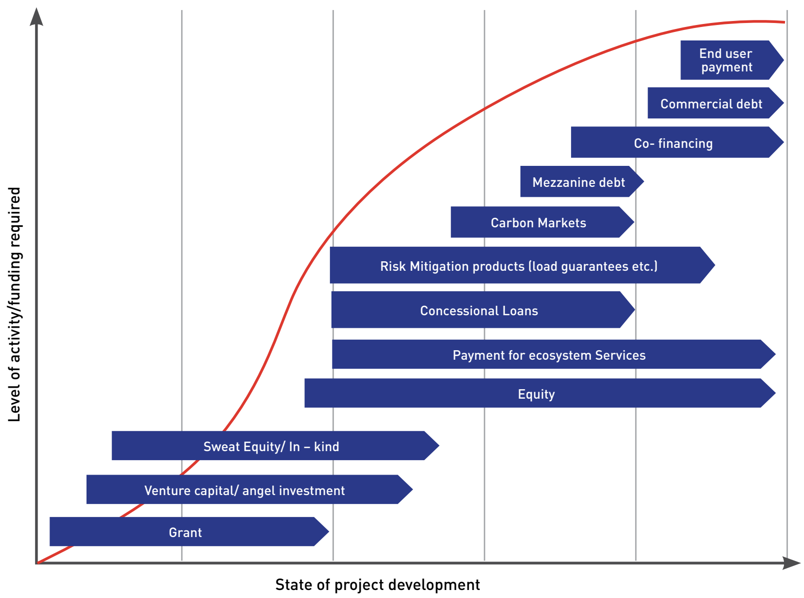


Figure 25: Relationship between funding require and project development.

5.4.1 Overview of the REIPPP programme

The REIPPPP provides the best example of financing mechanisms for the deployment of large scale renewable energy plants. Therefore, an overview is provided in this section on how projects in BW1-4 achieved financial close. A total of 86% of bidders in the REIPPPP (BW1-4) opted to finance their projects through a combination of project finance and equity, with only 13 bids making use of corporate funding. Project finance lends itself to renewable energy projects, and involves the setting up of a Special Purpose Vehicle (SPV), where the funding provided is dependent on the projected cash flows and not the balance sheet of the mine. However, the cost of capital and transactional costs are higher for the SPV approach, and therefore for a large, financially healthy company, corporate finance is a more cost effective approach. Most of the awarded projects REIPPPP (BW1-4) have 70-80% debt and 20-30% equity. A summary of the key external debt providers to BW1-4 projects is presented in Figure 26, and include the 5 major commercial banks, as well as DFIs such as DBSA and the IDC.

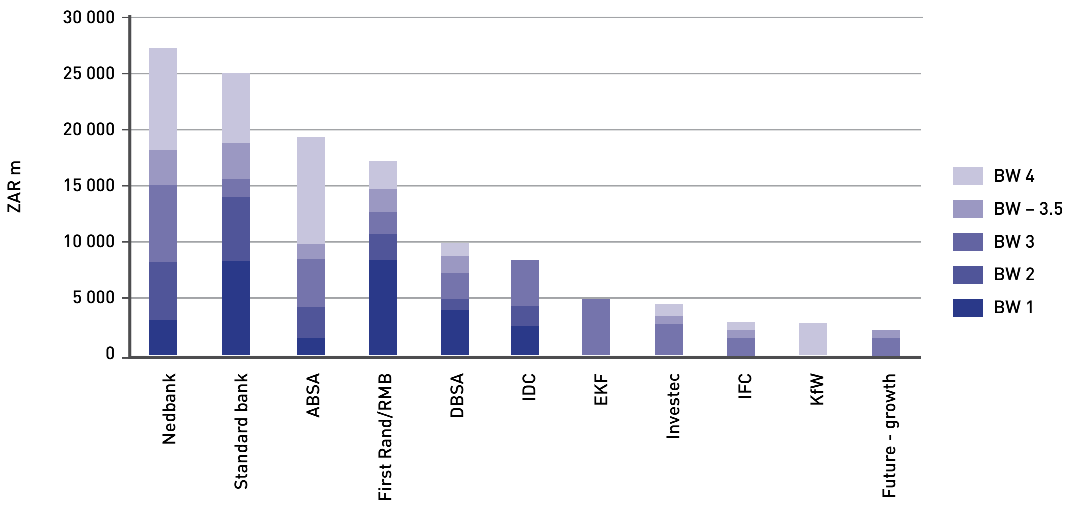


Figure 26: Largest nominal debt investors in the REIPPPP (ZAR m) at bidding stage.

