RENEWABLE ENERGY FEASIBILITY STUDY REPORT

Project Title:

FEASIBILITY STUDY, ECONOMIC AND INSTITUTIONAL ANALYSIS AND CONCEPTUAL DESIGN ON ENERGY MANAGEMENT AND RENEWABLE ENERGY AT SUNDUMBILI WATER TREATMENT WORK.

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Acronyms and Abbreviations

AC	Alternating Current
BESS	Battery Energy Storage System
CAPEX	Capital Expenditure
CCTV	Closed-Circuit Television
DB	Distribution Board
DC	Direct Current
DCB	Direct Current Combiner Box
DWS	Department of Water and Sanitation
GHI	Global Horizontal Irradiance
EPC	Engineering, Procurement and Construction
HOMER	Hybrid Optimization of Multiple Energy Resources
IDM	iLembe District Municipality
IDP	Integrated Development Plan
Kv	Kilovolts
kWh	Kilo Watt Hours
Kva	Kilo Volt Amps: apparent power
LCOE	Levelized cost of energy
MLM	Mandeni Local Municipality
MPPT	Maximum Power Point Tracking
MV	Medium Voltage
O&M	Operations and Maintenance
NERSA	National Energy Regulator of South Africa
OEM	Original Equipment Manufacturer
PLC	Programmable logic controller
PLD	Performance Liquidated Damage
POS	Point of Supply
PPA	Power Purchase Agreement
PR	Performance Ratio
PV	Photovoltaic
SLD	Single Line Diagram
SPD	Surge Protection Device
STC	Standard Test Conditions
USD	United States Dollar
VT	Voltage Transformer
WUL	Water Use License
WULA	Water Use Licence Application
ZAR	South African Rand

Executive summary

This report provides an overview of the Sundumbili Water Treatment Work (WTW) energy consumption profile and outlines opportunities for implementing a renewable energy system to supplement the plant's energy consumption and reduce long-term costs. An analysis was conducted to determine the most feasible energy mix that can supplement the plant's grid supply, thus reducing dependence on the grid and providing energy and cost savings. Solar rooftop and ground-mounted PV systems were assessed based on four system configurations shown below in Table 1.

Table 1: Renewable energy system configurations assessed

Scenario	Configuration
1	Rooftop Solar + Fixed Ground-mounted with Monofacial PV
2	Rooftop Solar + Ground-mounted Tracking System with Monofacial PV
3	Rooftop Solar + Ground-mounted Tracking System with Bifacial PV
4	Rooftop Solar + Ground-mounted Tracking System with Bifacial PV + BESS

Each system was modelled using PVSyst. PVSyst is an industry standard energy yield software package. The energy yield analysis was input into HOMER software to model the solar PV facilities, supplemented by the existing grid connection. HOMER is an industry standard software package that determines the most feasible solution from a levelized cost of electricity (LCOE) perspective.

Arup has determined that the plant does not have adequate area for installing a solar PV facility that would support its entire electricity load. The available ground and roof area can accommodate ~350kW$_p$, which would supplement approximately 8-9% of the plant's electricity requirements. A system of this size would cost approximately R 5 – 6 million, with a payback of period of between 9 – 10 years. A concept design was developed based on the configuration scenario considered most feasible, which is Scenario 3. These system configurations as investigated, would not provide energy security for the plant and would not be able to operate during loadshedding periods or periods of power outages, due to the system size being too small to support the plants entire load, which would require the support of a battery energy storage system. These systems also require the grid to be available in order to produce power for the plant. The recommended system, or either of the alternate systems if IDM chooses, can be pursued as a first phase (Phase 1) for the iLembe District Municipality (IDM) on their pathway to improving their energy security and reducing electricity costs and carbon footprint.

Development of a relatively small-scale system would allow the IDM to gain familiarity with solar technology, train and upskill the local labour force with regards to the operation and maintenance of solar PV facilities and create an appetite for further development in the community.

In parallel, a second phase (Phase 2) can be explored to achieve energy security for the plant. Under Phase 2, a larger scale ground-mounted solar facility (~3 – 3.2 MW), coupled with a battery energy storage system (BESS, 1400 kWh Lithium-ion could provide ~ 2 hours of autonomy), could supplement the plant's entire load demand. The BESS could be used during peak time-of-use (TOU) periods, reducing costs, or during loadshedding, providing a level of energy security and allowing the plant water operations to be uninterrupted. This would however require the leasing of approximately 7.5 ha of additional land for the construction of the large ground-mounted solar PV facility. A high-level investigation was conducted to explore the availability of additional land in proximity to the plant, that could be used for the installation. The findings and recommended next steps to explore Phase 2 are listed in Annexure 1.

1 Introduction

The Sundumbili WTW is a water purification plant owned and operated by the iLembe District Municipality (IDM). The plant is located on the northern bank of the lower Tugela River. The plant abstracts water from this river, treats the water and pumps it to remote bulk storage reservoirs which then supplies potable water to the central and northern areas of Mandeni, Ndulinde and surrounding areas.

In 2011, the pumping capacity of the Sundumbili WTW was upgraded to 40 ML/day. The plant presently provides between 25-30 ML/day of potable water, servicing 16 Wards and approximately 100,000 people. The water treatment facility comprises of various water purification stages and the plant's energy need is currently supplied by Eskom, and is split between two points of supply, namely:

- **Internal water works** which contains different water purification sections. It has a capacity and notified maximum demand (NMD) of 1,000kVA.
- **Raw water works** which abstracts water from the Tugela River and has a capacity of 500kVA and a notified maximum demand (NMD) of 400kVA.

Figure 1: Site overview (Source: Google Earth)

1.1 Scope of works overview

Arup was commissioned through the Vuthela iLembe LED Programme, to undertake a feasibility study for the IDM, regarding energy supply options that would be viable to supplement their current energy supply source (Eskom), with energy sources that are renewable and carbon (CO_2) free.

IDM has plans to reduce the plants energy consumption and cost expenditure and operate/manage the plant in a more energy efficient manner. Arup has prepared a feasibility study on the various options available for the plant to transition to renewable energy. This will in turn reduce CO_2 emissions associated with the plant and reduce the plant's overall energy costs. The renewable energy options considered are provided in Section 3.2.7 with a cost benefit analysis.

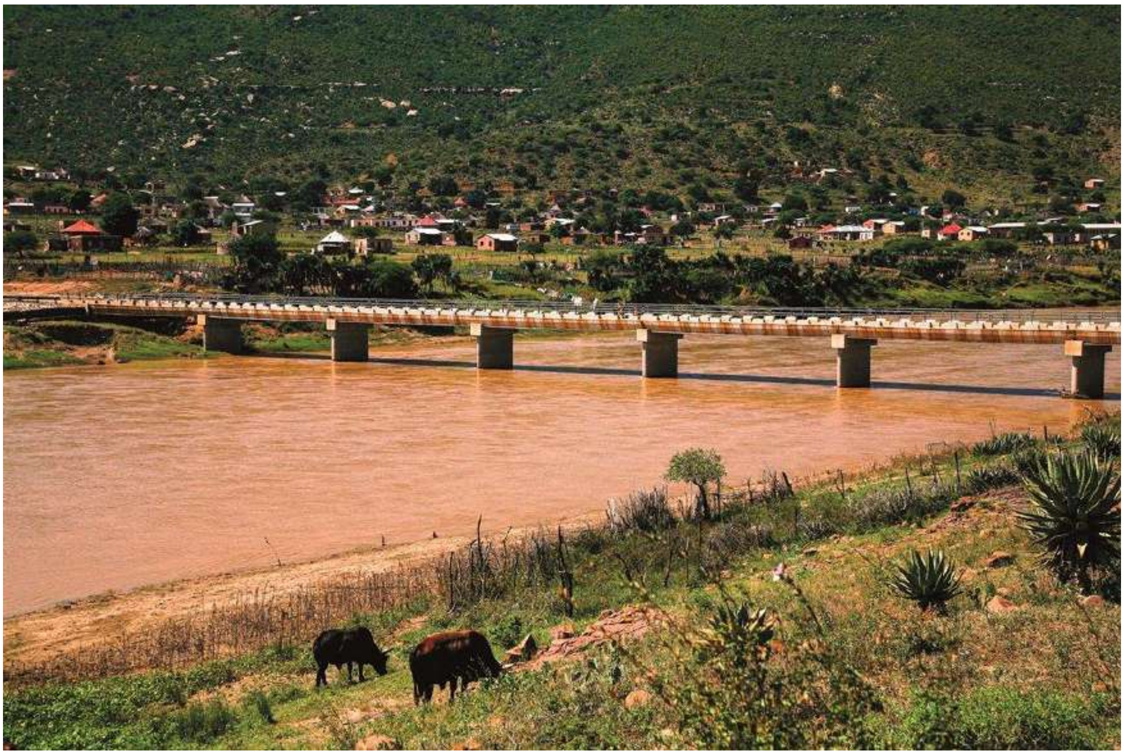


Figure 2: Tugela River [1]

1.2 Information review

A request for information was provided to the IDM. Certain information sets were not available for review, such as plant drawings and site layouts, single line diagrams (SLD) and historic plant consumption data. The following set of information was provided by the IDM and Vuthela. The information was reviewed, and the findings of these studies have influenced the compilation of this renewable energy feasibility study.

- Energy Consumption Data (2020 – June 2022)
- Eskom Consumption Bills (2021 – July 2022)
- The State of Municipal Water, Sanitation and Electricity Infrastructure by LTE Consulting (August 2020)
- Technology/opportunity Feasibility Report by Vuthela iLembe LED Programme (April 2020)
- Sundumbili WTW Energy Audit Report by SA-LED (November 2016)
- Regional Water and Sanitation Master Plan by Bosch – Vol. 2 (May 2016)

2 Methodology

A brief overview of the key steps taken for the technical and commercial analysis is provided below:

1. Sundumbili WTW Energy Demand Analysis

Investigation of efficiency measures and energy savings should always be a first step as best practice, prior to exploring renewable energy generation options. This item was covered under the Sundumbili WTW - Improving Energy Management and Efficiency Report, one of the study deliverables under the Vuthela contract VILP/I/036.

Additional review of annual energy use at the plant based on the different peak and off-peak periods was then undertaken.

2. Site Review

Analysis of the estimated solar energy resource data specific to the site.

Assessment of land area available for the installation of rooftop and ground-mounted solar installations at the Sundumbili WTW plant.

Incorporate site visiting findings and visual inspection data from the site visit conducted on the 14th of June 2022.

3. Renewable Energy Technologies Overview

Overview of short-list of renewable energy technologies available for use.

General method for technology integration within existing site.

Brief insight on availability of technology and associated resources.

Highlight key opportunities and constraints in adopting the technology.

4. Technical and Commercial Assessment

Overall assessment of each technology against a list of key criteria including technical, operational, and commercial factors.

Consideration is made based on the anticipated resource availability.

Identification of constraints that limit the potential to develop the technologies.

5. Conclusion and Recommendations

Recommendations on the configuration that best fits the energy needs of the plant as well as next steps recommended for the IDM to take forward.

The next chapter elaborates on the first three steps, whereafter the remaining steps are presented in separate chapters. In addition, there are chapters for the concept design for the recommended option along with initial analysis of the meteorological characteristics of the site and the operations and maintenance options for the IDM.

2.1 Sundumbili WTW Energy Demand Analysis - recap of initial assessments

Investigation of efficiency measures and energy savings should always be a first step as best practice, prior to exploring renewable energy generation options. This item was covered under the Sundumbili WTW - Improving Energy Management and Efficiency Report (study deliverable under VILP/I/036) which was issued on the 2 November 2022, outlining recommendations for the IDM to take forward. Key findings from the report are listed below. Please refer to the report for more detailed information.

Energy efficiency: During a site visit a review was conducted of the works, lighting, heating, and cooling systems installed at the plant buildings and administrative buildings. The lighting systems installed at the plant are already energy efficient and the plant does not utilize a centralized heating and cooling system or a building management system (BMS), therefore there are no further efficiency measures that can be incorporated at this stage. Energy efficiency regarding plant operations however can be improved by employing the recommendations set out in the report. An example would be the refurbishing the Power Factor Correction (PFC) at the facility which would reduce the maximum demand by ~12% and result in a cost saving of ~R37,000 a year.

Electricity meters: Electricity meters enable plant operators to monitor and evaluate a plant's electricity consumption, electrical data and compare this data against billing data. Energy management can be improved by the installation of digital meters to monitor the plants consumption and the efficiency of the plant motors. The plant site visit confirmed that there were no digital electricity meters currently installed at the Sundumbili WTW. Based on a review of the plant operations, a recommendation is made to install 8 electricity meters, which is estimated to cost approximately between R 395,723.11 and R 743,927.00.

Notified Maximum Demand: A previous study funded by the USAID South Africa Low Emissions Development Program (SA-LED) in 2016 indicated that the plant was not on Eskom's correct Notified Maximum Demand (NMD) billing threshold and as a result the plant was incurring significant penalties. The plant is metered on two separate accounts as it has two points of supply (POS) for the internal water works and the raw water works. A review of the plants NMD was conducted, and it was confirmed that the internal water work's NMD was increased from 500kVA to 1,000kVA in October 2021, whilst the raw water works NMD was kept at 400kVA. The plants electricity consumption and NMD are to be monitored going forward to avoid exceeding the threshold. No further action is required at this stage.

Tariff analysis: The raw water works tariff is recommended to be changed from Nightsave Urban Small to the Miniflex tariff. The Miniflex tariff was found to the most cost-efficient tariff. Eskom conducted an analysis with Arup which confirmed that the Miniflex tariff is a more cost-effective tariff for the plant.

Loadshedding status: A loadshedding exemption assessment was conducted for the plant as it provides a critical service (potable water supply) according to the National Regulatory Services (NRS) Quality of Supply Standard - NRS 048-9-2019. It was concluded, via engagement with Eskom, that due to the current state of national electricity supply, loadshedding provincial targets would not be met if water treatment plants are excluded from the loadshedding schedule. Based on Eskom's assessment the Sundumbili WTW is not eligible for exemption based on the plant feeder loads.

2.2 Site review - recap of initial assessments

A site visit was conducted on the 14th of June 2022. Arup's Engineer, Derrick Makhathini, was taken around the plant by Sifiso Zulu (Plant Supervisor) and Sithembiso Dlamini (Plant Operator) who shared information about the current and past operations of the plant. Table 2 below provides an overview of the site visit findings. The overall risk level of the site visit findings was set at **Medium-High**, as the plant is operational and providing water on a regular basis to its constituents; however, there are areas that have been identified that require maintenance, and/or refurbishment to allow the plant to continue to function optimally and avoid further deterioration.

Table 2: Site visit findings

Item under review	Commentary	Risk level	Mitigation
Site access	Site access was sufficient. All plant administrative buildings and plant rooms were accessible. The only area that was not accessible were the Eskom meter cubicles. The risk is set to **Low.**	L	No mitigation required.
Infrastructure	The plant's building and electrical infrastructure is dilapidated with some of the control and monitoring equipment systems not working, such as the power factor correction panels and electricity meters. The risk for this item is set to **Medium to High.**	M-H	General maintenance and refurbishment of the plant infrastructure is highly recommended to prevent further disrepair.

Item under review	Commentary	Risk level	Mitigation
	During the site visit, water leakage was present in the plant rooms, indicating that maintenance needs improvement. The Plant Operator indicated that delayed replacement of gland packing seals was the cause of what appeared to be water leaks. Information provided by the Plant Operator indicated that a transformer exploded in the High Lift Pump Room in April 2022, causing a fire and damage to equipment. A root cause analysis of what caused this explosion is currently being conducted. The risk is set **Medium to High** as the plant is operational; however, mitigations are recommended.	**M-H**	Maintenance of motors and motor piping needs to be properly implemented as the leakages noted in the high-lift pump room could cause hazards such as slips and falls, and electrocution should any of the live motor cables be in contact with the water.
Electricity consumption – Administrative Buildings	The plant and administrative offices mainly utilise fluorescent lighting indoors and LED lighting outdoors. The major power consumers in the administration buildings is the one air conditioner and fridge. The air conditioner mainly operates at night for approximately 8-hours for heating purposes during winter and cooling purposes during the summer. There are no immediate areas for energy efficiency measures to be implemented with regards to the lighting, heating and cooling systems. The risk is set to **Low.**	**L**	No mitigation required.
Electricity consumption – Plant Buildings	The only major power consumers in the plant buildings are the motors. The risk for these is set **Medium to High.**	**M-H**	Recommendations for efficient operation of the motors and the overall plant were provided in the report.
Metering	The existing meters on the electrical enclosures are analogue meters and thus do not have the capability of storing electrical data for evaluation. Arup's recommendation would be to install digital meters for the plant in order for the plant operators to be able to monitor and evaluate the plant's electrical consumption and compare this data against Eskom's electricity bills. Check metering could also be installed alongside Eskom's metering to check and verify the power supplied to the plant. The risk is set **Low to Medium** as the plant is operational; however, mitigations are recommended.	**L-M**	Installation of digital electricity meters are recommended.
Water loss	During the site visit the raw water piping as well as piping in the high-lift pump room appeared to have water leaks; however, according to information provided by the Plant Operator, the water loss was due to gland packings which needed replacement. A gland packing is a seal that prevents fluid loss from around the shaft of the motor and is essential for the efficiency of pumps and valves. The gland packings have since been replaced. Excessive water loss can result in the reservoirs taking longer to fill up, which leads to prolonged operation resulting in wear and tear of the motors and pumps and an increase in energy consumption. Raw water and high-lift stand-by pumps were removed for repair at the time of the site visit and were not able to be inspected. Maintenance schedules and maintenance activities are recommended to be monitored going forward. The risk is set **Low-Medium** as maintenance needs to be kept up to date to avoid water loss and maintain overall system efficiency as well as health and safety protocols.	**L-M**	Maintenance schedules and maintenance activities are recommended to be monitored going forward to avoid any areas of water loss resulting in decreased system efficiencies well as health and safety risks.

2.3 Renewable Energy Technologies Overview

A solar energy option coupled with an energy storage system, was requested for investigation in the Tender document (VILP/I/036). The proposed technology, based on solar photovoltaic (PV) panels, is well suited for the site based on the roof and land area available for use and the solar resource at the site. Table 3 below indicates the various benefits of selecting this technology.

Table 3: Solar technology benefits

Technological advantages	Commentary
Commercial maturity	Mature and well understood technology that is readily available.
Technical complexity	Technical complexity is low. The technology is relatively straightforward to install and maintain. Minimal maintenance is required. Plant operators could be trained to conduct basic plant operation.
Ease of integration	Relatively simple integration with the plant's current electrical system. Minimal interruption to the water plants daily operation.
Technology availability	Technology is readily available and easy to procure. The plant is situated ~2 hours from Durban, access to equipment or spare parts is not expected to be a challenge.
Key opportunities	Modular and scalable. Opportunity to install a smaller system if funding is constrained, and gradually scale up. 25-year plant operation of solar modules.