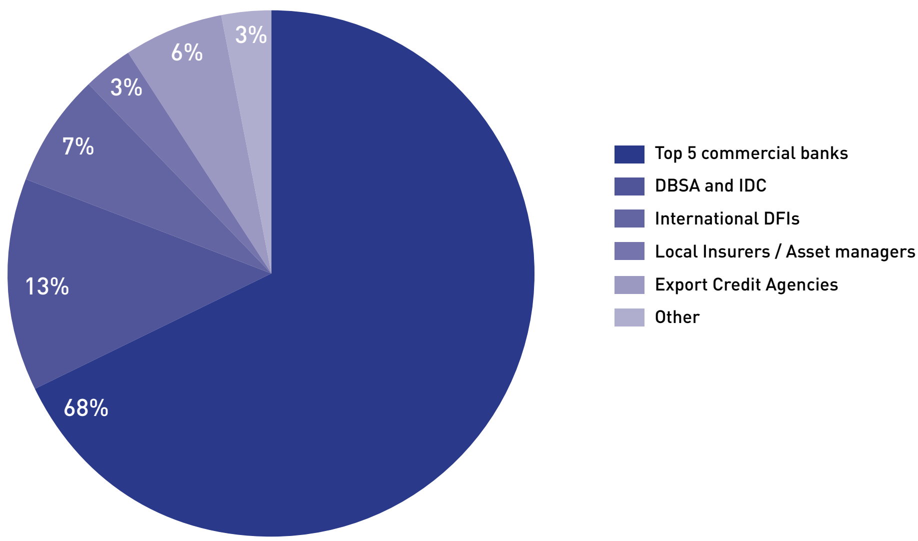


Figure 27: Percentage funding per lender category in the REIPPPP BW1-4.

One of the largest equity providers to the REIPPPP BW1-4 projects was the South African insurance company Old Mutual, along with a number of overseas energy companies looking for higher returns in developing markets.

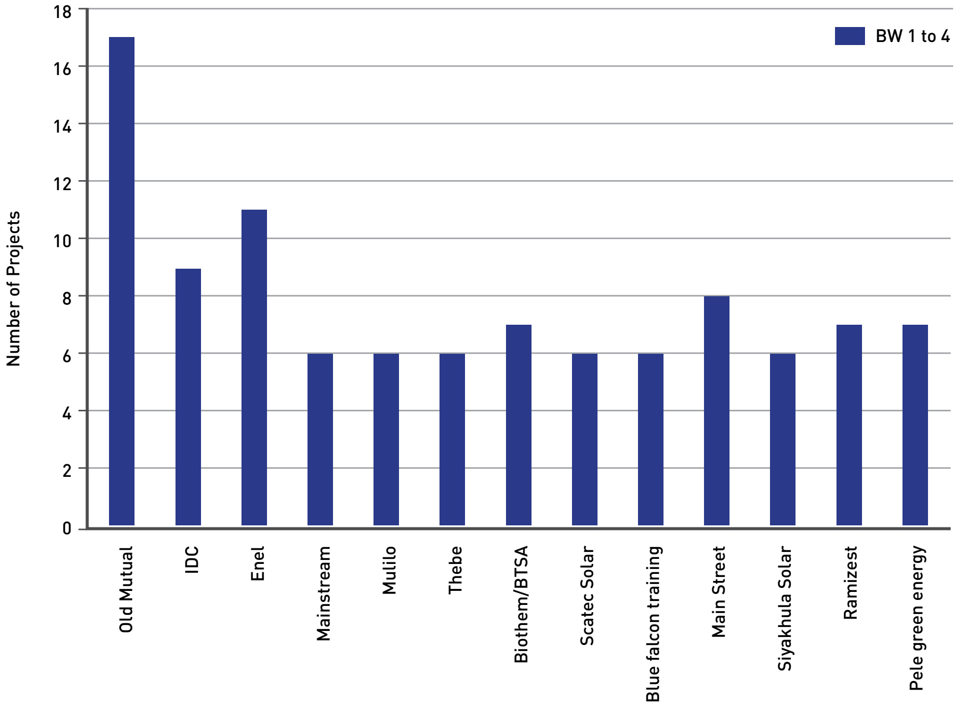


Figure 28: Major Equity Providers in the REIPPPP (BW1-4) by number of projects

5.4.2 Commercial Banks and Green Bonds

In 2018 the Johannesburg Stock Exchange launched a Green Bond segment that allows entities to raise capital for renewable projects, whilst allowing investors to meet their environmental and social governance mandates. In 2019 Nedbank had two issuances totalling R2.7bn, which were each over scribed by up to 4x, whilst Standard Bank recently used a $200m ten-year green bond that was taken up by the International Finance Corporation. The proceeds of both these bonds will go to support the financing of green projects, including solar PV and wind plants. Due to the sophisticated nature of the South African banking sector, which is well capitalised, 68% of the external debt to the REIPPPP bidders (BW1-4) was provided by local commercial banks and given the aspirations of commercial banks to issue higher levels of green financing, it is likely that a significant fraction of external debt for a bankable project could be secured from commercial banks.

5.5.3 Development Finance Institutions

As shown in Figure 27, local DFIs contributed a total of 13% to the external debt to the REIPPPP bidders (BW1-4), and international DFIs a further 7%. Both the Development Bank of South Africa (DBSA) and the Industrial Development Corporation (IDC) offer funds for competitive green financing. The details of these funds are given in this section.

DBSA Climate Finance Facility (CFF)

The CFF has been established as a collaboration between the DBSA and the Green Climate Fund (GCF). The objective of the CFF is to assist with the financing of low-carbon and climate resilient infrastructure projects in partnership with private lenders, with a focus on commercially viable projects that are not yet bankable in the private sector without support. The CFF offers sub-ordinate loans, with a minimum contribution of R50m and a loan tenor of up to 15 years. The typical capital structure for projects is as follows:

- Minimum of 20% Equity finance - Project sponsors / Shareholders
- Maximum of 30% Sub-ordinated loan (capped at R250 million) - CFF
- 50% Senior loan - Commercial banks

Applications involve the submission of a mandatory technical criteria template that can be found on the DBSA website and queries on the fund can be directed to cff@dbsa.org.

DBSA Project Preparation Fund

The DBSA have also established the Project Preparation Fund as a mechanism to provide funding for the development of infrastructure projects in support of the DBSA pipeline. These funds can be used to support the following:

- Creating an enabling environment for infrastructure projects to be implemented
- Conducting pre-feasibility studies
- Conducting bankable feasibility studies
- Assistance with costs to reach financial close

Enquiries on the fund can be directed to ppfinfo@dbsa.org.

AFD Green fund

The AFD Green Fund is a partnership between the Agence Francaise de Developpement (AFD) and the IDC. The fund is structured to provide finance for renewable energy and energy efficiency projects, but with a focus on smaller scale projects (R10m-20m), with a cap of up to R50m. The criteria of the fund are as follows:

- Total investment cost not higher that 25% of the Facility (ca R250 million per project)
- Normal risk pricing with a cap of Prime + 1.6% or an equivalent fixed rate
- Minimum investment period of 3 years
- Maximum payback based on energy savings of 8 years
- Standard IDC fees are applicable.

5.4.4 PPA model for deploying

An alternative model for the development of an alternative energy generator plant is the Power Purchase Agreement (PPA), which is a contract between the mine and an Independent Power Producer (IPP), who owns and operates the plant. The mine will typically specify the type of technology and plant size and run a competitive bidding process. In general, the competitive bidding process is likely to produce lower electricity prices than through engaging with an unsolicited proposal.

Through the signing of a PPA, the mine effectively creates an enabling environment for investment in an alternative energy plant, but it does not get involved with any of the plant financing and operation. This significantly de-risks the investment, reduces transaction costs to the mine and allows the mine to focus on core business. However, as the IPP expects a certain level of return the energy prices paid by the mine will be higher. In order for the mine to be able to capture some of the returns from the PPA, it is also possible to consider a joint venture, where the mine also invests in the SPV of the IPP, and continues to buy electricity according to a PPA.

5.4.5 National or international green fund

For many years, the energy storage industry has made great progress in developing the technology, standards, public policy and market rules that have formed the basis of today's market. These elements have led to the expanding opportunities for energy storage that now seem almost limitless—but in reality, those opportunities are severely inhibited by the lack of available and cost-effective capital. The low level of understanding and discomfort of funders on these issues prevents many from making an informed and timely decision as to which project to back. Beyond the much-needed capital, the structure through which capital is accessed can have an even wider impact on the development of this early-stage market.