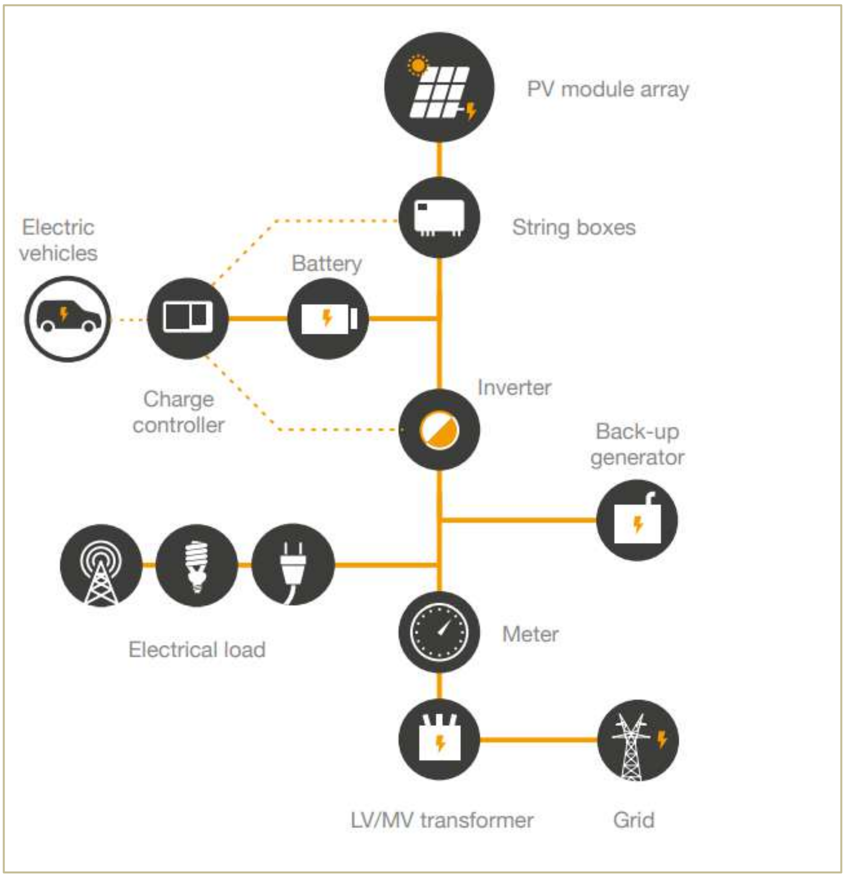


Figure 3: Solar PV technology components

3 Technical and commercial assessment

As part of this study, a comparison of four different solar PV configurations has been carried out. The aim is to provide IDM with the relevant information to support their renewable energy initiatives and decisions regarding their next steps required for implementation.

A comparison of the technologies and final conclusions are provided in this section. The short-listed technologies that were reviewed are: Solar PV (rooftop and ground-mounted) and battery energy storage systems (BESS).

A comparison of the technologies against key indicators is provided. The key indicators considered are explained further on the next page.

It must be noted that the implementation of the systems will have limitations and selection should be informed by further detailed investigations, e.g., confirmation of structural integrity of roof areas, ground testing for installation of ground-mounted PV and further discussions with technology suppliers, based on the availability of equipment.

Figure 4: Rooftop PV installation example

3.1 Site overview

A Hybrid Optimization Model for Electrical Renewables (HOMER) study was conducted to evaluate the different options of renewable energy available for integration at the plant. The HOMER model evaluates different supply options in conjunction with the current utility (Eskom) electricity tariff. Further information on the HOMER analysis is listed in Section 3.2. A solar PV facility was considered based on the roof and ground area available for installation, and the solar resource data at the site.

3.1.1 Locality

The location of the Sundumbili WTW is depicted in Figure 5 below. The plant is located in the Mandeni Local Municipality (MLM) of the iLembe District Municipality near the towns of Mandeni and Sundumbili. The coordinates of the facility are -29.1352° S, 31.3787° E. The plant is owned and operated by the iLembe District Municipality (IDM).

Figure 5: Site overview (Source: Google Earth)

3.1.2 Solar resource assessment

Figure 6 illustrates a solar resource map obtained from the SolarGIS resource database. SolarGIS is an industry standard and bankable source of meteorological data. It provides an indication of estimated solar energy resources available for power generation and other energy applications. It showcases the average daily / yearly sum of Global Horizontal Irradiation (GHI).

The GHI for the Sundumbili site is approximately **1654.8kWh/m²/year**, which is favourable considering the proximity of the plant to the coast, where the GHI is usually lower.

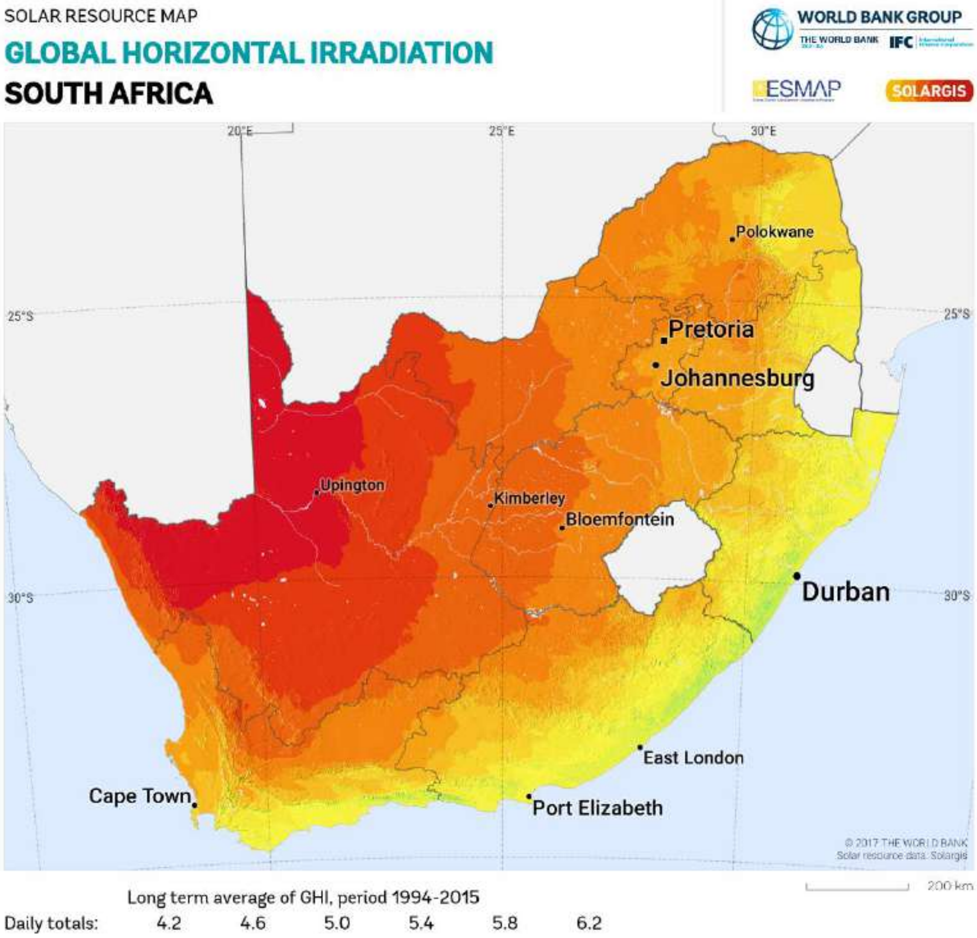


Figure 6: Monthly Average GHI for South Africa (Source: SolarGIS)

3.1.3 Global Horizontal Irradiation

The total solar radiation incident on a horizontal surface is referred to as global horizontal irradiance (GHI). It is calculated as the sum of Direct Normal Irradiance (DNI), Diffuse Horizontal Irradiance (DHI), and ground-reflected radiation. Figure 7 depicts the monthly irradiation forecast, with the GHI ranging from a high of around

6.62kWh/m²/day in summer to a low of around 3.41kWh/m²/day in winter. The average monthly GHI in this region is suitable for the installation of a solar facility.

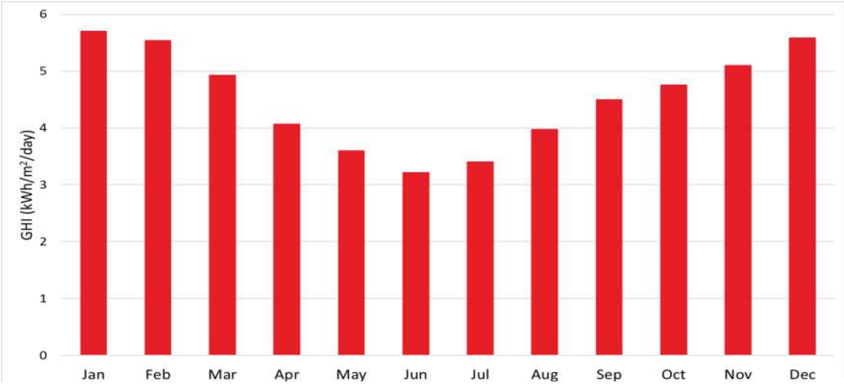


Figure 7: Site GHI for Sundumbili

4.2.2.2 Ambient Temperature

Based on the meteorological data for Sundumbili, the monthly average ambient temperatures are shown in Figure 8. The average annual temperature is estimated at 21℃. Cooler temperatures around or below the Standard Test Conditions (STC) of 25℃ are considered favourable for solar panels since lower temperatures results in lower losses due to the module's temperature coefficient characteristics / heat.

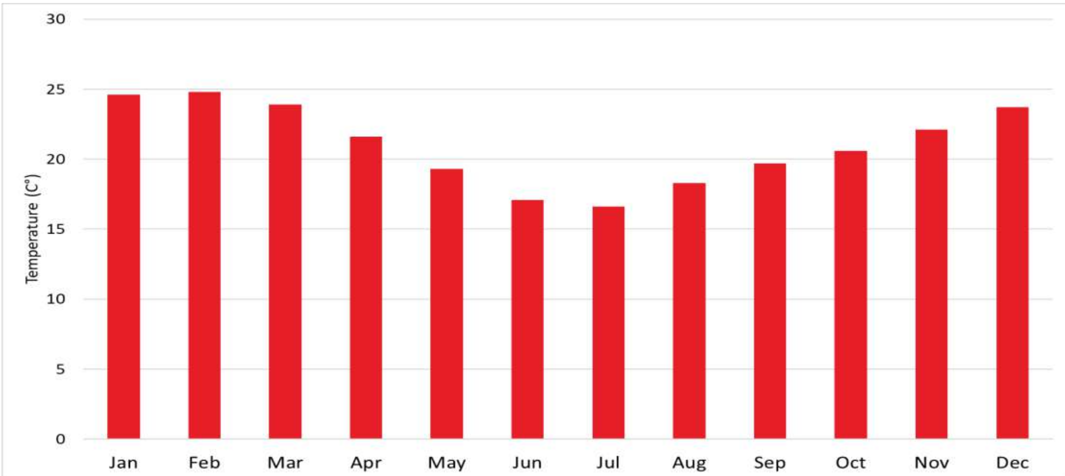


Figure 8: Monthly ambient temperature for Sundumbili

The plant operations area is ~2.6 ha, and the plant buildings and components make up ~1.2 ha of the total site. Figure 9 indicates the areas selected for ground and rooftop solar PV installations. The total investigated area available for installation of solar PV is ~0.5 ha of ground area (Areas 1 and 2) and a total roof area of 0.1 ha (Areas 3 and Area 4). Area 5 was identified as suitable for the setup of a control room and spare parts storage. In future a battery storage system could also be housed here.

A control room could typically comprise mainly of the control/monitoring equipment for the PV plant and trackers, such as computers which have the supervisory control and data acquisition (SCADA) system as well as desks, chairs, surveillance monitors and fire extinguishers. AC Combiner and LV distribution board typically also housed in the control room.

The roof area consists of the main plant building as well as the small pump room to the left of the main plant. Roof obstacles can limit the number of solar panels that can be installed on a roof, and nearby shading from larger buildings or structures, trees or vegetation, can limit the amount energy generated by a solar system. Referring to these aspects, and from initial visual inspections from the site visit, the roofs were deemed suitable for usage with no nearby shading occurring and minimal equipment situated on the roof areas, however structural integrity assessments/signs-offs are recommended and are considered best practice prior to installation.

Based on discussions with IDM plant operators, Area 6 contains the plant sand filtration section which will be used for future plant expansions. Should this area be explored in future for the installation of solar PV, it is likely that a structure would need to be erected above the filtration system where solar PV could be installed. An assessment would need to be made to ensure that the erection of a structure would not interrupt the operation of the filtration system. It can also be seen that a tree is in proximity to the area, which could cause shading or obstruction and may need to be removed.

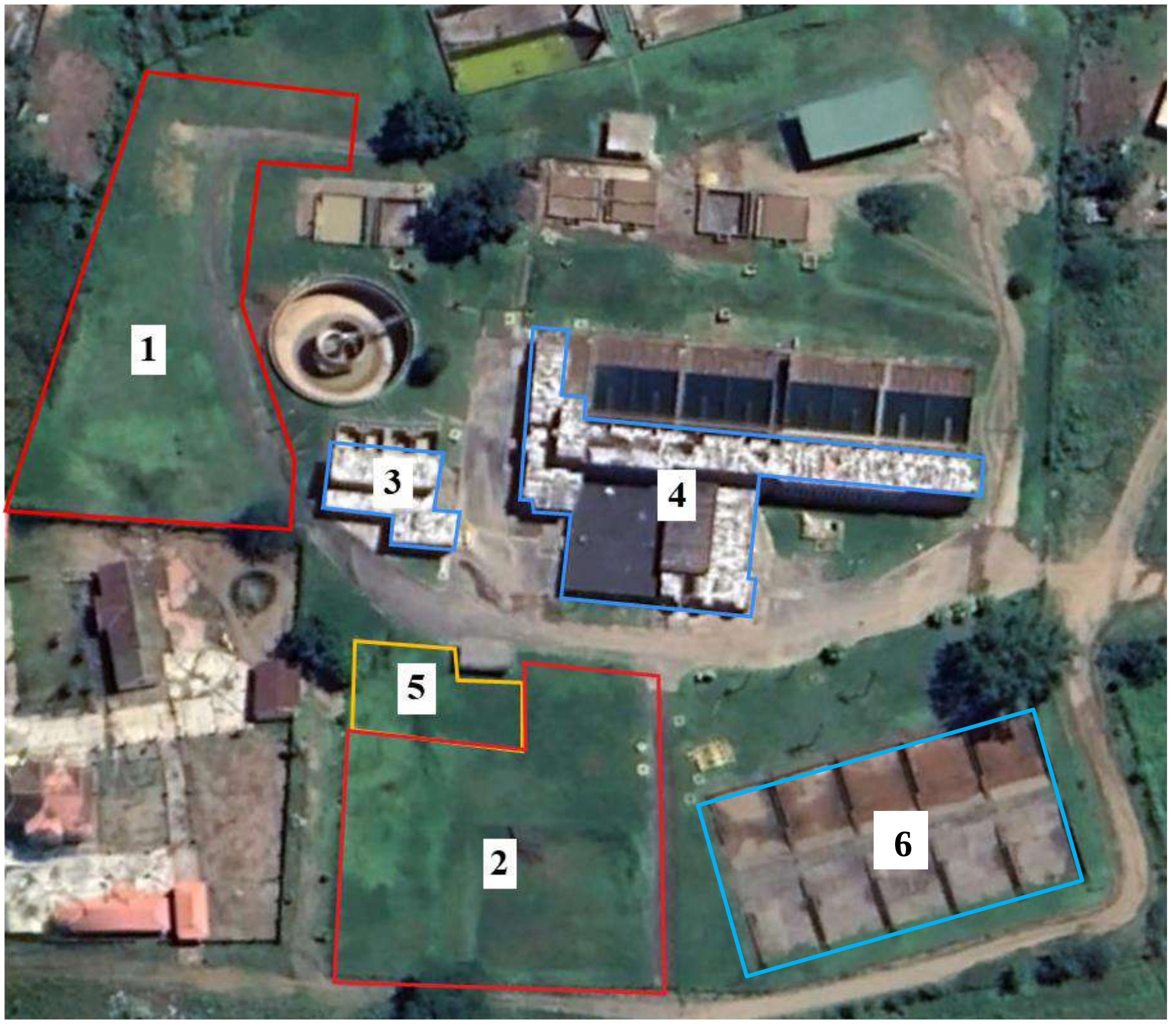


Figure 9: Aerial view of selected locations

Figure 10 and Figure 11 indicate pictures of the roof areas taken from the site visit conducted. The roofs are concrete, which will generally be assumed to be suitable to support the PV loading. However, as the buildings are old, a structural assessment is recommended to confirm the integrity of the roofs and the state of the waterproofing. Site visit findings did include slight cracks on the interior of the building roofs.

Figure 12 and Figure 13 indicate areas investigated for the installation of ground mounted PV. The majority of the land area is relatively flat with only slight inclinations. There is no presence of significant vegetation or large trees which would cause shading and need to be removed. This is favourable for the installation of a ground-mounted solar array. It can also be seen that the land is currently fenced and demarcated. Increased security would however be recommended in the form of electric fencing and a full-time guard on duty, in order to improve the site security and prevent theft and vandalism of the solar panels and accompanying equipment. Security measures are discussed further in Section 6.4.

Figure 10: Roof area

Figure 11: Roof area

Figure 12: Ground area available

Figure 13: Ground area available

Table 4 provides a summary of the estimated capacity that can be installed on the ground and roof areas that are considered to be available for use according to discussions with IDM and are deemed suitable for solar PV installation based on initial site visit findings. Arup's conservative benchmarks for ground mounted and rooftop solar PV installations, which have been considered in the capacity estimations, are listed below:

- Ground mounted PV systems: **~2.2 – 2.5ha/MWp**, based on single-axis tracking systems.
- Roof mounted PV systems**: ~80-100kWp/0.1ha**, based on flush mounted roof systems.

These ratios were obtained from previous project experience and will vary slightly according to roof conditions and system design.

Table 4: Potential capacity for installed solar PV

Area	Installation type	Est. Area (ha)	Installed Capacity (kWp)
Area 1	Ground	~0.2574	110
Area 2	Ground	~0.2543	108
Area 3	Rooftop	~0.0240	22
Area 4	Rooftop	~0.1206	109
Total		**0.6563**	**349**

3.1.4 Environmental requirements and permitting

Based on the land requirements and the system size, installation of a rooftop and ground-mounted system at the Sundumbili WTW is not expected to trigger any environmental assessments, permits or licenses. The IDM will thus be able to move quite swiftly toward implementation once funding secured.

3.1.5 NERSA generation license requirement

Based on the latest embedded generation capacity licence exemption limit of up to 100 MW, the project would be exempt from the NERSA licencing requirements.

3.1.6 Recommendations for next steps

The immediate next step in terms of implementation of the renewable energy system, should IDM agree to this implementation and the required funding be sourced, would be to conduct a structural assessment to confirm the suitability of the roofs for the installation of the solar system. This is expected to cost between R25,000 to R40,000 and could be done over a relatively short period. This would include a site visit by a professionally registered structural engineer who would sign off on the roof suitability for use. Based on the findings of the assessment, additional costing could be as a result of repair work or additional roof waterproofing that might need to be done prior to the installation taking place. As the building is quite aged there could be a likelihood of roof repairs or minor preparation that needs to be done before the solar system can be installed.

A detailed investigation and design of these solar facilities will need to be conducted. After which the necessary equipment for the construction of the solar facilities would be procured based on the sizing and quantities of the detailed design. Once construction is completed and commissioning is successful, the solar facilities can be handed-over the IDM for operation and maintenance. The structural assessments and any resulting repair work required (if any) could also be included in the EPC contractors' scope of work.

Should the IDM choose to go forward with the system, a training program is recommended to be set up with the plant personnel to educate them about the operation and maintenance of the renewable energy system, to enable a sense of ownership and buy-in and ensure that the long-term plant operation is maintained optimally, and that the installation of the system is well-received.

According to information provided by the IDM, there is an existing rooftop PV installation at the IDM ICT offices. The IDM is recommended to get in touch with the lead official who is responsible for procuring and installing this system to understand what lessons have been learned during this process and what pitfalls to avoid as well as what arrangements are in place in terms of the operation and maintenance of the system. The IDM is also recommended to approach KwaDukuza Municipality who is in the process of establishing an Energy Office, as well as the eThekwini Municipality who already has an Energy Office established and has been successful in installing rooftop solar systems on municipal buildings. Lessons learnt and knowledge sharing could take place between the municipalities to inform IDM on what pitfalls to avoid.

3.2 HOMER and Commercial Assessment

A study was conducted to determine the optimal size of a potential solar PV facility to be developed at the plant. This section of the report provides a summary of the HOMER system analysis. This analysis is primarily based on the land and rooftop areas available, the electricity consumption profile of the plant, the grid tariff schedule, a preliminary solar energy yield analysis, and system assumptions applied in the HOMER software.