Transitioning a working prototype hybrid energy storage technology from the lab to commercial status requires building out a supporting framework to enable the asset to operate successfully as part of the electric power system; not just as a technological product, but as a complete engineered system. As with other projects in the power sector, this growing class of systems requires technical and operational ecosystems of supporting equipment, market rules, and business practices which must be developed to support the cost-effective use of the technology in order to be deployed industry wide.

There are several national and international funds that will support industry to boost the implementation of an applied research and innovation project. South Africa's Technology Innovation Agency (TIA) and South Africa's National Research Foundation (NRF) often avail several funds for these types of scenarios.

As an example, in November 2019, TIA together with Egypt's Academy of Scientific Research and Technology (ASRT), signed a collaboration agreement to further enable the promotion of targeted market-oriented research cooperation and technology innovation partnerships between the two countries. Following this, TIA and ASRT invited interested participants to submit applied research and innovation project proposals in the domain of Disruptive Technologies with a focus on real-world solutions in agriculture, water, renewable energy and health.

The Call for Proposals followed a two-step process, wherein the first step entailed the submission of a Concept Note, and if that was accepted, the interested parties would submit a full proposal.

To apply to this Call, the applied research and innovation project partners had to meet the following criteria:

- Developing a new disruptive technology in the fields of agriculture, water and/or health.
- The proposed technology product, process or service must be innovative, and there must be a technological risk involved. In addition, there must at least be a proof of concept in place (e.g. prototype).
- Willing to enter into a partnership agreement with a partner organisation in SA and Egypt.
- Must be a registered start-up in line with the relevant SA and Egyptian legislation.
- Clearly show and motivate potential for SA and Egyptian markets.
- Have a civilian purpose.
- Have an obvious advantage and added value resulting from the cooperation between the participants, (e.g. joint tech dev opportunities, commercial leads, access to markets etc).
- A signed Partnership Agreement is mandatory before the actual start of the project. The Agreement will include the ownership and use of know-how and Intellectual Property Rights (IPR) settlements.

Project budgets were between R500 000 to a maximum of R1 million per project in SA and Egypt respectively. (i.e. The combined total value of project funding, to be contributed in equal part by TIA and ASRT, is R2m). The duration of the project was a maximum of 24 months.

To apply for the project, the applied research and innovation project partners had to complete a form with following sections:

- Project objectives
- Company profile (SA and Egypt)
- Overview of the project
    - Project outline / Description
    - Technological development
    - Commercialisation strategy / plan
    - List of project participant organisations
    - Details of work packages
    - Project deliverables
    - Project impact (social and economic)
- Details of applicants' involvement,
    - Objectives of partnering with member country partners
    - Benefits and impact of participation with member country partners
- Project budget details,
    - Motivation for co-investment
- Strategic significance of the project from a national research, development and innovation perspective

These sections likely will be present in any application form for national and international funds that will support industry.

Four challenges, in particular, are critical for the successful development of the hybrid energy storage market:

- Technology: Does the technology work? Has it been designed into a working system?
- Codes, Standards, and Regulations: Is the system able to be installed and operate within the wider electric power system?
- Public Policy: Is the market structured to allow it to operate in an economically effective role?
- Finance: Is there sufficient interest to develop projects profitably?

To answer these questions, the energy storage sector can look to the wind, solar, and energy efficiency industries as a guide for how nascent industries grow and overcome obstacles in the power market. In many areas, the opportunity for energy storage deployment is actually these very markets, thus understanding them is essential. The energy storage industry can gain valuable insights as to how each of these industries improved their technology maturity and established a commercial presence. Rewriting interconnection standards, market rules, and citing ordinances is difficult, but these have been the basis for the development of these other industries, and thus it will benefit the storage industry greatly to glean hard won lessons learned from these other markets.

Internationally, the Climate Investment Funds' Global Energy Storage Program (GESP) helped to deliver breakthrough energy storage solutions at scale in developing countries. The program makes Climate Investment Funds (CIF) the world's largest multilateral fund supporting energy storage, building on over $400 million in existing storage support. GESP funding is expected to mobilise an additional $2 billion of public and private investments for these vital technologies [63]. This investment program aims to:

- Help develop new storage capacity in developing countries
- Accelerate cost reduction
- Support integration of variable renewable energy into grids
- Expand energy access for millions of people

Concretely, GESP concessional finance—that is, finance with substantially below-market terms and conditions—will support:

- Solar, wind, and hybrid power projects with storage for grid services.
- A wide range of technically and economically viable storage systems, including but not limited to gravity-based technologies, thermal storage, and electrochemical batteries.
- Large-scale demonstration projects supporting less mature but technically viable, long-duration storage technologies.
- Mini-grids and distributed energy applications
- Policy and regulatory reforms to encourage:
- Participation and fair compensation of the full range of energy storage services
- Environmentally friendly storage technologies
- Battery recycling programs
- International cooperation to address key research, development, and knowledge gaps hindering long-term sustainable deployment of energy storage, including through piloting or testbeds of new technologies

This initiative is a global partnership of governments, multilateral development banks, and private corporations committed to delivering on a climate-smarter future through energy storage technologies.

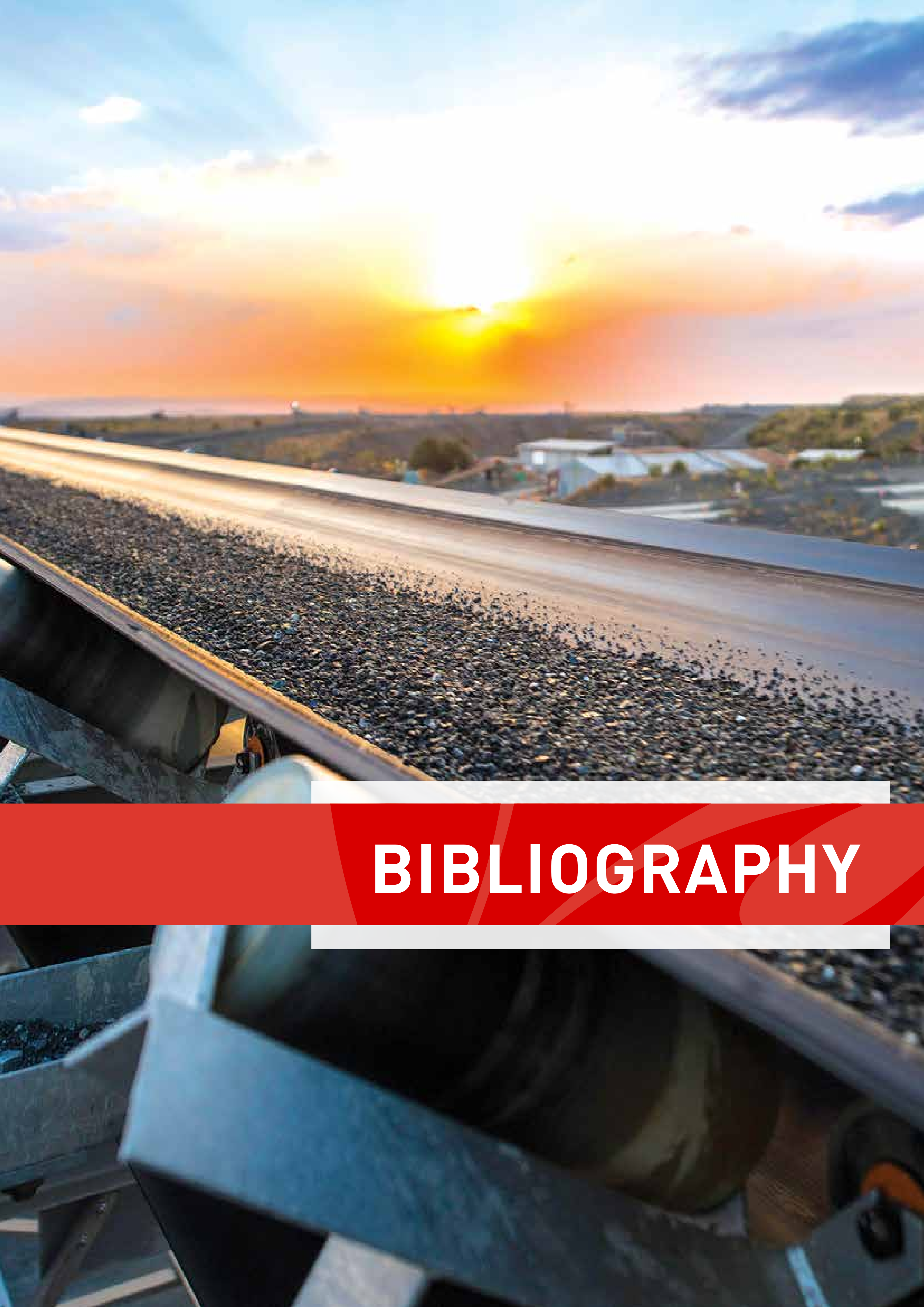
5.4.6 Green funding and schemes for EEDSM in mines

Table 11 provides basic information about national and international green funds and schemes that can support the mining sector to boost implementation of EEDSM activities.