3.2.1 Approach for the analysis

The following key assessments form part of the investigation for the energy generation options to serve the operational load demand at the Sundumbili WTW:

- Load profile analysis;
- Grid tariff analysis; and
- Overview of ground-mounted and roof-top solar PV facility.

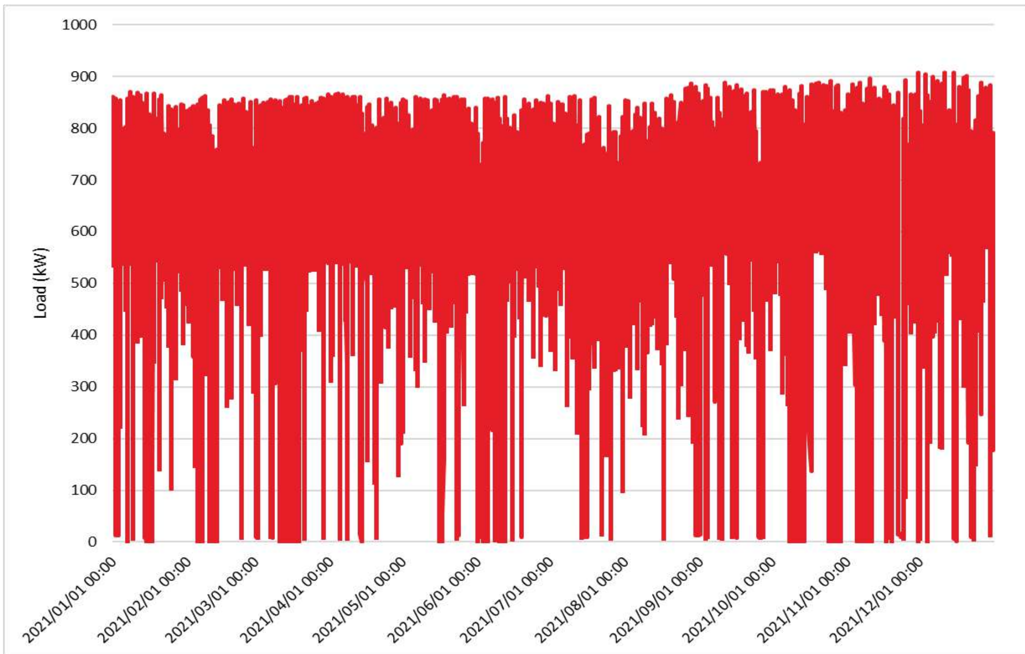
3.2.2 Load Profile Analysis

A load demand profile for the site is required to understand the onsite power requirements, which in turn informs the sizing of the optimal ground mounted and rooftop PV installation in accordance with the project objectives. Generally, for the most accurate measurement of the load profile, energy meter readings need to be taken constantly (at least hourly) for a year to understand, the daily, weekly, and seasonal profile of a facility.

3.2.3 Data received

The plant is supplied by two 11kV two feeders from Eskom. The 11kV is stepped down to 420V and 415V by two distribution transformers which then feed the internal and raw water works sections of the plant, respectively.

In order to understand the load demand requirements of the plant, the load data was obtained from Eskom for the two feeders and used to understand how much electricity the plant consumes. The profiles received for the plant include 60-minute interval data of grid energy supply for the period of **1 January 2021 to 31 December 2021**. Figure 14 below provides the annual load profile obtained based on this input data. The average combined daily consumption for the plant is **14,179kWh**. This load demand profile was imported into HOMER for use in the simulation to assess the most feasible renewable energy system, based on the plants usage pattern.



Metric	Baseline	Scaled
Average (kWh/day)	14,179	14,179
Average(kW)	590.79	590.79
Peak (kW)	908.04	908.04
Load factor	.65	.65

Random Variability

Day-to-day (%): **14.997**

Timestep (%): **34.356**

Peak Month: **April**

Figure 14: Combined load data

3.2.4 <u>Grid Tariff Analysis</u>

In order to optimise a hybrid system configuration, the grid tariff profile based on time-of-use (TOU) and distribution network charges was created as part of the HOMER simulation to define the purchase price of electricity from the grid. The plant's internal water works electricity tariff is based on Eskom's Miniflex TOU tariff. TOU periods are typically peak, standard, and off-peak periods and they differ during high and low demand seasons, see Figure 15 below. According to the consumption data, this supply is metered on the 11kV side. The Miniflex tariff is considered for the simulation as the plant's largest consumer (the internal water works) is charged on the Miniflex tariff, and the raw water works is recommended to be changed from the Nightsave Urban Small tariff to the Miniflex tariff, which was found to be a more cost-effective tariff.

Figure 15 to Figure 18 summarizes the peak and off-peak tariffs modelled in HOMER throughout the day and year, including week and weekend variations. This definition of TOU is based on Figure 18 which states the TOU periods during low and high demand seasons. This information is taken from Eskom's 2022/2023 tariff booklet. The darker shades of red, yellow, and green in Figure 18 represents the high season which ranges from June to August and the lighter shades represent the low season which ranges from September to May.

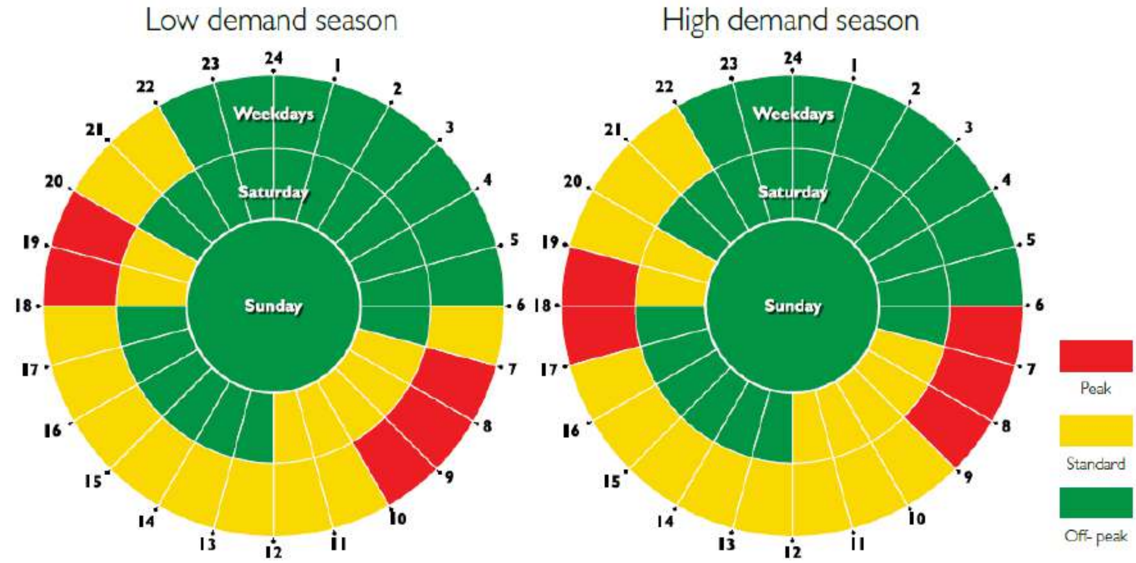


Figure 15: TOU periods (based Eskom's Miniflex tariff) [1]

		Demand R/kW/mo
Network Demand Charge		0.1029

Figure 17: Network Demand Charge as per Eskom's 2022/2023 tariff booklet

		Price R/kWh
Peak Jun-Aug		4.7192
Peak Sept-May		1.5397
Std Jun-Aug		1.4296
Std Sept-May		1.0596
Off Jun-Aug		0.7763
Off Sept-May		0.6721

Figure 16: Tarif structures as per Eskom's 2022/2023 tariff booklet

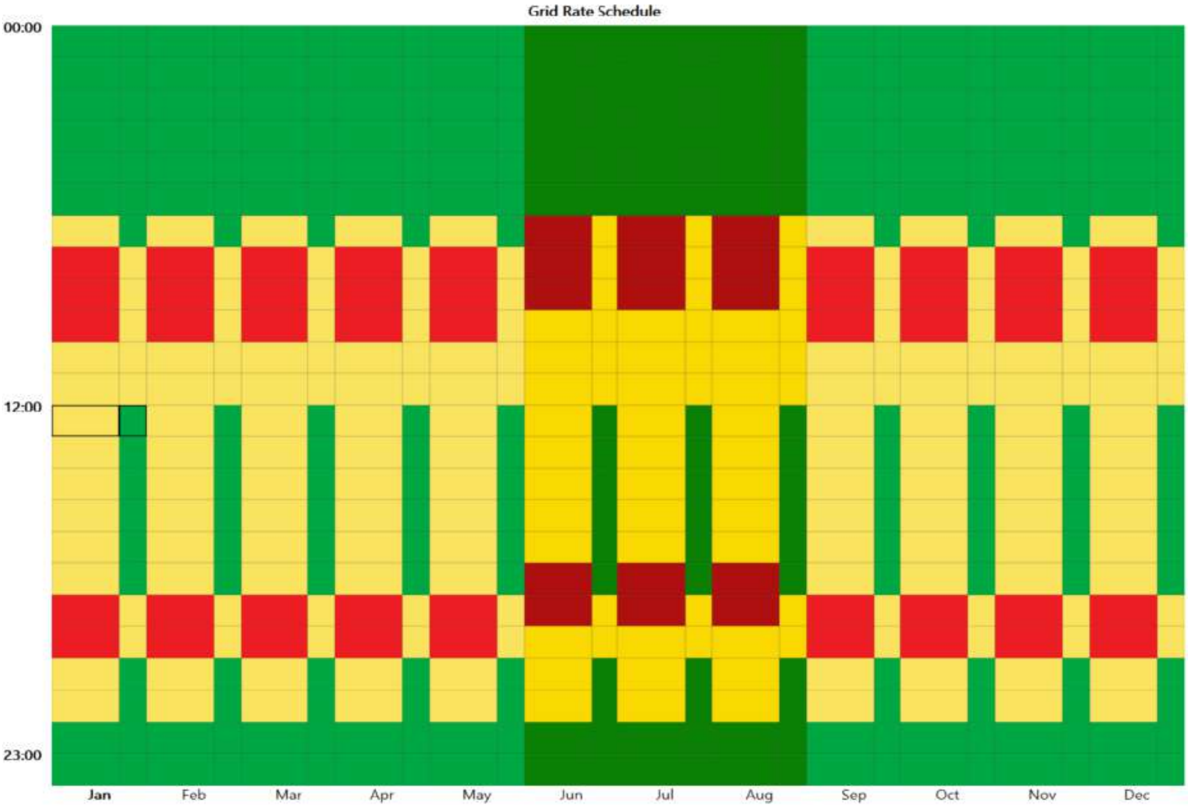


Figure 18: TOU periods for HOMER Simulations [1]

Assumptions

The following assumptions have been applied for the grid tariff analysis based on the information available and the use of the tariffs in the HOMER simulations:

- Tariffs based on 2022/2023 Miniflex rates (VAT incl.). The Miniflex tariff is considered as it is Arup's recommendation to move the entire plant to this tariff as it is a cheaper tariff. In addition, the HOMER software does not support the modelling of a load/s linked to two different tariffs.
- Service and administration charges not applied since these do not affect selection of green energy options.
- No load shedding considered for the system sized as the plant would not be large enough to provide back-up power during loadshedding.
- Grid tariffs increase of 8.61% for 2022 is considered.

3.2.5 Solar PV facility

As part of the preliminary investigation a typical solar PV facility was considered in HOMER software. Based on past project experience, the following solar PV facility design characteristics in Table 5 were considered for analysis in HOMER.

Table 5: PV System design characteristics

PV System design characteristics
PV Module
• Monocrystalline technology proposed due to high efficiency • Module capacity: 400Wp • Module dimensions: 2.02m x 1.004m x 0.035m • Module efficiency: 19.7% • Temperature coefficient: -0.37%/deg.C
Inverter
• String inverters typically used for plants 10 MW or less • Sizing of the string inverter can be carried out at detailed design stage
Single-axis tracker mounting system
• Currently the preferred design for ground mounted installation • Increased yield compared to fixed tilt system

3.2.5.1 Energy yield estimate

In addition to a standard rooftop PV installation, various ground-mounted system configurations were modelled to assess the potential energy yield that could be achieved. The standard rooftop PV systems are included in all 4 Scenarios, presented in Table 6. For Scenario 4, a 100kWh BESS with Solar PV and grid-tied system was considered; however, this option was ruled out due insufficient solar power being available to sufficiently charge the batteries, making this option uneconomical to pursue.

Tracking and fixed tilt ground-mounted PV systems were compared. Tracking systems allow the solar panel to track the sun path during the day, hence capturing the maximum amount of solar irradiation and maximising the energy yield. This is the reason tracking systems were selected to be modelled in addition to standard fixed tilt ground-mounted PV systems.

Simplistically, monofacial solar panels capture sunlight on the front side of the panel only. Bi-facial solar panels capture direct and indirect irradiation (reflected from the ground), allowing a higher energy yield to be achieved compared to monofacial panels. This is the reason that bifacial solar panels were selected to be modelled against traditional monofacial panels. As bifacial solar panels can be between 1-5% more expensive than monofacial panels, consideration needs to be given to the additional energy yield gain versus the extra capital cost that would be required.

Based on the initial analysis Scenario 3, which consists of a Rooftop Solar + Ground-mounted Tracking System with Bifacial PV panels, proves to be the most attractive option in terms of energy yield versus capital cost.

Table 6 below presents the annual specific yield obtained for each scenario based on the meteorological inputs and PVSyst energy yield analysis. Specific yield refers to the amount of energy (kWh) that is produced for every kWp of module capacity installed, over the course of a typical year. It is dependent on various factors such as location, weather profile estimates, module orientation and module selection. A module degradation of 0.5% per year was considered to account for the decrease in energy yield over the life of the panel. It can be seen that the highest specific yield value is achieved for Scenario 3, approximately 6% higher than Scenario 1.

Table 6: Specific yield per scenario

Scenario	Configuration	Specific yield (kWh/kWp)
1	Rooftop Solar + Fixed Ground-mounted with Monofacial PV	1,470
2	Rooftop Solar + Tracking System with Monofacial PV	1,533
3	Rooftop Solar + Tracking System with Bifacial PV	1,558
4	Rooftop Solar + Tracking System with Bifacial PV + BESS	1,558

3.2.5.2 PV system costs

The following solar PV facility cost figures, shown in Table 7, are based on industry benchmarks, Arup experience on current projects and local supplier knowledge. Capital and replacement costs cater for the entire solar PV facility. The operational costs (O&M) are related to plant routine maintenance required for day-to-day operation.

Table 7: PV system cost inputs (ZAR)

Configuration	2022 Cost estimate		
	Capital (ZAR/kW$_p$)	O&M (ZAR/kW/year)	Replacement (ZAR/kW$_p$)
Rooftop Fix Tilt	13,000	135	1,950
Ground-mounted Fixed tilt	14,500	169	2,175
Ground-mounted Tracking monofacial	16,000	192	2,400
Ground-mounted Tracking bifacial	16,300	192	2,445

Rates are included in USD in Table 8 for the benefit of international funding applications that might require USD rates. Exchange rate of 1 USD = 18.2259 ZAR is applied [2].

Table 8: PV system cost inputs (USD) [2]

Mount	2022 Cost estimate		
	Capital ($/kW$_p$)	O&M ($/kW/year)	Replacement ($/kW$_p$)
Rooftop Fix Tilt	713	7.4	107
Ground – Fixed tilt	795	9.3	119
Ground – Tracking monofacial	878	10.5	132
Ground – Tracking bifacial	894	10.5	134

3.2.6 Generation options analysis

The following section details the findings from the energy supply options analysis, which was completed using the HOMER software package, to investigate the lowest cost of energy to meet the load demand requirements under various scenarios.

3.2.6.1 Overview

The HOMER software package was used to analyse the preliminary feasibility of introducing solar PV to supplement the plant's electricity supply. Figure 19 below shows the typical configuration of the selected energy supply options included as an input to the simulations, which are summarised as follows:

- Grid supplied electricity (Eskom)
- Roof and ground mounted PV
- Battery energy storage system

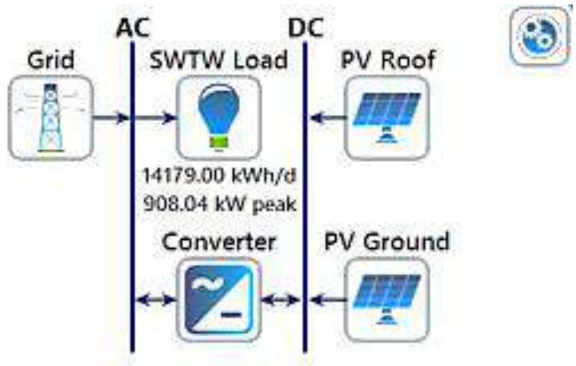


Figure 19: Schematic of generation options modelled in HOMER

3.2.6.2 Cases considered

A single scenario is considered using the generated load demand profile and grid tariff schedule. The following cases are compared as part of the main results:

- Scenario 0 : Load served with grid-supplied power only, which is the Base Case scenario ["Grid only"].
- Scenario 1, 2 and 3: Load served with a combination of grid-supplied power and solar PV energy ["Solar PV and Grid"].
- Scenario 4 : Load served with a combination of grid-supplied power, solar PV energy and BESS ["Solar PV, Grid and BESS"].

3.2.6.3 Modelling assumptions and notes

The results of the HOMER simulation are sensitive to both the main inputs (load demand and grid tariff) as well as the overarching assumptions defined in the software. The following key modelling assumptions and notes have been used for the simulations in HOMER and are the basis of the results provided. These are additional items to those covered initially in this section. They include:

- Grid carbon emission factor: 0,9006 $kgCO_2e$ per kWh [3]
- Discount rate: 10%
- Estimated inflation rate: 6%
- Project lifetime: 25 years
- Solar PV lifetime: 25 years
- Loadshedding scenarios are not considered as the system size will be too small to accommodate this.
- No export of power to the national grid.

- Service and administration charges not applied since these do not affect the selection of generation options.

The model simulated takes into consideration the plants combined load and calculates how much energy can be offset by the renewable technologies, therefore reducing CO_2 emissions and cost. Solar PV energy yield figures in HOMER software are high-level and based on calibration with PVsyst results; therefore, are subject to change during more accurate energy yield simulations.

3.2.7 HOMER Results

Based on the inputs, assumptions, and analysis of the facility's load and potential installed capacity for the roof and ground mounted system, three cases that detail the potential energy mixes are presented below:

1. Grid only:

This is the base case scenario and illustrates the amount of energy the plant consumes from the grid. This energy is based on the plant's 2021 consumption data. The plant consumes on average 14,179kWh/day which results in approximately 4,660 tCO_2/kWh/year of emissions.

2. Solar PV and Grid:

Subject to roof structure and ground condition investigations, a total of 349kWp combined ground and roof-mounted solar PV can potentially be installed on the identified plant areas, covering a combined total area of ~0.66 ha. Installing a renewable energy system on these areas will offset between 8% to 9% of the plant's grid consumption during the day. This offset will be affected by the daily solar irradiation received by the solar panels. The following solar PV facility configuration scenarios were considered:

- Rooftop Solar PV + Ground Mounted Fixed Tilt PV with Monofacial PV Panels
- Rooftop Solar PV + Ground Mounted Tracking System with Monofacial PV Panels
- Rooftop Solar PV + Ground Mounted Tracking System with Bifacial PV Panels

These options were all feasible and they showcase a reasonable rate of return of ~9% as well as a payback back period of approximately 9-10 years. The results for these scenarios are presented in a Table 9 below.

3. Solar PV, Grid and Battery Energy Storage System (BESS):

The scenario of integrating BESS with solar PV and the grid was considered; however, to sufficiently charge the batteries at a low cost of energy, additional solar PV capacity will need to be installed, for which there is no additional land area available within the facility to install.