Table 11: Information of funding and schemes

NAME	INSTITUTION	FUNDING TYPE	KEY INFORMATION	SIZAE OF INVESTMENT (RM)	WEBSITE
12L EE Tax Incentive	South Africa National Energy Development Institution (SANEDI)	Rebate	This tax incentive provides an allowance for businesses to implement energy efficiency savings. The savings allow for a tax deduction of 95c/kwh saved on energy consumption. The savings must be verified and measured by a SANAS accredited Measurement and Verification (M&V) Body.	Depends	https://www.sanedi.org.za/12L.html
Section 12-B Regulation-Production of renewable energy and fuels allowance	Department of Trade and Industry (dti)	Rebate	This section of the Income Tax Act provides for an accelerated capital allowance for machinery, plant implements, utensils or articles (owned by the taxpayer), which are brought into use for renewable energy generation. The allowance is calculated as 50% of the cost of construction of the assets for the taxpayer in the first year, 30% in the second year, and 20% in the third year.	Depends	https://fincor.co.za/tax-incentives-and-renewable-energy/
Section 12-I Tax Incentive	Department of Trade and Industry (dti)	Rebate	This tax incentive provides for an additional investment allowance on manufacturing assets (new or used), applied to a project that qualifies as an industrial policy project. The project must be approved by the Minister of Trade and Industry. Only projects larger than ZAR 200 million qualify for this allowance.	Over R200m	http://www.thedtic.gov.za/financial-and-non-financial-support/incentives/12i-tax-allowance-incentive/

NAME	INSTITUTION	FUNDING TYPE	KEY INFORMATION	SIZAE OF INVESTMENT (RM)	WEBSITE
Sustainable Energy Fund for Africa	The African Development Bank	Equity Grant	Project Preparation Grants (Component I): for renewable energy and energy efficiency project with total capital investment needs in the range of USD 30 – 75 million. Seed/Growth Capital (Component II): It will mainly target renewable energy and energy efficiency projects requiring total investments of USD 10 – 30 million range. "	R50m-R200m, Over R200m	www.afdb.org/en/topics-and-sectors/initiatives-partnerships/sustainable-energy-fund-for-africa/
Energy Efficiency Loans	Standard bank	Loan	This loan scheme provides financial support to businesses wishing to reduce their operating costs through investment in energy efficiency technologies.	Depends	https://www.standardbank.co.za/southafrica/business/products-and-services/business-solutions/industry/natural-resources/renewable-energy
ecoEnergy Loan	First National Bank (FNB)	Loan	This loan scheme provides financial support to businesses wishing to reduce their operating costs through investment in energy efficiency technologies.	Up to R1,000,000	https://www.fnb.co.za/business-banking/business-loan/ecoEnergyLoan.html
Eco Finance	Sunlyn Investments (Pty) Ltd (subsidiary of Safsin Bank)	Loan Rebate Grant	Comprehensive solution that extends from finance for energy optimization products to helping claim applicable rebates and incentives and all the steps in between.	Depends.	https://www.sunlyn.co.za/services/equipment-finance/eco-finance/overview/



BIBLIOGRAPHY

Aidonis, A. D.-l. (2002). *PROCESOL II-Solar thermal plants in industrial processes: Design and Maintenance Guidelines.*

Broe et al. (2012). Validated wind power plant modelling for accurate kpi benchmarks. *European Wind Energy Conference & Exhibition 2012.*

Canadian Solar. (2020). *BiKi Module CS3U-400MB-AG datasheet.*

Canadian Solar. (2020). *BiKu Module CS3U-365PB-AG datasheet.*

Canadian Solar. (2020). *KuDymond CS3U-370P-AG datasheet.*

Chatterjee, A. (2014). *Optimization of mine ventilation fan speeds according to ventilation on demand and time of use tariff.* Masters' Dissertation, University of Pretoria, Pretoria, South Africa.

Eskom. (2010, February). *The Energy Efficiency Series. Towards an Energy Efficient.* Retrieved June 10, 2020, from http://www.eskom.co.za/sites/idm/Documents/121040ESKD_Mining_Brochure_paths.pdf

First Solar. (2020). *Series 6 Module datasheet.*

Gellings, C. W. (1995, October). The concept of demand-side management for electric utilities. *Proceedings of the IEEE,* 73(10), 1468-1470.