Alternatively, a portion of installed capacity of PV could be dedicated to charging the BESS which would thus reduce the solar PV available for use by the plant. The amount of solar PV generated would also be insufficient to charge a suitably sized BESS system. The BESS could be charged using the grid, but this would also be unfeasible as it would increase the operating costs as well as the carbon footprint of the plant as grid energy would be dedicated to the BESS as well as the plant. A BESS system also attracts replacement costs of ~R664,000 per year (depending on battery size, usage patterns and the battery technology selected). BESS has a relatively shorter lifespan (again depending on usage patterns and technology selected this could be between ~7-15 years) compared to PV modules (lifespan of 20-25 years).

The CAPEX cost used for modelling these systems is based on local suppliers, industry standards and Arup's project experience benchmarks. A 20-year financial analysis as well as energy production and offsets for Scenarios 1 to 4 is included in Section 8 as well as in Annexure 3.

Table 9: HOMER analysis results (ZAR)

Scenario	Grid supplied	Solar PV	Energy Demand covered by PV	LCOE	CAPEX	Annual OPEX	IRR	Simple Payback	Net Present Value	Emission Reduction
	[MWh/yr]	kWp	[MWh/yr]	[ZAR/kWh]	[ZAR'mil]	[ZAR'mil/yr]	[%]	[Years]	[ZAR'/mil]	[CO2 kg/yr]
0. Base case	5,175	-	-	1.12	-	5.81	n/a	n/a		-
1. Base case + Rooftop Solar + Ground Fixed System	4,712	349	519	1.08	4.86	0.054	9.3	9.6	3.26	417,725
2. Base case + Rooftop Solar + Ground Tracking System Monofacial	4,688	349	545	1.08	5.19	0.06	8.5	10	2.87	438,448
3. Base case + Rooftop Solar + Ground Tracking System Bifacial	4,679	349	555	1.07	5.26	0.06	9.4	9.3	3.50	473,479
4. Base case + Rooftop Solar + Ground Tracking System Bifacial + BESS	4,679	349	555	1.10	5.86	0.09	9.0	10	3,28	450,403

Based on the energy consumption bills, the Sundumbili WTW currently pays approximately R5.81mil a year. This cost can be reduced via the implementation of the solar facilities discussed in this report. The savings that can potentially be achieved are mentioned in section 8 as well as in Annexure 4.

Rates are included in USD in Table 10 for the benefit of international funding applications that might require USD rates. Exchange rate of 1 USD = 18.2259 ZAR is applied [2].

Table 10: HOMER Analysis Results (USD)

Scenario	Grid supplied	Solar PV	Energy Demand covered by PV	LCOE	CAPEX	Annual OPEX	IRR	Simple Payback	Net Present Value	Emission Reduction
	[MWh/yr]	kWp	[MWh/yr]	[USD/kWh]	[USD'mil]	[USD'mil/yr]	[%]	[Years]	[USD'/mil]	[CO2 kg/yr]
0. Base case	5,175	-	-	0.06	-	0.318	n/a	n/a		-
1. Base case + Rooftop Solar + Ground Fixed System	4,712	349	519	0.06	0.23	0.003	9.3	9.6	0.18	417,725
2. Base case + Rooftop Solar + Ground Tracking System Monofacial	4,688	349	545	0.05	0.28	0.003	8.5	10	0.16	438,448
3. Base case + Rooftop Solar + Ground Tracking System Bifacial	4,679	349	555	0.06	0.29	0.003	9.4	9.3	0.19	473,479
4. Base case + Rooftop Solar + Ground Tracking System Bifacial + BESS	4,679	349	555	0.06	0.32	0.004	9.0	10	0,18	450,403

3.3 Conclusion

Following the HOMER analysis of above system configurations for the Sundumbili site, the results indicate that a combination of rooftop (130 kWp) and ground-mounted solar PV (219 kWp) of approximately 349 kWp in total, integrated with the grid supply from Eskom, is feasible. The most attractive option being the tracking system with bifacial solar PV modules, presented in Scenario 3, due to the system being able to achieve a higher energy yield at a slightly lower LCOE. Bifacial modules were found to generate ~2 % more energy at ~1% extra capital cost. This option also results in the highest carbon emission reduction equating to approximately 473 t CO_2/kWh/year.

The systems (Scenario 1 to 4) have a similar LCOE of between R1.07/kWh and R1.08/kWh as well as similar internal rates of return and payback periods of 9.1 – 9.4% and 9.3 – 9.6 years, respectively. The most attractive system, Scenario 3 (tracking system with bifacial modules), provided the highest return rate at 9.4% resulting in the shortest payback period of 9.3 years.

Scenario 4 showcases the cost implications of integrating a battery storage system in addition to the Scenario 3 configuration. Scenario 3 produces the highest energy yield and would thus be better suited to charge the battery energy storage system. The solar PV facility size is not large enough however to charge the BESS system to a level that would provide reasonable autonomy. The current achievable autonomy for a PV plant of this size is ~0.14 hours (~8 minutes), which is extremely low. To achieve a better autonomy a larger portion of the solar PV facility would need to be dedicated to battery charging which would decrease the energy available for the load and thus decrease the grid offset energy amount. The LCOE for integrating a battery storage system is R1.09/kWh. The battery capital investment and maintenance cost for this scenario is ~R664,600 and R33,230/year, respectively. Considering an autonomy of only ~.14 hours (~8 minutes), at these costs, this scenario is not feasible.

It is important to note that the considered solar PV facilities do not provide the plant with reliability of supply during a grid outage or load shedding. This is because the PV plant's inverters are grid-tied inverters and thus operate in parallel to the grid. The grid is required to provide a reference signal (frequency, voltage, and phase angle) to the inverters for them to start up and synchronize with the grid to start supplying energy. The main benefit of a grid-tied solar PV facility is its simplicity and low operational and maintenance costs as off-grid systems require batteries to store the energy produced by the solar PV facility which can then be discharged to supply the plant's load. An off-grid system is generally used in situations where no grid is available. The batteries would need to be sized accordingly to meet the load energy requirement. The solar PV facility would also need to be sized to sufficiently charge this battery system. Due to this battery integration, an off-grid system is much more expensive compared to an on-grid system.

Integration methodology of the solar PV facility to the WTW's existing electrical infrastructure/switchboard will need to be developed. Earthing and lightning protection should be investigated at the detailed design stage. Site security, which is discussed in Section 6.4, should also be investigated further and included. In summary, the following technical aspects require further investigation and consideration:

- Integration of the solar PV facility with the existing electrical infrastructure.
- Site security risk.
- Earthing and lightning protection.

Items not costed for in this study:

- Control room structure – this requires a preliminary investigation to be costed and should be done at detailed design stage. Control room construction could range from R200,000 – R300,000. Lower costs could be achieved depending on exact space requirements. This cost excludes cabling and electrical equipment which would be specified at detailed design stage by an EPC.
- Security – A high-level cost estimate for security has been provided in the BOQ based on assumptions and visual inspection of the site visit, however, IDM will need to determine how much security is needed based on the detailed design and community experience.

4 PV Facility Concept Design cont.

A typical solar PV facility consists of a solar PV module array, mounting structures, inverters, and transformers (if required, for larger systems). Other components such as cabling, safety and electrical equipment also form part of a solar PV facility; however, for the purposes of concept design, only the major components were considered.

The solar PV module array is the generating unit of a facility where electricity is generated via the harnessing of light energy in the form of irradiation and converted into electrical power by the modules. The power generated from the module is transmitted to inverters using DC cabling where it is converted from DC to AC current by the inverters. Inverters also have other functions within a solar PV facility which shall be discussed later in the report. If required, transformers are used to step the voltage up or down to the required interconnection point voltage.

4.1 PV Module Technology

Solar PV modules are made of a variety of materials; however, the most common PV modules use in commercial solar PV facilities can be divided into three categories, namely:

- Monocrystalline;
- Polycrystalline; and
- Thin Film.

Crystalline modules are made from crystalline silicon material while thin film modules use less material than the crystalline modules and are made from rare metals like tellurium – the most common being Cadmium Telluride combination. Crystalline modules can be manufactured as monofacial or bifacial, i.e., absorbing light from the front only or from both the front and rear side of the module. These are described in more detail in Table 11.

Table 11 : Crystalline module technology comparison

PV Module Type	Description
Monocrystalline 	• *Cells are made up of a single crystal structure.* • *Modules achieve better efficiencies than polycrystalline modules.* • *Often more expensive than other module types.* • *PV module efficiency: 18% - 22%.* • *Available in Bifacial modules*
Polycrystalline 	• *Cells consist of a multi-crystalline structure.* • *Cheaper and easier to manufacture than monocrystalline.* • *PV module efficiency: 17% - 20%.* • *Available in Bifacial modules*
Thin Film 	• *Cadmium Telluride (CdTe) is the largest invested thin film cell technology.* • *Manufacturing costs 30% - 50% less than other thin film cell technologies.* • *Material very toxic, therefore modules need special decommissioning and recycling processes to protect the environment.* • *PV module efficiency: 14% - 17%.*

4.1.1 Module Selection

The selected module technology for this feasibility study is a monocrystalline technology. This was done through selecting various manufacturers and technologies and comparing the energy output for the space available to determine the most optimal module selection. Bifacial modules were investigated as an option for the site for the ground-mounted solar tracking system. Bifacial modules provided approximately 2% higher energy yield at approximately 1% higher capital expenditure (CAPEX).

Key equipment selection and optimisation is expected to form part of the detailed design phase to be completed by a selected Engineering, procurement, and construction (EPC) contractor who would provide the most optimal solution which may have increased energy yield output and therefore savings for the Client.

The selected module for the concept design of the facility is the bifacial 400Wp monocrystalline TSM-DE15H TallMax module by Trina Solar. This module has a maximum efficiency of 19.7%. A procurement design may utilise newer technology, depending on when construction would proceed. Due to constant development in technology, a higher-power module may be available during procurement, however it is prudent to conduct the study with current technology as a higher power module will result in an improved or smaller facility layout and a higher energy yield.

The technical module specifications can be found in Table 5. Trina Solar is a first-tier PV module manufacturer (as rated by Bloomberg New Energy Finance) with an annual module production capacity of 8 GW and has delivered over 70 GW of module since its inception in 1997. At a nominal capacity of 349kWp, the proposed Sundumbili solar PV facility will require 873 modules (combined rooftop and ground-mounted) to be installed. The AC capacity will be limited to 300kW_{ac} (5 units x 60 kW inverters).

4.1.2 Inverters

The main function of an inverter in a solar PV facility is to convert the DC current generated by the modules into AC current. Inverters are also equipped with control units to ensure:

- Maximum Power Point Tracking (MPPT);
- Anti-islanding;
- Harmonic current emissions are within limits; and
- DC injection is restricted.

Inverters are generally classified into string inverters and central inverters, as is described in the Table 12.

Table 12: Inverter comparison

Inverter Type	Description
String Inverter	• Small and light – usually handled by one person and do not require special plant for site distribution and can be installed on walls or on the back of the PV module mounting structures. • Both single phase and three-phase designs are prevalent. • Mass produced – may suffer from random quality issues. • Off-the-shelf items – readily available from various distribution channels. • Consumer-oriented. Product and documentation designed for average consumer. • Efficiency is in line with central inverters. • One MPPT per unit minimum. More versatile and less prone to mismatch losses. • When broken, they only affect a relatively small part of the array. Can be temporarily replaced while taken off-site to be fixed. • Spare units can be easily stored onsite thereby facilitating replacement if needed. • Require a lot less DC cabling and no additional equipment. • Can be more expensive per kW than central inverters.
Central Inverters	• Large and heavy, need to be craned in place and require civil works. • All central inverters are three-phase. • Industrial quality units. • Usually made to order, with longer lead times. • Commercial-oriented, require specially trained personnel to install, commission and maintain. • Initially more efficient, mostly due to lack of integrated transformer. • Usually equipped with one to three MPPTs, which may increase losses. • When broken, a large part of the array is offline. Need specialist team call-out in most cases. • DC cabling a lot more complex – need additional equipment, such as DC Combiners and DC Fuse boards. • Cheaper per kW than string inverters.

4.1.3 Inverter Selection

The Huawei SUN2000-60KTL-M0 string inverter was selected for the concept design. The overall capacity of the proposed solar PV facility is relatively small, which favours smaller inverters as opposed to large central inverter would take a large a section of the facility out of service during a failure or maintenance. As the site is relatively remote, string inverters will be easier to transport and replace in the event of failure. The use of string inverters will also remove the need for string combiner boxes as string isolation can be done at the inverter. Some key inverter characteristics are presented in Table 13.

Table 13: Summary of inverter specifications

Parameter	Details
Manufacturer	Huawei
Model	SUN2000-60KTL-M0
Type	String
Max efficiency	98.7%
European efficiency	98.5%
MPPT Voltage Range	200-1000V
Max input current per MPPT	22A
Max number of inputs	6
Rated AC Active power	60kW

Parameter	Details
Max AC Apparent power	66kVA
Rated output current	86.7A
Max output current	95.3A
Monitoring	Included
Dimensions (W x H x D)	1,075 × 555 × 300 mm

Figure 20: Sample Huawei inverter

Source: Huawei Solar

The Huawei inverter, example is shown in Figure 20, is rated at 400 V_{ac} (3 phase/N and PE) output. This inverter can be connected at the point of supply to the supply the plant at the rated voltage. A total of 5 units (rated output 60kW) will be utilised for the facility, which is a total AC capacity of 300 kW_{ac}. The overall DC loading of the facility will be 1.16 (DC:AC) which is within limits of the inverter's characteristics. The string inverters would need to be mounted on the frame of the solar PV mounting structures. An alternate mounting method is also available in which the inverters can be mounted on individual concrete foundations with enclosures for protection against the elements.

4.1.4 Mounting Structure

Solar PV facilities can be roof mounted, integrated into a building façade or ground mounted. The Sundumbili solar PV facility is proposed to comprise of both a rooftop and ground-mounted system. Mounting structures for ground-mounting PV systems can be designed to actively track the sun's path using motorized trackers. Various mounting structures are described below.

Mounting Structure Type	Description
Fixed Tilt 	• Consists of a mounting structure anchored to the ground. • The mounting is fixed at a constant tilt and azimuth (usually northern facing for plants in the Southern hemisphere) and the PV system does not track the sun.
Single-Axis Tracking 	• These are mounting platforms that can rotate around a single axis. • The axis of rotation can either be vertical, horizontal, or tilted towards north with horizontal axis tracking being the most common. • The single-axis systems allow the approximate tracking of the sun's position, while it is moving from east to west.
Rooftop	• Various rooftop solar mounting structures are available. The mounting structure/ fixtures are dependent of the roof makeup i.e., roof tiles, IBR sheeting, concrete etc.

Mounting Structure Type	Description
 Image source: Solar Power World [4]	• As the plant has concrete flat roofs, the installation illustrated on the left-hand side is the recommended layout and fixture which uses concrete ballasts/blocks. The ballasts secure the panels to the roof and prevent wind lift or other any panel disturbance, without attachment to the roof structure that could compromise the roof waterproofing.

4.1.5 Mounting Structure Selection

A horizontal single axis tracking system is proposed for the ground-mounted systems, as this provides the best energy yield per installed capacity.

The STI Norland STI-H250 dual row single axis tracker shown in Figure 21 and Figure 22 was selected for the concept design. The arrangement utilised is two modules in portrait on the torque beam. The STI-H250 can accommodate up to 60 solar panels per beam, with a motor shared between two rows. Maximizing the number of modules per tracker is best for reducing balance of plant costs.

Sharing a motor between two rows allows for more modular installation as well as increased resiliency of the project as the system will have smaller critical points-of-failure, effecting less of the facility due to component outage. In addition, a capital and operational cost saving is achieved by not applying a motor to each row.

Figure 21: STI Norland Dual Row Tracker

Modules will be mounted in portrait on the torque frame (source: https://www.stinorland.com/).

Figure 22: STI Norland Dual Row Example

(source: https://www.stinorland.com/).

The inter-row pitch was calculated to be most optimal at 6.5 m, to avoid inter-row shading, considering the space available. The definition of the pitch is illustrated in Figure 23 below.

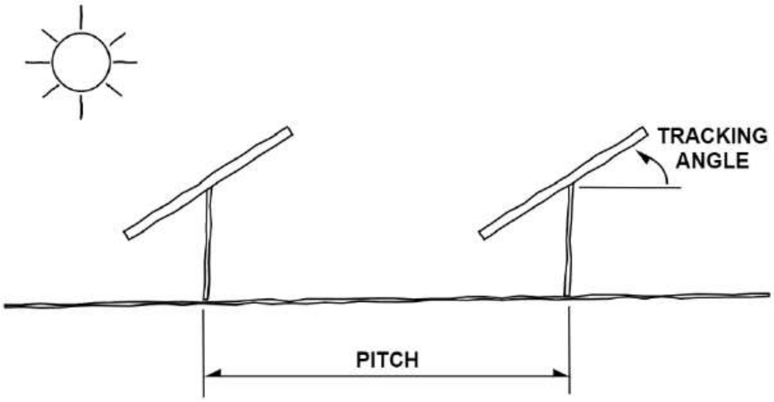


Figure 23: Profile of tracker tables

4.1.6 System design

Table 14 and Table 15 describes the overall system design characteristics of the proposed ground-mounted and rooftop solar systems.

Table 14: PV plant ground-mounted design characteristics

System Design Characteristics	
Nominal DC Capacity [kWp]	219
Inverter Capacity [kWac]	60
Number of PV Modules	548
Number of Inverters	3
Modules per String	16
Row Pitch [m]	6.5

Table 15: Rooftop PV design characteristics

System Design Characteristics	
Nominal DC Capacity [kWp]	130
Inverter Capacity [kWac]	60
Number of PV Modules	325
Number of Inverters	2
Modules per String	15

4.1.7 PV Field design

The rooftop PV systems are estimated to consist of 325 modules in total. These systems are proposed to be connected to string inverters which will in turn be connected directly to the main LV pane located in the main plant room.

The ground mounted PV systems (Area 1 and Area 2) are estimated to consist of 548 modules in total. These fields will also be connected to string inverters. These inverters are proposed to be connected to an AC Combiner Box located in Area 5, demarcated for a control room. These areas can be seen in Figure 9.

This AC combiner box will collect the AC power output from the inverters and a single AC cable will then transport this power to the main LV panel in the plant control room thus integrating the two roof and ground mount systems. The ground-mounted solar PV facility is proposed to be built utilising dual row tracker beams arranged with two solar panels in portrait.

4.2 Cable Selection and connectors

PV facilities comprise of three cable types, DC cables, AC cables (low-voltage and medium-voltage), and communication cables.

4.2.1 DC Cables

DC cables come incorporated with the modules as lead cables. These are standard copper cables and have an MC4 connector included. Modules are interconnected together to form a PV string using these cables. The PV strings will be connected to the inverters by DC string cables. These are typically 6mm^2 DC solar rated cables. It is typical for 6mm^2 Cu single core cables; red and black insulated cable be utilised. DC cables should be sized to limit system DC losses to below 1.5%.

4.2.2 AC Cables

AC power cables will be utilised to transfer AC current from the inverter to the main LV panel in the plant room (housed in Area 4). The EPC contractor shall design a suitable LV cable for the chosen inverter and voltage. During the detailed design of the facility by the selected contractor it is proposed that the cable selection be optimized based on measured circuit lengths as well as service conditions and requirements. AC cables should be selected to limit system AC losses to below 0.5%.

4.2.3 Communication cables

Communication cabling between the inverters, trackers, and the main LV panel in the plant room should be industrial rated, shielded Cat 5e, Cat 6, RS485 or fibre cables suitable for direct burying. A similar cable could be utilised for connecting the weather stations to the nearest network point.

4.2.4 Lightning protection

The average annual number of lightning flashes influencing a structure to be protected depends on the thunderstorm activity in the region where the structure is located and on the physical characteristics of the structure. The ground flash density is the basis for a risk assessment as per SANS 62305-2:2010:12 which identifies the number of direct lightning strikes per km^2/year. A value of the density must be determined for the geographic location of the structure by means of a ground flash density map obtained from South Africa Weather Service. To evaluate whether lightning protection is needed; the EPC contractor will be required to appoint a suitably qualified consultant to perform a lightning risk assessment in accordance with the procedures in SANS 62305-2:2010-12.