GIZ. (2016). *Biogas Technology Matrix.*

Gonzalez et al. (2017). Key performance indicators for wind farm operation and maintenance. *Energy Procedia,* 137, 559-570.

Hau, E. (1988). *Windkraftanlagen - Grundlagen, Technik, Einsatz, Wirtschaftlichkeit*.

IEA PVPS. (2019). *Trends in Photovoltaic Applications 2019.* . International Energy Agency, Photovoltaic Power Systems Technology Collaboration Programme. Report T1-36: 2019.

IFC. (2015). *Utility-Scale Solar Photovoltaic Power Plants: A Project Developers Guide.* International Finance Corporation.

Klein, P., Sereme, B., Brovko , F., Maponya, F., Nhleko, T., & Nontso, Z. (2019). *Preliminary Value Proposition of Alternative and/or Regenerative Energy Sources for the Mining Industry.* Mandela Mining Precinct.

Krokoszinski, H. J. (2003). Efficiency and effectiveness of wind farms-keys to cost optimized operation and maintenance. *Renewable Energy* , 28(14).

Lee, J. &. (2019). *Global Wind Report* 2019. GWEC.

NREL. (n.d.). *Photovoltaic Research: Best Research Cell Efficiency Chart.* (National Renewable Energy Laboratory) Retrieved 6 14, 2020, from https://www.nrel.gov/pv/cell-efficiency.html

NREL. (n.d.). *Photovoltaic Research: Champion Photovoltaic Module Efficiency Chart.* (National Renewable Energy Laboratory) Retrieved 6 14, 2020, from https://www.nrel.gov/pv/module-efficiency.html

Philipps, S. P., Bett, A. W., Horowitz, K., & Kurtz, S. (2015). *Current Status of Concentrator Photovoltaic (CPV) Technology.* Fraunhofer ISE and NREL.

Potgieter, J. G. (2011). *Agricultural Residue as a Renewable Energy Resource: Utilisation of Agricultural Residue in the Greater Gariep Agricultural Area as a Renewable Energy Resource.* University of Stellenbosch : MEng Thesis .

REUK. (n.d.). *Betz Limit - Wind.* Retrieved 7 7, 2020, from www.reuk.co.uk/Betz-limit.htm

SHC. (2020). *Solar Heat Worldwide 2020.* Solar Heating and Cooling Programme, International Energy Agency.

VENTI Japan. (n.d.). *Wind Power.* Retrieved 7 7, 2020, from http://www.venti-japan.jp/en/windpoweren.html

Xia, X., & Zhang, J. (29-31, March 2010). Energy efficiency and control systems-from a POET perspective. Control Methodologies and Technology for Energy Efficiency, (pp. 1-6). Vilamoura, Portugal.

APPENDIX

APPENDIX A: APPLICABLE STANDARDS AND GUIDELINES FOR SOLAR PV PLANTS

The following is a non-exhaustive list of standards and guidelines. It is the responsibility of the reasonably experienced EPC contractor to be familiar with these and other standards.

South African National Standards (SANS)

SANS 97 (Electric cables-Impregnated paper-insulated metal-sheathed cables for rated voltages 3.3/3.3 kV to 19/33 kV)

SANS 474/NRS 057 Code of practice for electricity metering

SANS 780 (Distribution Transformers)

SANS 1029 (Miniature substations for rated AC voltages up to and including 24 kV)

SANS 1063 (Earth rods, couplers and connections)

SANS 1213 (Mechanical cable glands)

SANS 1339 (Electric cables - Cross-linked polyethylene (XLPE) insulated cables for rated voltages 3.8/6.6 kV to 19/33 kV)

SANS 1507 (Electric cables with extruded solid dielectric insulation for fixed installations (300/500 V to 1 900/3 300 V) (All parts)

SANS 1874 (Switchgear - Metal-enclosed ring main units for rated AC voltages above 1 kV and up to and including 36 kV)

SANS 1885 (AC metal-enclosed switchgear and control gear for rated voltages above 1 kV and up to and including 36 kV)

SANS 10142-1 (The wiring of premises Part 1: Low-voltage installations)

SANS 10142-2 (The wiring of premises Part 2: Medium-voltage installations above 1 kV AC not exceeding 22 kV AC and up to and including 3 MVA installed capacity)

SANS 10198 (The selection, handling and installation of electric power cables of rating not exceeding 33 kV) (all parts)