This should be done to avoid damage resulting from lightning strike (direct or indirect lightning strike) and specific protection measures must be taken to protect objects and human safety.

4.2.5 Equipment warranties

The following minimum warranties on major equipment are expected to be offered by the equipment manufacturers.

Table 16: List of typical equipment warranties

Item	Equipment	Warranty period
1	PV modules	10 years product warranty 25 years linear performance warranty
2	Inverters	5 years standards plus 5 years warranty extension
3	Mounting structure	12 years
4	Plant controller and monitoring system	5 years
5	Pyranometer	5 years
6	Irradiance sensors, ambient temperature sensor, module temperature sensor and wind speed and direction sensor	1 year
7	Meter	3 years
8	AC cables	1 year
9	DC cables	2 years
10	MC4 connectors	1 year

4.3 Facility layout

The solar PV installation will consist of the arrays indicated in Figure 27, Figure 28 and Figure 29. The design makes use of the maximum land areas that fall within the site boundary as well as the rooftop areas of the plant and admin buildings. The plant has two Eskom grid connection points.

- **Internal water work**s which contains different water purification sections. It has a capacity and notified maximum demand (NMD) of 1,000kVA.
- **Raw water works** which abstracts water from the Tugela River and has a capacity of 500kVA and a notified maximum demand (NMD) of 400kVA.

The internal water works Eskom point of supply is located near Area 2, indicated in Figure 24. The distribution board/main LV panel for this connection point is located within Area 2, in the main plant building. See Figure 25 for the location of the raw water works location which is a significant distance from the water plant. The distribution board/main LV panel for this connection point is located within the pump room. The solar PV facility could input into either of these points.

We have proposed to connect the solar supply into the main plant building which services the internal water works. This would avoid additional cable length costs and electrical losses that would be associated with taking the power supply from the solar facility to the raw water works pump room. The energy saving will be the same regardless of the solar PV being injected into a single point or being split between the internal water works and the raw water pumps.

Low voltage infrastructure, cables distribution costs and costs associated with the erection of a control room would need to be separately assessed by the EPC contractor. Figure 26 illustrates the potential interconnection layout in a block diagram for the purpose of indicating design intent only. Detailed design will be done by the EPC contractor.

Figure 24: Plant site areas

Figure 25: Raw water work connection point

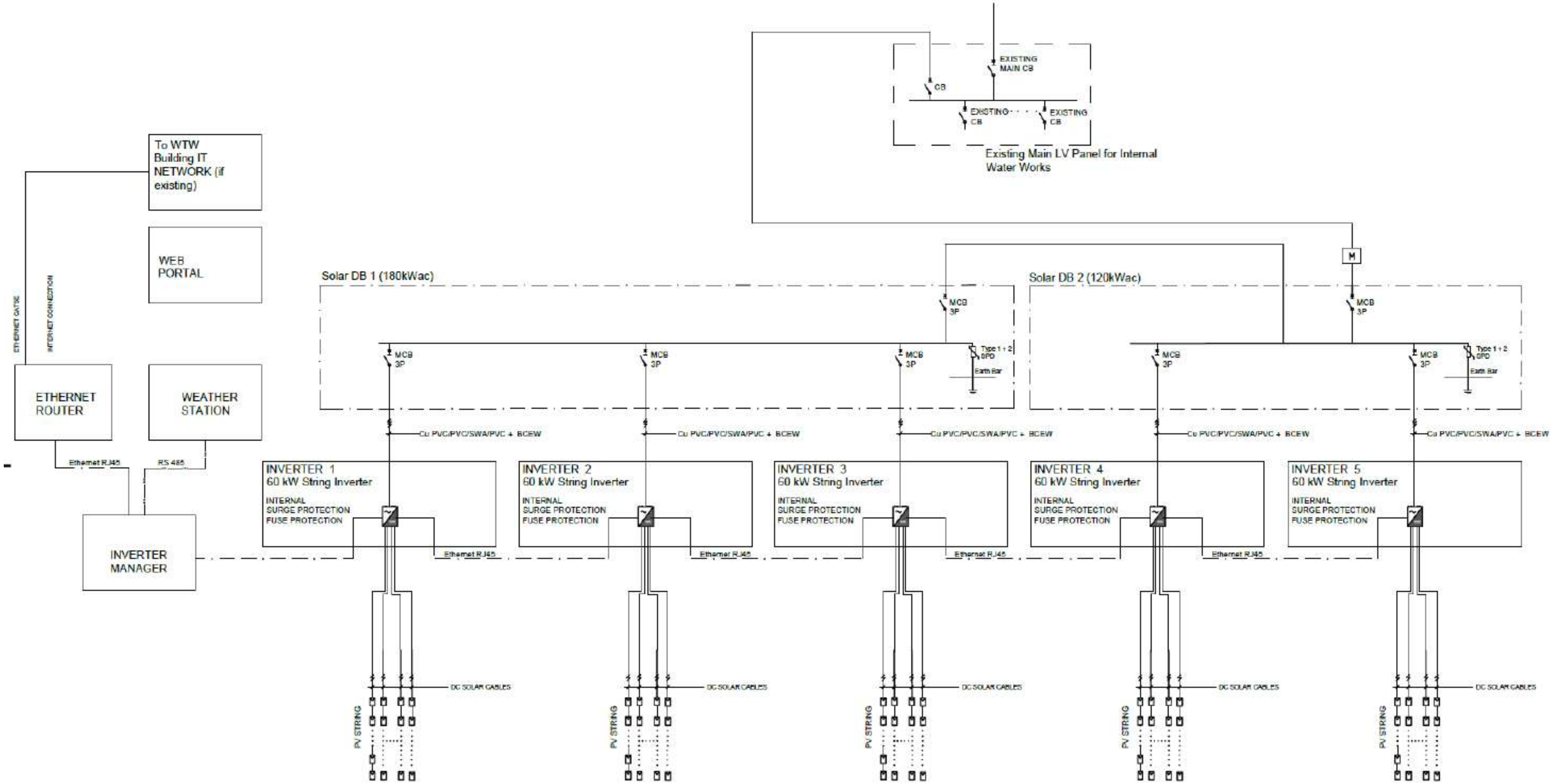


Figure 26: Interconnection block diagram

Notes pertaining to the interconnection diagram, Figure 26:

- This block diagram shows design intent only. Detailed design to be done by an EPC contractor.
- Cable routes and underground containment to be measured and confirmed on site by an EPC contractor.
- Solar Distribution Board (DB) 1 or solar DB 1 is a new AC DB housed in the control room.
- Solar DB 2 is a new AC DB in the main LV panel room in the plant admin building.
- It is assumed that the room containing the existing main LV panels has sufficient space for the new Solar DB 2.
- It is assumed that the main LV panel can be modified to accept the new incoming solar PV connection.
- The inverters indicated are all 60kWac, 400V with sufficient DC inputs to support the intended solar PV array. Charge controllers shall be integral per string. Inverters to be suitable for outdoor mounting.
- Each inverter shall be connected via a communications cable to the data concentrator mounted in solar DB 2. The data concentrator to be connected to the cloud-based monitoring platform.
- Power quality meter to be installed on the output of Solar DB 2 and linked to the cloud-based monitoring platform.

Figure 27: Area 1 - Ground-mounted bifacial tracking solar system

Figure 28: Area 2 - Ground-mounted bifacial tracking solar system

Note: The pitch length depicted in Figure 27 and Figure 28 differs from that depicted in Figure 23, however, both pitch depictions represent the same distance.

Figure 29: Area 2 + Area 4 - Rooftop PV systems

5 PV Yield and Meteorological Assessment

5.1 Meteorological Data

5.1.1 Solar Resource Data

Arup has obtained meteorological data from the following sources to determine the most suitable source for the energy yield simulation for the Sundumbili facility. The period over which the data stretches for each source is provided below:

- Meteonorm v7.3: 1991 - 2010
- NASA-SSE: 1983 – 2005
- PVGIS: 2007 – 2016
- SolarGIS: 1994 – 2020

Meteonorm data is gathered by interpolating results from records of the nearest weather stations and using satellite data where weather station records are not available. NASA-SSE, PVGIS, and SolarGIS data is sourced from satellite records.

5.1.1.1 Global Horizontal Irradiance (GHI) Data

Arup compared the annual GHI data provided by the Meteonorm v7.3, to NASA-SSE, PVGIS-SAF and SolarGIS weather data sources. The comparison between the four data resources is shown in the Table 17 and Figure 30.

Table 17: Comparison of annual global horizontal irradiation data

Global Horizontal Irradiation (kWh/m^2/period)							
Month	**Meteonorm**	**NASA SSE**	**Diff (%)**	**PVGIS**	**Diff (%)**	**SolarGIS**	**Diff (%)**
Jan	197.0	171	-13.0%	166	-15.9%	177	-10.0%
Feb	169.0	147	-12.8%	170	0.6%	156	-7.9%
Mar	164.0	149	-9.3%	156	-5.0%	153	-6.6%
Apr	126.0	122	-3.6%	113	-10.1%	122	-3.2%
May	107.0	105	-1.8%	116	8.5%	112	4.3%
Jun	94.0	89	-5.5%	98	4.1%	96	2.6%
Jul	101.0	98	-2.7%	114	12.9%	105	4.4%
Aug	120.0	117	-2.3%	120	-0.2%	123	2.6%
Sep	132.0	131	-0.9%	135	2.6%	135	2.3%
Oct	160.0	141	-11.6%	147	-7.8%	148	-7.8%
Nov	173.0	146	-15.5%	160	-7.8%	154	-11.3%
Dec	199.0	169	-15.3%	172	-13.4%	174	-12.7%
Year	**1,745**	**1,585**	**-9.2%**	**1,667**	**-4.5%**	**1,655**	**-5.2%**

The value for the annual global horizontal irradiation provided in the Meteonorm v7.3 file is 9.2% higher than the NASA-SSE dataset, 4.5% higher than the PVGIS dataset and 5.2% higher than the SolarGIS dataset. This indicates that the Meteonorm dataset is not within a reasonable range of the data available and therefore requires an alternative source to be used. Arup has chosen SolarGIS as the replacement dataset since this source is a high-quality industry standard source with typically lower uncertainty values and thereby higher levels of accuracy.

This is confirmed in Figure 30, where it can be seen that SolarGIS is more consistent with other datasets available and tracks the same curve as NASA-SEE throughout in the Typical Mean Year (TMY). The Meteonorm TMY data also overestimates the GHI data from October to February compared to the other data sources.

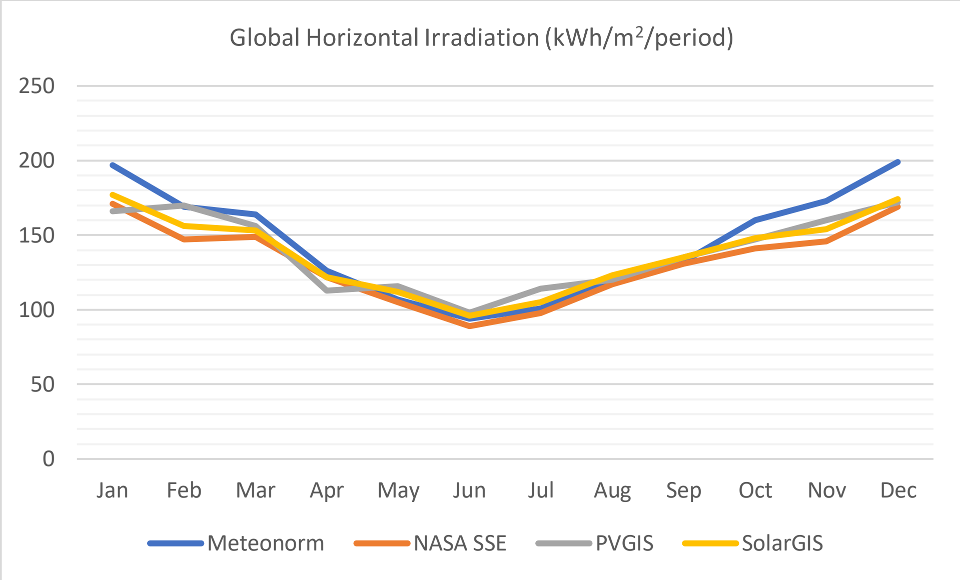


Figure 30: Comparison of monthly irradiance data

5.1.2 Temperature Data

Arup has compared the Meteonorm average ambient temperature data with the same datasets used for the GHI comparison. Ambient temperature is the air temperature of any object or the environment where equipment is stored. The comparison is shown in Table 18. The Meteonorm and PVGIS sources track each other closely, while NASA-SSE and SolarGIS have slightly higher temperatures values.

Table 18: Temperature data comparison

Average Monthly Ambient Temperature (°C)							
Month	**Meteonorm**	**NASA-SSE**	**Diff (°C)**	**PVGIS**	**Diff (°C)**	**SolarGIS**	**Diff (°C)**
Jan	24.5	23.4	-1.10	24.8	0.30	24.6	0.10
Feb	24.9	23.7	-1.20	24.2	-0.70	24.8	-0.10
Mar	23.4	23.3	-0.10	21.9	-1.50	23.9	0.50
Apr	21.2	22.0	0.80	20.6	-0.60	21.6	0.40
May	18.6	20.7	2.10	19.1	0.50	19.3	0.70
Jun	16.3	19.0	2.70	16.5	0.20	17.1	0.80
Jul	15.6	18.7	3.10	16.0	0.40	16.6	1.00
Aug	17.6	19.6	2.00	18.6	1.00	18.3	0.70
Sep	19.2	20.5	1.30	19.7	0.50	19.7	0.50
Oct	20.9	20.6	-0.30	20.6	-0.30	20.6	-0.30
Nov	22.4	21.6	-0.80	21.5	-0.90	22.1	-0.30
Dec	23.9	22.6	-1.30	21.0	-2.90	23.7	-0.20
Year	**20.7**	**21.3**	**0.60**	**20.3**	**-0.36**	**21.0**	**0.30**

Figure 31 demonstrates the temperature comparison. It can be seen that NASA-SSE temperatures are higher from May to August, compared to the other datasets, whereas PVGIS, Meteonorm and SolarGIS track very closely along the same curves.

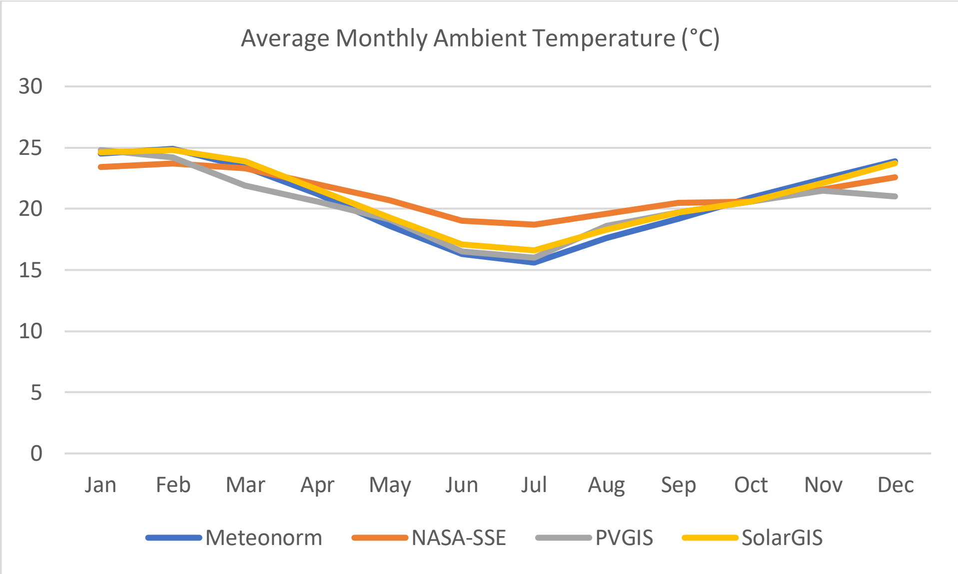


Figure 31: Comparison of monthly temperature data

5.2 Long Term Yield Assessment

5.2.1 System Configuration

Table 19 below indicates the PV system specifications for both the ground-mounted and rooftop solar systems.

Table 19: PV system specifications

Modules		
Manufacturer	-	Trina Solar
Model	-	TSM-DEG15MC-20-(II)-400-Bifacial
Nominal Rated Power (STC)	[Wp]	400
Power Tolerance	[%]	0.75
Module Efficiency at STC	[%]	19.49
Temperature Power Coefficient	[%/°C]	-0.37
Inverters		
Manufacturer	-	Huawei Technologies
Model	-	SUN2000-60KTL-M0
Nominal Rated AC Power (STC)	[kW]	60
System Characteristics: Ground-mounted system		
Nominal Capacity (DC)	[kW_{dc}]	219
Inverter Capacity (AC)	[kW_{ac}]	60
DC / AC Ratio	-	1.2
Quantity of PV Modules	-	548
Quantity of Inverters	-	3
Modules per String	-	16
PV System Type	-	Single-axis tracking

Tracking Angle Range	[°]	±55
Backtracking controls		Yes
Pitch (row separation, centre to centre)	[m]	6.5
System Characteristics: Rooftop system		
Nominal Capacity (DC)	[kW_{dc}]	130
Inverter Capacity (AC)	[kW_{ac}]	60
DC / AC Ratio	-	1.2
Quantity of PV Modules	-	325
Quantity of Inverters	-	2
Modules per String	-	15
PV System Type	-	Roof mounted

5.2.2 System Performance Parameters

1.1.1.1 PV System Performance Parameters

Table 20 below provides a summary of all system performance parameters that are factored into the energy yield assessments. Most of the parameters are an input to PVsyst software and are also calculated using PVsyst algorithms. The additional parameters are used in the post-processing of the PVsyst results to obtain the long-term yield assessments. Table 20 shows the energy flow table containing the specific performance parameters applied to the energy yield simulations.

Table 20: Summary of System Performance Parameters

Modelling Inputs		
Inclined Irradiation	Transposition Model	Perez. The Perez model is a more sophisticated module than the Hay model and is typically used together with lower uncertainty GHI datasets.
Shading and Reflection	Shading Model	Shading model built in PVsyst as per system configuration.
	Horizon shading loss	Calculated in PVsyst Horizon obtained from Meteonorm v7.3
	Structure shading loss	Calculated in PVsyst Backtracking activated
	Reflection loss (IAM factor)	Module specific IAM profile provided by the manufacturer.
	Soiling loss	1.5%
PV Modules	PV loss / gain due to irradiance level	Calculated in PVsyst
	Thermal losses	Thermal loss factor applied for ground mounted configuration: 29 W/m²
	Shadings: electrical loss	According to module strings layout as applied in PVsyst.
	Light induced degradation	-2.0% Standard Arup assumption.
	Annual degradation	-0.5% Standard Arup assumption

Modelling Inputs		
	Module array mismatch loss	-2.0% Generic loss applied to account for modules with differing I-V curves.
	DC Ohmic wiring loss	-1.5% Standard Arup assumption. To be updated in detailed design.
AC electrical components	Inverter losses	Calculated in PVsyst using inverter .OND files.

5.2.3 Availability

The annual yield forecast generated by PVsyst is usually at the output of the on-site transformer or point of connection (PUC) and does not account for any system availability losses (plant and grid availability) which is shown in Table 20. The availability assumptions are based on Arup's market knowledge relating to plant PV facility availability internationally, as well as what is considered to be industry standard.

5.2.4 Soiling

Soiling of PV modules is an important consideration affecting plant performance. Soiling needs to be monitored to prevent soil build-up on modules, particularly for mineral and metal silicates, which can bond with the front glass sheet and become difficult to remove without abrasive techniques. Use of abrasive cleaning methods can potentially void the Original Equipment Manufacturers (OEM) warranty.

Soiling build-up leads to a reduction in the irradiance received by the solar cells and can also lead to mismatch between solar cells within the module and between modules within a string. Mismatch can then lead to hot spots and accelerated degradation of the modules. All of these factors contribute to decreased energy production both in the short term and long term.

Based on the site visit, the Sundumbili site does not appear to be subject to any nearby dust generating activities (such as mining) or dusty roads or debris which could result in significant soiling at the site. The site appears to have tarred road and sufficient vegetation to prevent dust from loose soil particles. As such, the potential soiling loss has been estimated at 1.5% across the roof and ground-mounted systems, which is a conservative approach. With sufficient frequent cleanings and monitoring of the solar panels, a soiling loss of 1% or lower could be achieved.

Soiling ratio measurements are required for sites in locations that expect an annual soiling loss 2 % and above. Soiling measurement devices would therefore not be deemed necessary for the plant. It is recommended reference cells be mounted at the rooftop and ground-mounted systems as a means of monitoring soiling. Reference cells are placed within or near the PV array at the same angle/tilt as the array. One reference cell is allowed to accumulate soiling at the natural rate and the second reference cell is periodically cleaned. A measurement and control unit measures and compares the electrical outputs of the soiled reference device and the clean reference device to determine the fraction of power lost by the soiled reference module due to soiling.

Module washing is the most wide-spread solution used to combat soiling. Dry cleaning of modules would not be recommended if the humidity proves to affect the soiling in such a way that it causes cementation or a build-up of metal silicates on the modules.

Demineralised water or water with a low hardness (less than 20mg of $CaCO_3$ per litre) should be used for the cleaning process. Brushes with a soft material or as specified by the module manufacturer should be used and checked throughout the cleaning process to ensure that the dirt accumulated on the brushes do not scratch the module surface.

5.2.5 Performance Ratio (PR)

The PR is a measure of total system losses and compares the actual yield of the system to its theoretical maximum yield with no system losses. The performance ratio calculated in the yield simulations is indicative of the assumed losses of the facility. The resulting PR range is estimated to be between 84% - 86% which includes self-consumption, plant availability, grid availability and PV module degradation.

5.2.6 Degradation

Light induced degradation (LID) is the loss in performance of solar PV modules due to exposure to the sun, it is more rampant in thin film modules than crystalline modules. LID is usually high in the first year of operation of the module and lowers throughout the rest of the module operating years. According to a conservative view from polycrystalline module suppliers, LID of 1.0% is expected for the first year of operation, thereafter a constant degradation of 0.5% can be expected for the rest of the rated module operational life.

6 Weather stations, performance monitoring and security

A weather station should be provided linked into the same monitoring system as the inverters to provide remote monitoring and control via the cloud. A typical system, such as MeteoControl (commonly used software in the utility PV industry) as shown in Figure 32, allows the reporting of faults, energy production (down to solar PV string level), power production, irradiation and temperature data, as well as automatic calculation of performance metrics, such as Performance Ratio (PR).

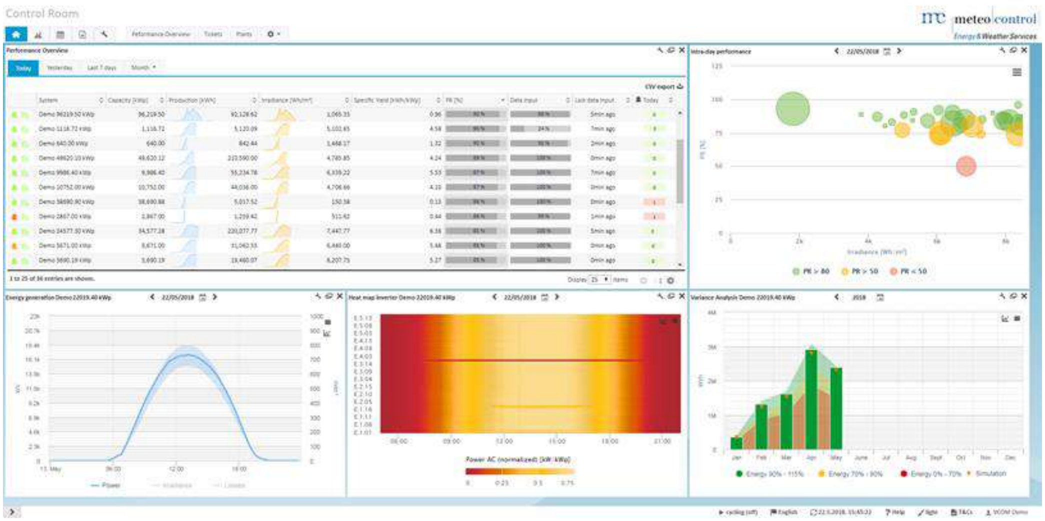


Figure 32: Typical dashboard of PV facility monitoring system

Example shown is for the MeteoControl platform

PR is the key performance parameter used to assess the successful delivery of the facility, as well as monitor the performance on an ongoing basis. The calculation utilises inputs from the on-site irradiation sensors (pyranometers) and energy meters to determine if the facility is performing optimally.

PR is the ratio of the actual energy production to the total theoretical energy production corresponding with the irradiation measured on-site. The PR can typically range from 78% to 84%, depending on the equipment and facility design. PR is usually guaranteed on an annual basis and the theoretical or ideal energy will consider an annual degradation percentage to account for PV module degradation, typically in the range of 0.4% to 0.7%.

The approximate cost of a weather station is R228,600. This cost is based on previous project data and updated costing should be provided at detailed design stage.

6.1 System Metering

For the system metering, an energy meter should be installed at each of the incomers from the PV facility at the customer switchboard. Essentially, one power quality meter needs to be installed in total. Energy metering should also include power quality and harmonic measurement functionality. Energy should be metered at Class 0.2 and will report and log information to the central metering system, including the solar PV energy measurement platform. The cost of reputable energy meters is approximately R40,000.

6.2 Monitoring equipment

The string inverters will act as dataloggers for the solar PV facility. These would communicate via a RS485 network to smart dataloggers situated at the AC Combiner distribution boards. The facility weather stations will also connect directly to these smart dataloggers. The dataloggers act as reporting PLCs, which send information back to the central cloud-based monitoring system.

A typical network diagram is shown in Figure 33. This example uses Huawei propriety equipment, such as SmartLogger and NetEco (SCADA back-end), however, there are other products on the market that can be utilised. The chosen inverter from Huawei is not OEM specific and can interface with other manufacturer SCADA systems and front ends.

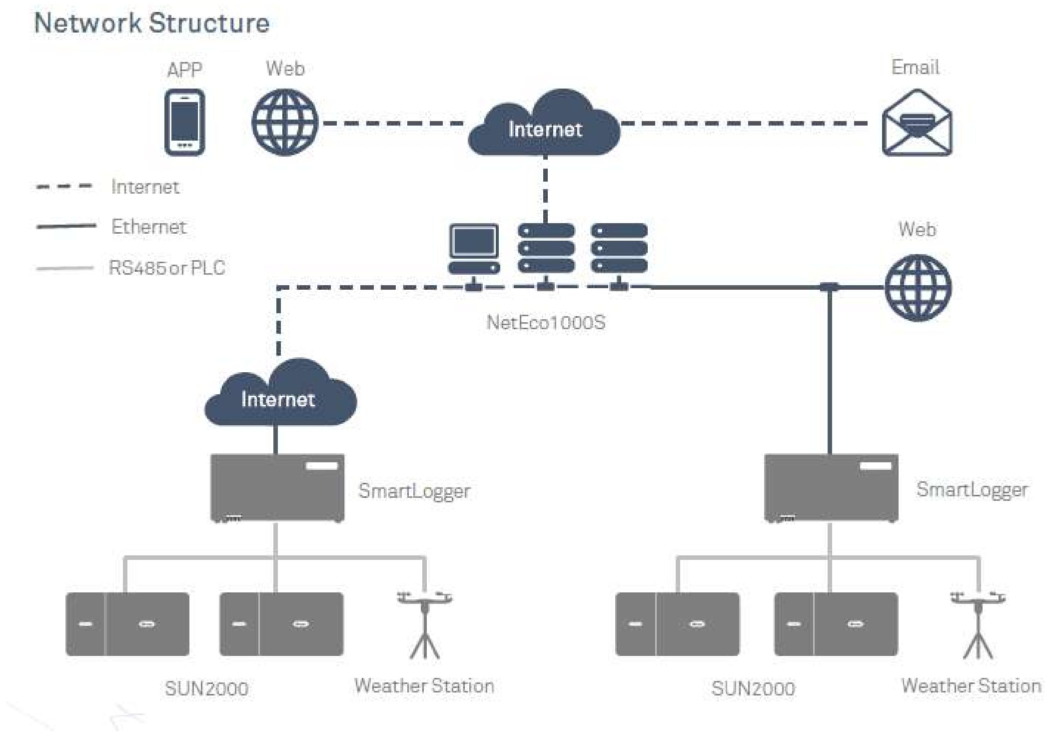


Figure 33: Typical network structure for monitoring equipment

6.3 Sensors

Sensors form part of the weather station and are suggested to provide monitoring and performance information to the Client. However, the sensors can be rationalised by the EPC contractor during detailed design.

6.3.1 Irradiation Sensors

Pyranometers are utilised to monitor irradiance at the site. This data is directly used to validate the performance of the solar PV facility via the performance ratio (PR). Two types of pyranometers are typically found on utility scale PV farms, Inclined and Global Horizontal Irradiance (GHI) pyranometers. Inclined pyranometers, as shown in Figure 34 are mounted on the PV tracker table and move with the module table, thus recording irradiation at the same angle as the PV modules throughout the day. GHI is measured by a horizontally fixed pyranometer mounted at a weather station either in the PV field or at the control building. Inclined and GHI pyranometers are to be specified as per IEC 61724 standard.

Figure 34: Typical inclined Kipp & Zonen Pyranometer

Source: https://www.kippzonen.com

6.3.2 Temperature sensors

Ambient temperature sensors are required for the ground-mounted system and shall form part of the EPC contractor design. Ambient temperature sensors and back-of-module temperature sensors as shown in Figure 35.

Figure 35: Typical back of module temperature sensor

PV modules are highly sensitive to temperature and show a rapid degradation of power production with increased temperature. Temperature data is used to validate the performance of the PV modules and monitor performance against the manufacture's performance guarantees. In the case of bifacial PV modules, it is important that the placement of back-of-module temperature sensors during installation minimises rear-side shading and ensures OEM warranties are not void. Ambient and back of module temperature sensors are to be as per IEC 61724.

6.3.3 Rain and Wind Sensors

Rain has an initial negative impact on production only during the event but will typically provide a degree of module cleaning, which has a positive effect on energy production in the short to medium term. Wind sensors are typically included for weather condition recording and to safely stow the trackers in the event of high wind speeds. Low wind levels have a positive impact on modules performance due to the cooling effect on the modules. In rare cases, high winds can cause damage to PV module and sub-structures, although with an adequately designed structural and clamping system, this can be mitigated. Automatic stowing of trackers also mitigates this risk. Rain and wind sensors to be as per IEC 61724.

6.3.4 Reference Cells

Reference cells are single photovoltaic cells mounted in the field under the same operating conditions as the energy producing modules. The purpose of the reference cells is to assess the effect of soiling or dust build-up on the modules. The reference cells are cleaned daily and kept free of any obstructions to act as reasonable reference for comparison. The power output of the reference cell can be used to determine if excessive dust or dirt is building up on the module tables and thus if the cleaning regime requires adjustment. Reference cells help to quantify the actual soiling loss being experienced based on the cleaning frequency implemented during the year. Soiling measurement is recommended for sites where this loss may exceed 2% of energy production, which is not expected to be the case for the Sundumbili site. Reference cells are recommended as per IEC 61724.

6.3.5 Weather station summary

The recommended weather stations, together with proposed measured equipment, are listed below. Quantities as per IEC 61724:

- Inclined pyranometer
- Global Horizontal Irradiance pyranometer
- Back of module temperature sensors
- Ambient temperature sensor
- Wind speed
- Wind direction
- Reference cell

6.4 Security

Based on the proximity of the local community to the solar PV facility the security risk for the project is higher than for projects in remote areas. Security risks also include the high risk during the facility construction phase, with copper and equipment theft being a major concern. In addition, social unrest from local communities as well as discontent from labour brokers and unions are also common during construction of PV projects. Theft of solar PV modules and operations vehicles has also been witnessed in some projects previously; therefore, it is critical that adequate measures are put in place to alleviate security risks throughout the lifetime of the project.

Security risks during construction can be mitigated by transferring full site responsibility to the EPC contractor. Regarding operations, the security risks can be mitigated by adequate monitoring of the boundary fence and points of entry by means of suitable security lighting, CCTV, electric fencing, security guards and pedestrian/vehicular access control. For this reason, it is recommended that site security be given the necessary level of attention during the subsequent project phases. We recommend the employment of a security consultant to establish the best strategy in terms of armed response availability, perimeter patrol, number of staff on site, communication equipment (radios, and so forth) and operating plans and procedures.

7 Operations and Maintenance Requirements

7.1 Institutional arrangements

It is proposed that the IDM personnel on site will be trained or upskilled by the EPC contractor to conduct basic PV system maintenance. For major maintenance activities / breakdowns, a contractor (under a Service Level Agreement) will be required to perform the maintenance outside of the Defects Liability Period. The following sections outline the recommended minimum maintenance activities which should be performed (these can be performed by IDM water plant operators).

7.1.1 Weekly Maintenance

The minimum anticipated weekly maintenance activities which should be performed at the PV plant are detailed in Table 21.

Table 21: Weekly maintenance activities

PV Plant Component	Maintenance Activity
Meteorological equipment	Clean and make sure they are in place at the correct angle or orientation. Visual inspection of temperature sensors.

7.1.2 Monthly Maintenance

The minimum monthly maintenances activities which should be performed at the PV plant are detailed in Table 22.

Table 22: Monthly maintenance activities:

PV Plant Component	Maintenance Activity
Modules	Check for broken glass or major occurrences of discoloration, bubbling of encapsulate, warpage, etc. DC wiring and junction box connections secured and contained as intended; no loose cables, no connectors dipped in water puddles. Cable fastening inspection. Visual inspection of module junction boxes for discolouration or evidence of thermal effects. Check reference cell to determine if module cleaning is needed.
AC and DC electrical equipment	Check the condition of conductors, connectors, enclosures and fuses.
Inverter Components	Check for integrity of wiring and terminals, note unusual noises, controls and LCD screen operation, cooling fans. Clean inverter cabinet and check for moisture ingress.
Communications and monitoring Equipment	Ensure proper recording .
Mounting structures and trackers	Check for any deformation. All fasteners secure and in place. Secure fixing of modules- check for misaligned modules as evidence of slip. Maintenance of actuator and all moving parts.
Site	Check and remove any high vegetation that may cause shading for the ground-mounted modules.

7.1.3 Annual Maintenance

The minimum annual or annual maintenances activities which should be performed at the PV plant are detailed in Table 23 below.

Table 23: Annual maintenance activities

PV Plant Component	Maintenance Activity
Health and safety	Emergency drills. Fire extinguisher service. Tool calibration.
Mounting Structures and Trackers	Annual corrosion inspection and repair. Torques checks and retightening.
Modules	Thermal imaging. String testing.
Inverters	Thermal imaging. Check all fuses, bolts, surge arresters and door seals.
Meteorological equipment	Calibration.

7.2 Spares

A minimum spare holding philosophy is to be adopted for the plant; however, there are certain spares which are critical to house on site and should be provided by the EPC contractor, these should include at minimum:

- PV modules
- Inverters
- Fuses
- Circuit Breakers
- MC4 connectors
- Monitoring data-logging unit
- Surge protection devices
- DC cabling
- Tracker components
- Tools and testing equipment

A comprehensive list which indicates the availability of spares locally must be supplied by the EPC contractor as part of the spare parts strategy for the solar PV facility. All spare parts will be kept in a storeroom which will be part of the control room.

8 Cashflow Summary

Table 24 provides high-level cost savings provided by the proposed rooftop and ground mounted scenarios which amount to a 349kWp solar PV facility. The table also provides a summary of the capex cost which is a once-off cost for each scenario, and operation and maintenance (opex) costs which occurs each year of operation. Cumulative annual savings for year 1- 9 and year 1- 25 are also provided. These savings were determined by analysing the cashflow that can potentially be achieved by the solar PV facilities offsetting the grid energy purchases. This cashflow is provided in Annexure 4 and it outlines the solar PV generation and grid generation offset in kWh, the capital costs, operation and maintenance costs and from this, the potential energy cost saving the Sundumbili plant could achieve.

Table 24: Cost saving summary

Scenario		Capex (ZAR)	Opex (ZAR)	Year 1 Annual Saving (ZAR)	Year 1-9 Cumulative Annual Saving (ZAR)	Year 1-25 Cumulative Annual Saving (ZAR)
1	Rooftop Solar + Fixed Ground-mounted with Monofacial PV	R 4,865,500	R 56,561	R 508,183	R 4,474,445	R 11,899,319
2	Rooftop Solar + Ground-mounted Tracking System with Monofacial PV	R 5,194,000	R 59,598	R 531,086	R 4,675,615	R 12,431,681
3	Rooftop Solar + Ground-mounted Tracking System with Bifacial PV	R 5,259,700	R 59,598	R 541,843	R 4,7790,557	R 12,685,241

Table 24 above shows that Scenario 3 will result in the most cost savings, ~7% and ~2% higher than the savings of Scenario 1 and 2.

9 Funding mechanisms

Funding for the procurement and installation of PV systems can be supported by financial incentives and subsidies, depending on local government's policies and priorities.

9.1 Typical Solar Power Funding Mechanisms

There are numerous financial mechanisms for commercial and industrial businesses to finance solar power, including bank loans, project finance, Power Purchase Agreements (PPAs), fixed roof rentals, lease agreements, blended financing, and capital investment. A brief outline of each mechanism is discussed in this section.

9.1.1 Bank Loans

The most common approach to finance solar power projects remains a bank loan, using a debt financing mechanism. This type of financing mechanism is most suited to small solar power projects (typically up to 1 MW_p) where the parties enter into a loan agreement for the transfer of an amount of funds from the lender to the borrower. The amount borrowed must be returned to the lender within an agreed period. The biggest advantage of this funding mechanism is that the borrower retains full ownership of the solar power plant.

9.1.2 Project Finance

Project finance is the funding of long-term solar projects using a non-recourse or limited recourse financial structure. The debt and equity used to finance the project are repaid from the cash flow generated by the project. The funding mechanism is characterised by the presence of several partners including financial investors, banks, landowners, engineering companies (construction and operations). The main feature of project finance is that the solar facility is transferred to a separate legal entity created specifically for the project, namely the Special Purpose Vehicle (SPV). Most large-scale solar power projects (typically greater than 5MWp) are project financed.

9.1.3 Power Purchase Agreements

PPAs are long-term contracts between a solar project developer and the buyer, where the design, installation, operation, and maintenance of the system are fully covered by the developer. There are no upfront costs for the buyer and this funding mechanism usually includes insurance and performance guarantees, with the biggest advantage being reduced electricity costs from day one. The buyer purchases electricity from the developer at a predetermined rate (usually significantly cheaper than the national grid), which is based on the amount of energy the buyer uses.

9.1.4 Fixed Roof Rental

In a fixed roof rental, the solar power developer pays a fixed monthly payment to the property owner, as compensation for using the property roof space. The property owner pays the developer for the energy used from the solar system, based on NERSA or municipal rates. The costs for the system maintenance, operation, and insurance rests with the developer.

9.1.5 Lease Agreement

Under a solar lease agreement (also referred to as equipment rental), the solar power provider pays for the installation, maintenance and management of the solar panel and its components, while the consumer pays a fixed monthly lease payment for the duration of the lease term (based on the estimated annual production of the solar system). A lease agreement differs from a PPA in that the consumer pays a fixed monthly amount rather than agreeing to purchase the power generated by the system at a set price per kilowatt-hour (kWh).

9.1.6 Blended Financing

Blended finance is the strategic use of development finance for the mobilisation of additional finance towards sustainable development in developing countries. The funding mechanism attracts commercial capital towards projects that contribute to sustainable development, while providing financial returns to investors.