SANS 10199 (The design and installation of earth electrodes)

SANS 10200 (Neutral earthing in medium voltage industrial power systems)

SANS 10292 (Earthing of low-voltage distribution systems)

SANS 10160 (Load assumption and structural design)

SANS 10313 Protection against lightning - physical damage to structures and life hazard

SANS (IEC) 60076 (Power Transformers – All Parts)

SANS (IEC) 60529 (Degrees of protection provided by enclosures (IP codes)

SANS (IEC) 60947 (Low-voltage switchgear and control gear)

SANS (IEC) 62271 (High-voltage switchgear and control gear (All Parts))

NRS

NRS 013 (Medium Voltage Cables)

NRS 031 (Alternating current dis-connectors and earthing switches (up to 145 kV))

NRS 029 (Current Transformers)

NRS030 (Inductive Voltage Transformers)

NRS 048 (Electricity Supply: Quality of Supply)

NRS 053 (Accessories for medium-voltage power cables (3.8/6.6 kV to 19/33 kV))

NRS 074-1 (Low-voltage (600/1 000 V) cable systems for underground electrical distribution Part 1: Cables)

NRS 074-2 (Low-voltage (600/1 000 V) cable systems for underground electrical distribution Part 2: Accessories)

NRS 088-1 (Duct and direct-buried underground fibre-optic cable Part 1: Product specification)

NRS 088-2 (Duct and direct-buried underground fibre-optic cable Part 2: Installation guidelines)

NRS 089-1 (Maintenance of electricity networks – Part 1: Underground Distribution Networks)

NRS 089-3-2 (Maintenance of electricity networks Part 3: Substations Section 2: Power transformers, circuit-breakers, isolators and instrument transformers)

NRS 089-3-3 (Maintenance of electricity networks Part 3: Substations Section 3: Miniature substations, distribution transformers and electrical enclosures)

NRS 097-2 (Grid Connection of embedded generation Part 2)

NRS 097-2-3 (Grid Connection of embedded generation Part 2 Small Scale Embedded Generation - Section 3: Simplified utility connection criteria for low-voltage connected generators)

RPP Grid Code (Grid connection code for renewable power plants (RPPS) connected to the electricity transmission system (TS) or the distribution system (DS) in South Africa)

IEC

IEC 60287: (Electric cables – Calculation of the current rating – All Parts)

IEC 62305 (Protection against lightning – All Parts)

IEC 60364 (Low-voltage electrical installations – All Parts)

IEC 60364-7-712 (Requirements for special installations or locations - Solar photovoltaic (PV) power supply systems)

IEC 61215 (Terrestrial photovoltaic (PV) Modules - Design qualification and type approval – Part 2: Test procedures)

IEC 61643-11 (Low-voltage surge protective devices - Part 11: Surge protective devices connected to low-voltage power systems - Requirements and test methods)

IEC 61643-11 (Low-voltage surge protective devices - Part 12: Surge protective devices connected to low-voltage power distribution systems - Selection and application principles)

IEC 61936 (Power installations exceeding 1kV AC – All Parts)

IEC 61724 (Photovoltaic system performance monitoring - Guidelines for measurement, data exchange and analysis)

IEC 61730 (part 1 and 2 safety)

IEC 62108 (Concentrator photovoltaic (CPV) modules and assemblies - Design qualification and type approval)

IEC 62109 (Safety of power converters for use in photovoltaic power systems)

IEC 62727 (Photovoltaic systems - Specification for solar trackers)

IEC 62817 (Photovoltaic (PV) module safety qualification)

IEC 60228 (Conductors of insulated cables)

IEC 62116 (Utility-interconnected photovoltaic inverters - Test procedure of islanding prevention measures)

IEC 60502-1 Power cables with extruded insulation and their accessories for rated voltages from 1 kV (Um = 1.2 kV) up to 30 kV (Um = 36 kV) - Part 1: Cables for rated voltages of 1 kV (Um = 1.2 kV) and 3 kV (Um = 3.6 kV)

IEC 60502-2 Power cables with extruded insulation and their accessories for rated voltages from 1 kV (Um = 1.2 kV) up to 30 kV (Um = 36 kV) - Part 2: Cables for rated voltages from 6 kV (Um = 7.2 kV) up to 30 kV (Um = 36 kV)

Others

TÜV2 Pfg 1169 (Requirements for cables for use in photovoltaic-systems)

DST 34-1765 Distribution standard for the interconnection of embedded generation