9.1.7 Capital Investment

Another mechanism to fund solar power projects is to fund the project using existing cash reserves, where upfront costs are high, but the benefits can be rewarding.

9.2 Funding Mechanisms for Municipalities

9.2.1 Municipality Project Funding Constraints

Municipalities receive annual funding as part of the national budgetary allocation through unconditional and conditional grants, however, more than often must raise their own funding. One of the main constraints for funding municipal infrastructure projects relates to the financial health and creditworthiness of some municipalities. When raising funding for a project, potential lenders will look at the creditworthiness of the municipality to support its decision to provide funding. A poor credit rating will deter potential lenders.

It has been suggested that lenders have had difficulties using municipal budgets and municipal financial reports to gauge underlying financial conditions to assess the credit risks involved in lending to the municipality. In addition, municipalities can also at times have trouble retrieving revenue from the public to repay loans timeously. Based on conversations with Eskom during the data gathering phase, it is understood that the IDM's Eskom payments are up to date, which is indicative of a potentially good financial status, however this would need to be confirmed by the IDM.

The Public Finance Management Act (PFMA), enacted in 1999, and the Local Government: Municipal Finance Management Act (MFMA) enacted in 2003, constitute the essential framework for financial management in the public sector. The PFMA applies to the national and provincial spheres of government, and the MFMA applies to the local sphere [5]. The Municipal Finance Management Act (MFMA) has historically made the process of municipalities entering contracts longer than 3 years complex. The term of a Power Purchase Agreement (PPA) is typically longer than 20 years and this presented a constraint to municipalities and project developers. The MFMA currently allows municipalities to enter contracts up to 30 years via a Public-Private Partnership (PPP), however, this mechanism and procurement framework can be time consuming and expensive.

9.2.2 Solar Power Funding for Municipalities

There are several organisations that can provide funding for solar power projects, including government, Development Finance Institutions (DFIs) and commercial organisations. The funding mechanisms can come in the form of grants, loans, municipal fiscus, Public-Private Partnerships (PPPs), Power Purchase Agreements (PPA) and others. GreenCape is a non-profit organisation that has developed a database of funding sources for green energy projects. The database can be accessed on GreenCape's website [6], which is continually updated and contains information on funding opportunities, the types of funding and organisation's providing the funding and contact details.

The application requirements for funding will be specific to each organisation. As a typical example from a commercial bank in South Africa, Standard Bank's application requirements to finance a solar PV facility can be found in Annexure 2.

The Municipal Infrastructure Support Agent (MISA) has several programmes to support municipalities. One such programme is the Infrastructure Delivery Management Support (IDMS) program. The objective of the IDMS is to deliver infrastructure projects on behalf of identified municipalities and provide infrastructure financing, procurement and contract management guidance and advice to municipalities. It also focusses on the development of institutional capacity of municipalities to procure and contract manage infrastructure projects efficiently and effectively. Infrastructure financing is one of the sub-programmes of the IDMS, where the purpose is to facilitate processes to support innovation and private sector financing on infrastructure and Municipal Infrastructure Grants (MIG). This is something municipalities can benefit from, and more information can be found on the MISA website[1].

As per the Clients request, Trade & Investment KwaZulu-Natal (TIKZN) and Swedfund were explored as funding opportunities, however, the mandate of these organisations do not align with the solar PV facility being investigated as part of this study. TIKZN do not fund projects, but rather act as facilitators of investment, while Swedfund do fund solar PV projects, but do not provide financing to smaller plants (as is the case with the solar PV facility in this study).

The South African Local Government Association (SALGA) published a guideline for municipalities on the financing of Energy Efficiency and Renewable Energy projects in South Africa (SALGA, 2014) [7]. The guideline was first published in 2014 and is therefore quite old, but is still a valuable document that can be used by municipalities looking to explore the use of renewable energy. Included in the guideline are several financing mechanisms available to municipalities. The guideline provides a summary of these mechanisms including a description, examples, strengths, weaknesses and the municipality's role in implementing the mechanism. The most applicable funding mechanisms have been extracted from the guideline and are summarised and explained in Table 25.

Table 25: Solar Power Funding Mechanisms for Municipalities [8]

Mechanism	Description	Examples	Strengths	Weaknesses	Municipality's Role
Grants	Non-repayable funds made available by government, donor funder or the private sector.	• EEDSM (Energy Efficiency Demand Side Management) programme • Green fund • Donor funding from foreign countries • UK PACT (UK Partnering for Accelerated Climate Transitions)	The most accessible form of funding for municipal Energy Efficiency (EE) / Renewable Energy (RE) projects. Provides a municipality with access to its own energy efficiency or renewable energy fund. Can customise the application of the fund to suit the municipality's needs. Funding opportunities increase if the municipality can demonstrate a good track record. There is an opportunity for replicability and peer learning between municipalities.	Access to these funds tend to be highly competitive and therefore hard to obtain. Funds tend to have a short-term time horizon trying to address a multitude of objectives. Funding pots are often for pilot projects instead of roll-out. Municipality may not have the capacity, skills or experience to implement. If the municipality demonstrates a poor implementation track record, they may lose future funding opportunities. Fund opportunities for infrastructure implementation may be harder to obtain than funding for feasibilities.	Municipality applies for funds, which often means preparing and submitting a proposal to funding agents. If successful, municipality implements the project subject to the specified terms. On-going monitoring and evaluation of project will be required. Reporting on project achievements and sharing learnings with other Municipalities will be expected.
Loans	Lending money from the private/financial sector.	• Commercial banks - Standard bank, Absa, Nedbank, etc. • DTI Manufacturing Competitiveness Enhancement Programme (MCEP) • The Industrial Development Corporation (IDC) & Kfw Green Energy Efficiency Fund (GEEF) • French Development Bank (AFD) • Sustainable Settlements Facility (SSF) • The Development Bank of Southern Africa (DBSA)	Can provide funding for upfront costs, particularly if the payback period is short. Often loans from the foreign funders have reduced / lower interest rates than local commercial banks. The fund can be custom-made to serve the need of the user.	Municipalities may choose not to take loans for EE / RE initiatives unless the financial benefits can be clearly defined in relation to the loan repayment criteria. Municipalities cannot provide loans to the private sector due to restrictions imposed by the MFMA. Fund will have to be repaid with interest. Securing the funds could take a long time and be associated with high transaction costs. A municipality can borrow funds to implement projects only if it can demonstrate the ability to repay the loan.	Providing the relevant information to industry and other partners concerning the options available. Assisting the private sector in finding and negotiating the terms of the finances, as well as implementing the project. Facilitator / mediator between users and loan financers.
Municipal Fiscus	Motivation for allocation of municipal funds for EE / RE initiatives (generated by the municipal	EE and RE projects motivated through and included in municipal: • Integrated Development Plan (IDP)	Very direct impact with high visibility. Strong demonstration effect. Municipality can offset the cost of implementation with internal savings from reduced grid electricity	Limited budget available in most municipalities. EE / RE may be a low priority for many municipalities which see their primary mandate as delivering basic services.	Identification of feasible EE / RE projects with a reasonable payback period that can be motivated for internal funding. 'Piggy back' energy efficiency

Mechanism	Description	Examples	Strengths	Weaknesses	Municipality's Role
	rates base, and user charges for Municipal utilities).	• Service Delivery and Budget Implementation Plan (SDBIP). The SDBIP details the implementation of service delivery and the budget for the financial year in compliance with the MFMA. • Sector Plans • Project Business Plans.	consumption in its service delivery infrastructure and administrative buildings. Reduced operating costs in the medium to long term, helping to ensure sustainable service delivery. Renewable energy generation within the municipality's own infrastructure can help to enhance the security of supply of essential services (e.g. wastewater treatment).	Cost savings cannot necessarily be ring-fenced to recover costs of initial implementation.	projects onto other capital and infrastructure maintenance projects for which funding is secured.
Public-Private Partnerships (PPPs)	Long-term contractual agreements between a private operator/company and a public entity, under which a service is provided, generally with related investments by both private and public sector partners.	• Installation of small-scale renewable energy alternatives (Working for Energy) • Johannesburg and EnergSystems - Waste to energy initiatives. • Olievenhoutbosch Housing Project.	Can secure long-term and substantial financial support, particularly for large and complex projects. Can inject external expertise into the domain of the municipality operating context. Municipality can achieve desired outcomes (e.g. renewable energy generation, reduced carbon emissions) without having to carry the full costs of installation and operation.	Very high barriers to entry and transaction costs with the establishment of PPPs. Cumbersome, complex contracting process requiring substantial legal expertise. Requires projects of sufficient scale to implement. Poor performance of private sector partner creates liability and costs for the municipality.	Identify projects, initiate, and facilitate process. Likely to carry the transaction cost. Some of the activities could be assigned to third parties at cost to the municipality.
Power Purchase Agreements (PPA)	Municipality agree to purchase power from an independent Power producer (IPP) or embedded power generation (EPG) facility.	Mbombela Municipality and Friedenheim Irrigation Board	Increased surety of electricity supply. Opportunity for cost-cutting if production costs are lower than Eskom Tariffs. Opportunity to promote the establishment of renewable energy generation projects locally with associated socio-economic benefits.	Tariffs cannot exceed Eskom rates, so the rate of return may be unfavourable for energy producers. MFMA historically limited municipalities entering into contracts longer than 3 years and independent power producers (IPPs) would typically look for a 20-year contract, hence this was a challenge. There could be technical challenges to connecting IPPs to the network. Does not become a funding source for municipal EE / RE initiatives.	Municipality can identify projects, partners, and draft contracts for PPAs. Long-term purchasing of energy.

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ANNEXURE 1 – PHASE 2

Assessment of additional land area

Arup has determined that the plant does not have adequate area for installing a solar PV facility that would supplement the plants entire electricity load. The available ground and roof area can only accommodate ~349 kWp, which would supplement approximately 8-9% of the plant's energy requirements. From the plant's load demand, it is determined that the plant would need a solar facility of approximately 3 – 3.2 MW in order to supplement its entire load, with the use of net metering.

Net metering allows surplus power to be exported to the grid and in return credits are earned by the exporter to be used at times when the plant is not generating power i.e., during night time. A net metering agreement with Eskom can be arranged so the plant can export surplus electricity to grid and earn credits. This solar facility can be coupled with a battery energy storage system (BESS). The BESS could be used during peak time-of-use (TOU) periods to reduce costs, or during loadshedding, thus providing energy resilience for the plant operations. This would however require the leasing of approximately 7.5 ha of land for the construction of a ground-mounted solar facility of this size.

A high-level investigation was conducted to explore the availability of additional land that could be used that is near the plant. Two pockets of land were identified using Google Earth. See Figure 36 below.

Figure 36: Additional land area investigated

Approximately 60% of the land is under the jurisdiction of traditional leadership and is managed by the Ingonyama Trust Board. The Ingonyama Trust was established in 1994 by the KwaZulu Government in terms of the KwaZulu Ingonyama Trust Act, (Act No 3KZ of 1994) to hold all the land that was owned or belonged to the KwaZulu Government [9]. Most of the Ingoyama Trust land in the IDM is located in Maphumulo, Ndwedwe, Mandeni, and to the north-west of KwaDukuza. The total combined plots are estimated to be 12.29 ha.

Land Area A is assumed to be used as a community soccer pitch based on visual inspections and map data. This use case is however, unconfirmed by the IDM and the Ingonyama Trust Board at this stage. Based on the information provided via telephonic conversations with Sibonelo Simelani at Enterprise iLembe, the land adjacent to Area B (white building structures) is currently used for the setup of hydroponic tunnels, and the rest of the land is under the use of a community co-operative for the faming of vegetables. The hydroponic tunnels are currently not used, and a contractor has recently been appointed to revamp the facilities. There is appetite from Enterprise iLembe to potentially use surplus electricity generated from a solar PV facility, should this be realised. The IDM is recommended to engage with Enterprise iLembe for potential collaboration on this venture.

Agri-PV

According to the 2020 Profile Analysis District Development Model for IDM, the main economic sector in iLembe is agriculture which contributes 4.47% to the economy. Integrating this agriculture economy with Agri-PV could uplift the broader economy in iLembe by providing co-benefits of clean, reliable electricity whilst maximising land use. Agri-PV is suggested for further investigation for the agricultural land that is currently being used for farming activities on land Area B.

This would enable farming to continue with minimal interruption, whilst generating electricity, which could result in additional co-benefits (such as increasing crop yield and reducing evaporation). Land Area B could pose as a successful first-of-a-kind (FOAK) commercial scale demonstrator project (there are currently no large scale agri-PV systems installed in South Africa) that could be replicated and scaled in the rest of the municipality.

Agri-PV introduces a means to use land for both power generation and agriculture. Predominantly in utility scale solar farms, the solar PV panels are installed close to the ground and are kept free of vegetation to avoid shading and/or to reduce chances of fire. Agri-PV allows for crop production to be built beneath the solar PV array whilst producing electricity. Agri-PV is based on structuring the array in a manner that allows an optimal amount of light and shade on the ground, specific to the type of crop being grown. This provides a co-benefit for production of food crops, such a soil protection and water savings, whilst and at the same time generating electricity.

Effects of Solar PV shading on crop production

Excessive sunlight can impact the growth of crops negatively. Plants require a certain amount of sunlight daily and any additional sunlight received after the saturation point does not increase photosynthesis, however it increases transpiration. This leads to increased irrigation requirements. Certain crops benefit from regulating the amount of sunlight they receive, as many crops have been observed to have adverse growth under excessive sunlight conditions. With agri-PV, solar modules can be installed in a manner to allow the optimal amount of sunlight and shade. See Figure 37 and Figure 38 for images of agri-PV installations.

Figure 37: Agri-PV installation [10]

Figure 38: Agri-PV mounting structure [8]

Table 26 below provides a comparison of Agri-PV's pros and cons.

Table 26: Agri-PV pros and cons

Pros	Cons
Vegetation under modules can contribute to lower soil temperatures and increase solar performance of modules.	For bifacial modules, which rely on solar energy reflected off the ground onto the underside of the PV module, depending on the crop this could have the effect of reducing overall PV yield.
The shading by the PV panels provides reduced plant drought stress and more constant temperature as the panel can act as a thermal buffer.	PV system are electrically "live", therefore there is additional fire and electrical safety risk.
Potential to extend agricultural growing seasons and reduce water consumption.	Cleaning of PV modules can be difficult due to height of installation which is typically higher for agri-PV.
Potential to improve irrigation through rainwater harvesting systems that can be incorporated.	Additional operation and maintenance complexity due to the presences of crops.
Physical protection of crops.	Complex installation compared to standard ground mounted PV systems.
Rehabilitation of land.	Additional costing and procurement time associated with bespoke structures.
Energy production.	
Surplus power supply to communities/business.	
Reduces grid reliance.	
Increased ability to install high-value, shade-resistant crops for new markets.	

Figure 39: Agri-PV installation [11]

Environmental requirements and permitting

The land area requirements and the system size anticipated for a large-scale ground-mounted system at the additional land areas indicated above, are expected to trigger environmental assessments, permits and licenses. Figure 42 and Figure 43 provide an overview of the recommended next steps that should be taken to investigate these options further.

Initial assessments

A first pass assessment was conducted to determine the potential system size that could be accommodated using land area B for the installation of a large-scale ground-mounted solar system, coupled with a battery energy storage system that could supplement the plants load during load shedding or during the peak time of use periods.

Modelling assumptions and notes

A larger scale ground-mounted solar facility (~3 – 3.2 MW), coupled with a battery energy storage system (BESS, 1440 kWh Lithium-ion battery could provide ~ 2hours of autonomy), is modelled in HOMER to provide high-level energy generation, energy offset and cost assessments. The results of the HOMER simulation are presented in Table 27 and are sensitive to both the main inputs (load demand and grid tariff) as well as the overarching assumptions defined in the software. The following key modelling assumptions and notes have been used for the simulations in HOMER and are the basis of the results provided:

- Grid carbon emission factor: 0,9006 kgCO_2e per kWh [3]
- The storage technology utilizes a generic Lithium-Ion battery pack with a capacity of 100 kWh per unit.
- Discount rate: 10%
- Expected inflation rate: 6%
- Project lifetime: 25 years
- Solar PV lifetime: 25 years
- Storage lifetime: 12 years
- 2-hour battery autonomy
- Loadshedding scenarios are considered i.e., two hours of loadshedding per day, for two weeks, each quarter, is considered.
- Export of power to the national grid via net metering.
- Grid export for excess electricity generation considered for the net metering scenario.
- Service and administration charges not applied since these do not affect the selection of generation options.
- Ingonyama Trust Land is available for lease by IDM for the Sundumbili WTW. A total land area of 12.20 ha is assumed to be available based on measurements on Google Earth.

- General solar PV costs per kW are used as detailed agri-PV costs estimates are not yet readily available in South Africa.

Table 27: HOMER analysis results for 3 MW Solar Facility (ZAR)

Scenario	Grid supplied	Solar PV	Energy Demand covered by PV	Storage Capacity	LCOE	CAPEX	Annual OPEX	Replace ment	IRR	Simple Payback	Net Present Value	Emission Reduction
	[MWh/yr]	*kW_p*	*[MWh/yr]*	*[kWh]*	*[ZAR/kWh]*	*[ZAR'mil]*	*[ZAR'mil/yr]*	*[ZAR' mil/12 yrs]*	*[%]*	*[Years]*	*[ZAR'/mil]*	*[CO_2 kg/yr]*
Base case	*5,175*	*-*	*-*	*-*	*1.12*	*-*	*5.81*	*-*	*-*	*-*	*-*	*-*
Base case + Rooftop Solar + Tracking System Bifacial + BESS	*0*	*3,200*	*5,953*	*1,200*	*0.55*	*62.3*	*1.11*	*1.95*	*7.7*	*10.8*	*12.4*	*2,673,901*

The model simulated takes into consideration the plants combined load and calculates how much energy can be offset by the renewable technologies, therefore reducing CO_2 emissions and cost.

Solar PV yield figures in HOMER software are high-level and based on calibration with PVsyst results; therefore, are subject to change during more accurate energy yield simulations.

Storage Analysis

Peak periods of electricity use attract a more expensive tariff due to generation plants having to ramp up production to accommodate the increase in load demand. Energy storage can contribute to meeting electricity demand during peak TOU periods, thereby avoiding more expensive charges during these peak hours. Greater grid flexibility is possible as distributors can buy electricity during off-peak times when electricity is cheaper, and avoiding high electricity charges during these peak TOU times. Storage can also provide reserve capacity that can be called upon in the event of the electricity becoming unexpectedly unavailable, such as in the cases of loadshedding or grid outages. Figure 40 provides an application and technology overview with regards to discharge and storage capabilities of various battery technologies available on the market.

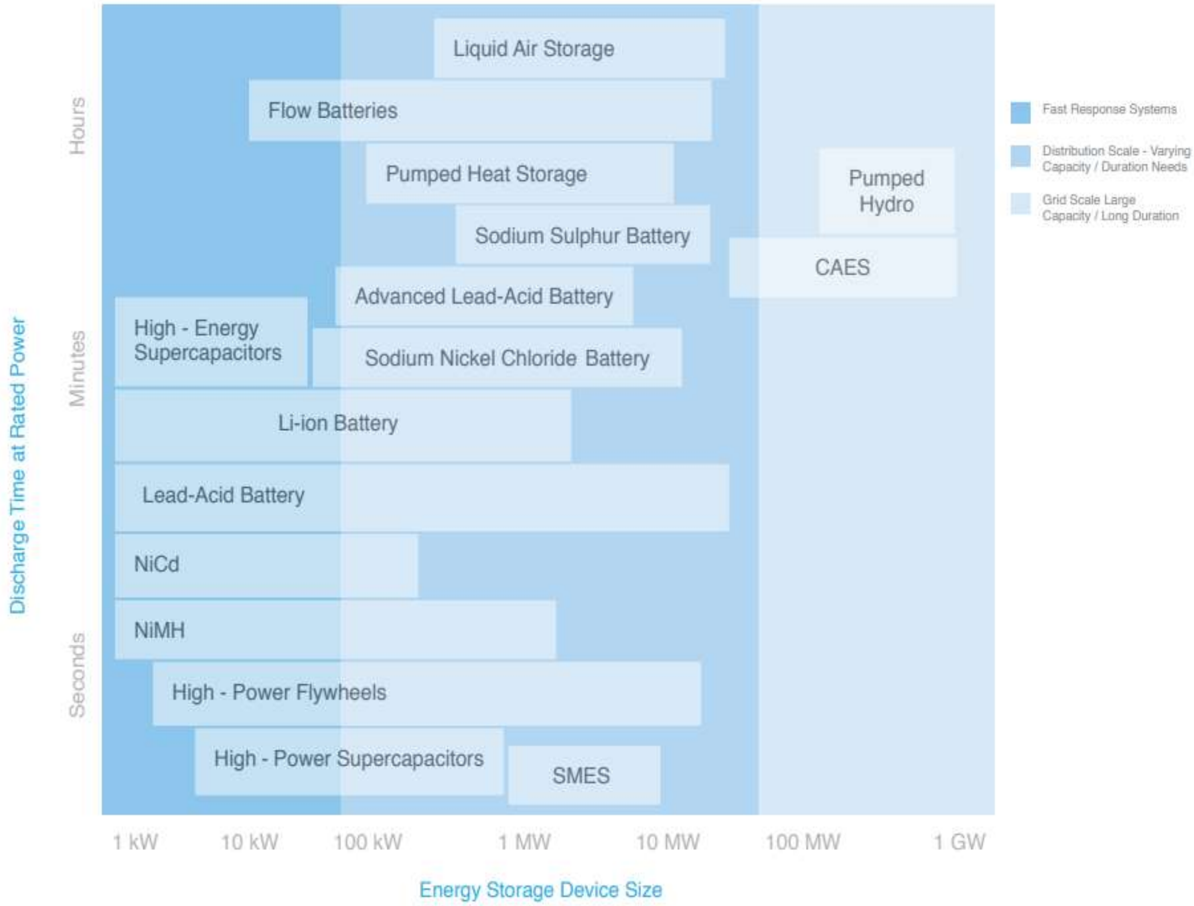


Figure 40: Application and Technology Overview

Arup has conducted a comparison of three electrochemical battery technologies based on capability, availability and cost. These include Lithium-Ion ($LiFeSO_4$), Lead Acid and Nickel Cadmium (NiCd) battery technologies. Energy density in Table 29 refers to the energy that can be stored in the battery per unit volume, and power density refers the amount of energy a battery can store compared to its size. These technologies have all been fully commercialized.

As can be seen, lithium-ion battery technology outperforms lead acid and nickel cadmium in most aspects. Lithium-ion storage has the highest power and energy densities meaning it can deliver power quickly when it is needed, and it is also capable of holding large amounts of energy in relatively small sizes. This technology also has the highest efficiency which ranges from 85% to 90%. The depth of discharge is ~90% which means the battery can be discharged to 90% of it's capacity without degrading the battery's electrodes. Over-discharging a battery degrades its electrodes, which reduces its ability to store energy and thus limits its lifespan. The lifetime of the battery is also favorable at 12-15 years.

Lithium-ion batteries are generally more expensive; however, the extra investment justifies their benefits over the long term. Due to these reasons lithium-ion would be the recommended battery technology should this option be pursued.

Table 28: Comparison of Lead Acid, Lithium-ion and Nickel Cadmium technologies

Type	Power Range	Energy Density Wh/l	Power Density W/l	Efficiency %	Lifetime year	Depth of Discharge %	Cost $/kWh	Environmental Impact
Lead Acid (Pb-A)	20	50-80	10-400	75-80	3-15	50	65	High
Lithium-Ion (LiFePO4)	100	200-500	500-2000	85-90	12-15	90	137	Medium/Low
Nickel Cadmium (NiCd)	40	60-150	150-300	60-65	10-20	-	-	High

Lithium-Iron (Li-ion) Battery Technology

Lithium ion (Li-ion) batteries are rechargeable batteries in which lithium ions move from the negative electrode to the positive electrode during discharge and back again during charging. They are commonly used in consumer electronic products that require a high energy density. The implementation of which is expected to reduce costs and improve performance.

Research and development in various other battery chemistries is ongoing with the goal of improving performance and lowering costs. Li-ion technology is versatile in that it can provide fast response times as well as be supplied from small to medium size capacity. This, in addition to the factors below, contributed to this technology being selected for this assessment. Figure 41 illustrates the Li-ion battery technology components.

Why Lithium-Ion storage?

A number of battery technologies are available in the market currently, however Li-ion batteries have the highest energy output compared to its competitors. A few characteristics of the Li-ion battery are mentioned below that make it suitable for various applications:

- Li-ion energy output ranges from ~88-90% whereas other technologies typically range between ~74-85%.
- This high energy output comes at a relatively reasonable cost per kWh with costs ranging from $137 in 2020 to potentially $101 in 2023.
- Li-ion batteries can tolerate more discharge cycles with >80% depth of discharge. This allows more energy output from the battery.
- Li-ion batteries have a high specific energy density (Wh/kg) making it suitable for longer discharge times in relation to its size. However, this high energy density also increases the risk of a thermal event.
- They also have a high-power density (W/kg) making it suitable for applications requiring fast response times.
- They have a lifetime of between 12-15 years.

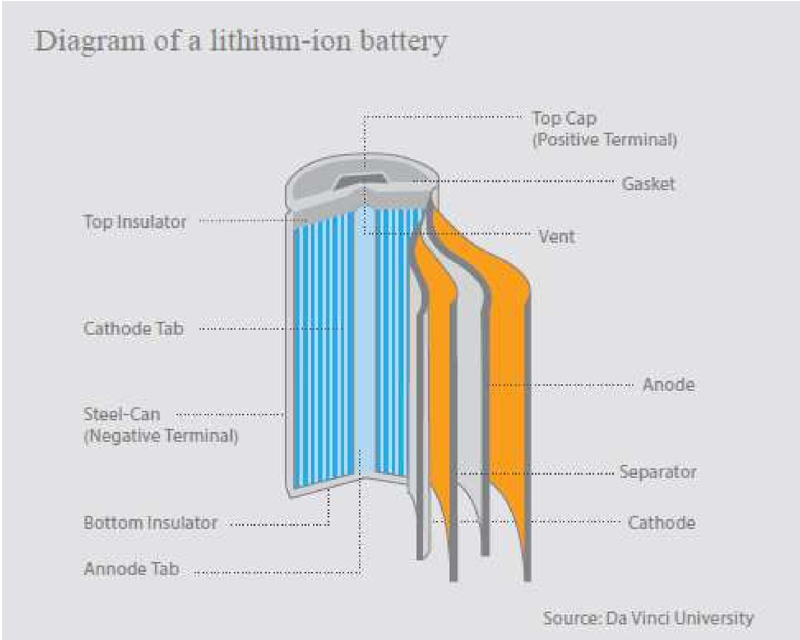


Figure 41: Li-ion Cell Configuration

Next steps

Table 29 provides an overview of recommended next steps that can be taken by IDM to further explore the use of the additional land areas and either close the initial findings and determine the land unsuitable for project development or take it further if it is deemed fit for purpose. The following implementation arrangements could be further explored.

- The IDM leases the land from the Ingonyama Trust and develops the land to provide power to the Sundumbili WTW. Surplus electricity can be sold to the nearby community or a net metering agreement with Eskom can be arranged so the Sundumbili WTW can export surplus electricity to the grid and earn credits for electricity use.
- Enterprise iLembe or a private developer can choose to develop the land and sell electricity to the Sundumbili WTW.

Table 29: Recommended next steps

Item	Commentary	Activities	Deliverable	Indicative timeline	Level of complexity
Land use approval	Land use approval is subject to a specific process outlined by the Ingonyama Trust Board.	- Presentation to local Chief/Inkosi - ITB 1 Form approval - ITB Form approval	Land use lease in place.	3 – 6 months	**Low-Medium**
Stakeholder engagement	Buy-in from local community members that will be impacted by the use of the additional land area for the installation of a large-scale solar PV facility. Community education and buy-in is key to the long-term sustainability and successful implementation of the project and to avoid negative impacts of the project.	- Stakeholder mapping exercise to identify community stakeholders with high impact and high influence to the land area that is proposed for use. - Workshops with community members to raise awareness of the intended land use, identify opportunities for co-benefits and identify and mitigate any potential negative impacts or unintended consequences.	Community project awareness. Community buy-in and support. Risk mitigation.	3 months	**Low**
Environmental consultant	The appointment of an environment consultant will be required to establish if there are any environmental sensitivities in the area, such as indigenous plant species growing in the vicinity of the land area in question. Based on the site verification, the consultant will determine if a Basic Assessment (BA) will be required as well as a Water Use License Application (WULA) due to the proximity to waterways near the land areas being appraised. See further below for information on the BA and WULA processes.	- Appoint environmental consultant. - Environmental consultant to conduct a site visit and prepare a recommendations report.	Recommendations report on which environmental permits and licenses are required such as a Water Use License or Basic Assessment. Based on the above assessment a wetland and aquatic assessment could be required as well as a heritage assessment. If a full Basic Assessment is required, this could take a minimum of 9 months to complete.	2 weeks for initial assessment 6 – 9 months in Basic Assessment is required	**Low**
Geotechnical investigation	The appointment of a geotechnical specialist will be required to establish if the land area soil composition is suitable for the installation of agri-PV structures since the land area is in close proximity to the Tugela River and two waterways nearby.	- Appoint geotechnical consultant. - Geotechnical consultant to conduct a site visit where ground testing is performed and prepare a recommendation report.	Determination on the suitability of the land area for installation of ground-mounted solar or agri-PV structures.	2 weeks	**Low**

Basic Assessment (BA) Process

The regulatory timeframes for a BA which is 6-9 months, is depicted in the following flowchart in Figure 42. The timeline provided is based on the typical regulated timeframes as per the Environmental Impact Assessment (EIA) regulations - and for relevant specialist studies to be undertaken. An important aspect is that generally 4 – 8 weeks are allocated in advance of embarking into the EIA process to undertake specialist studies and ensure that the engineering input (concept design, engineering services report, geotechnical information, details on design and risk assessment etc.) is available and can be utilised by the relevant specialists. Once an EIA number is obtained, one has to meet the regulated timeframes or else the application lapses and a new application will be required to be started.

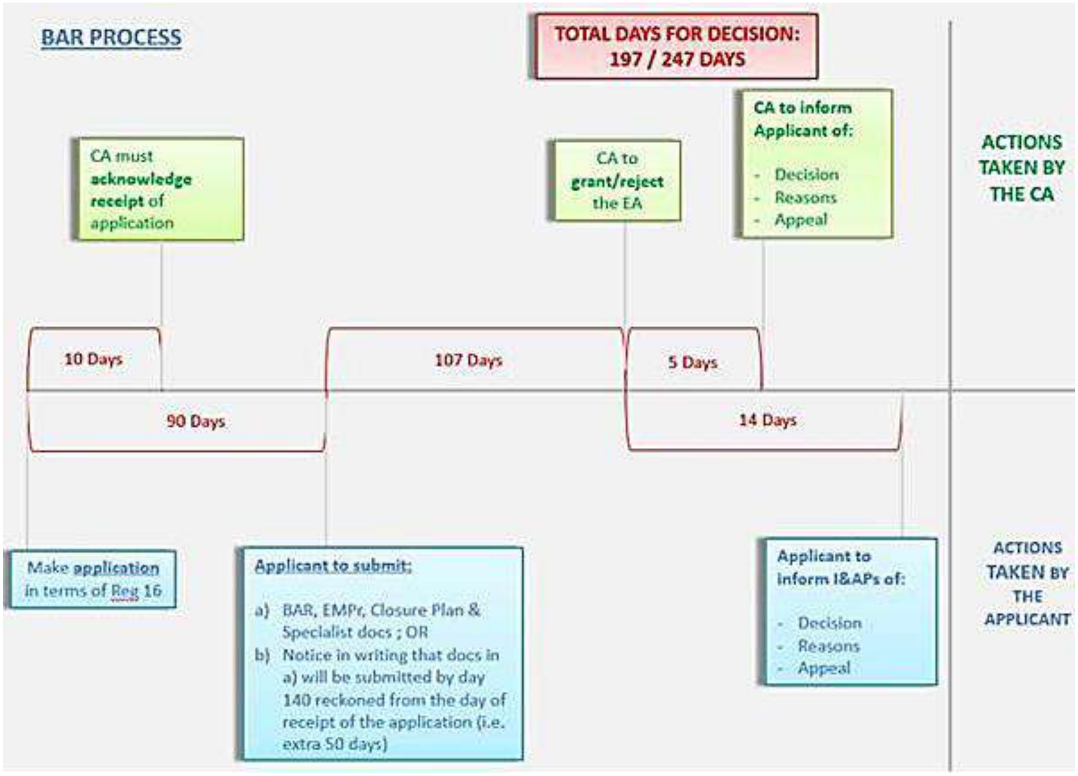


Figure 42: WULA Process

Water Use License Application (WULA) Process

The typical regulatory timeframes for a WULA is 90 days and is depicted in Figure 42. The timeline provided is based on the typical regulated timeframes as per the WULA regulations however this excludes the time required for specialist studies to be undertaken.

The authority has 90 days in which to make a decision once the WULA is submitted. They can provide their decision at any time during this period. An important aspect is that generally 4 – 5weeks are allocated in advance to embarking on the WULA process. This allows specialist studies to be undertaken and ensures that the engineering detail required is available and can be utilised by relevant specialists. Applicants may be requested to advertise the proposed water use, or to invite interested and affected parties to comment. This however can be done concurrently with the BA process.

The Regional Office starts with the implementation of the license, including issuance and highlighting any conditions that might be attached to the water use license. An application for a water use license can take up to 90 days to process, depending on the complexity of the application, its benefits to the nation, and its possible impacts. Generally, low impact, high value license applications will be processed quicker.

Phase	Description	Responsible person	Time frames
1. Pre-application process	Engagement between the applicant and DWS to determine type of authorisation, conduct site inspection and information requirements.	Applicant	No count
	Applicant submits the application, technical report supporting the application is identified. Applicant compile technical report and submit to the Department		
2. Screening of technical report	The technical reporting supporting the application is screened, resulting in its acceptance or rejected. If rejected the application is closed.	Department	90 days
3. Assessment and decision	The application and technical report are evaluated, leading to recommendations and decision.		

Figure 43: Basic Assessment

ANNEXURE 2 – TYPICAL FUNDING APPLICATION REQUIREMENTS

Standard Bank funding requirement example

Standard Bank finances solar PV facilities in the commercial and industrial space and can also assist clients in finding credible installers in the market. Their preferred finance product is asset-based finance up to 10 years with no deposit where justifiable. Asset-based refers to lending that is secured by an asset. If the loan is not repaid, the asset is taken. Standard Bank funds projects up to 100 MW in size with an interest rate typically at prime + 1% or 2%, but this can depend on the risk rating. The below funding requirements are based on the requirement for a business, and it is assumed that the requirements would be similar to that of a municipality.

Solar PV Funding Application Requirements for Standard Bank:

Confirmation of borrowing entity and the following information for this entity:

- 3 Year comparative annual financial statements (AFS)
- Updated management accounts
- Updated Debtors and Creditors list
- Bank Statements for 3 months
- Projected cash flows for the term of debt
- Detailed Organisational Structure demonstrating shareholding
- Confirmation of proposed capital structure for funding
- ID's and Proof of addresses of all Shareholders and Directors
- Balance sheets of all shareholders in the group

Details of proposed system;

- Itemised system costs
- Brands and relative warranties applicable for the panels, inverters, batteries etc
- Year 1's kWh production split by;
  - P90 projection for PV
  - and Storage output
- Annual average load profile for site/catchment area
- Degradation rates applied to the system
- Clear roadmap of how municipal/Eskom sign off will be obtained
- What is the current levelized cost of energy/tariff (excl. VAT) per kWh that the customer is paying to Eskom/Municipality?
- Confirmation of who owns/holds title to the property where solar is being installed
- Collateral on offer for funding
- Details on Operation and Maintenance costs/contracts
- SLA on O&M with relevant company
- Copy of the draft/signed off take agreements
- Tariff structure and escalations applied to the tariff
- Detailed cash flow for the project with specific time scale on how the project will roll over the term of debt from first disbursement

For the off taker:

- 3 Year comparative AFS
- Updated management accounts
- Updated Debtors and Creditors
- Bank Statements for 3 months

Construction arrangements Debtors and Creditors

Confirm if the project be done as a wrapped EPC project and if so, confirm the details of project developer/installer and relevant SLA's in place as well as a business profile.

Clarify construction agreements that have being concluded and how do they address risks around project completion and costs of overruns (Details on performance guarantees in place to support the EPC process).

ANNEXURE 3 – PVSYST REPORTS

PVsyst reports for the modelled roof and ground-mounted systems are included below.

Version 7.2.19

PVsyst - Simulation report

Grid-Connected System

Project: Sundumbili WTW

Variant: Ground - Tracking System (Bifacial)

Unlimited Trackers with backtracking

System power: 218 kWp

Mandeni Local Municipality - Sundumbili - South Africa

Author

Arup (Pty) Ltd (South Africa)

Project summary

Geographical Site
Mandeni Local Municipality - Sundumbili
South Africa

Situation

Latitude	-29.14 °S
Longitude	31.38 °E
Altitude	45 m
Time zone	UTC+2

Project settings
Albedo 0.20

Meteo data
Mandeni Local Municipality - Sundumbili
SolarGIS Monthly aver. , period not spec. - Synthetic

System summary

Grid-Connected System

Unlimited Trackers with backtracking

PV Field Orientation
Orientation
Tracking horizontal axis

Tracking algorithm
Astronomic calculation
Backtracking activated

Near Shadings
No Shadings

System information

PV Array		Inverters	
Nb. of modules	544 units	Nb. of units	3 units
Pnom total	218 kWp	Pnom total	180 kWac
		Pnom ratio	1.209

User's needs
Unlimited load (grid)

Results summary

Produced Energy	375.5 MWh/year	Specific production	1726 kWh/kWp/year	Perf. Ratio PR	86.92 %

Table of contents

General parameters

Grid-Connected System | **Unlimited Trackers with backtracking**

PV Field Orientation

Orientation
Tracking horizontal axis

Tracking algorithm
Astronomic calculation
Backtracking activated

Backtracking array

Nb. of trackers	10 units
Unlimited trackers	
Sizes	
Tracker Spacing	6.50 m
Collector width	4.10 m
Ground Cov. Ratio (GCR)	63.1 %
Left inactive band	0.02 m
Right inactive band	0.02 m
Phi min / max.	-/+ 55.0 °
Backtracking strategy	
Phi limits	+/- 50.3 °
Backtracking pitch	6.50 m
Backtracking width	4.10 m

Models used

Transposition	Perez
Diffuse	Perez, Meteonorm
Circumsolar	separate

Horizon
Free Horizon

Near Shadings
No Shadings

User's needs
Unlimited load (grid)

Bifacial system

Model: 2D Calculation, unlimited trackers

Bifacial model geometry

Tracker Spacing	6.50 m
Tracker width	4.14 m
GCR	63.7 %
Axis height above ground	2.00 m

Bifacial model definitions

Ground albedo	0.25
Bifaciality factor	70 %
Rear shading factor	5.0 %
Rear mismatch loss	10.0 %
Shed transparent fraction	2.0 %

PV Array Characteristics

PV module

Manufacturer	Trina Solar
Model	TSM-DEG15MC-20-(II)-400-Bifacial
(Original PVsyst database)	
Unit Nom. Power	400 Wp
Number of PV modules	544 units
Nominal (STC)	218 kWp
Modules	34 Strings x 16 In series
At operating cond. (50°C)	
Pmpp	199 kWp
U mpp	593 V
I mpp	335 A

Inverter

Manufacturer	Huawei Technologies
Model	SUN2000-60KTL-M0_400Vac
(Original PVsyst database)	
Unit Nom. Power	60.0 kWac
Number of inverters	3 units
Total power	180 kWac
Operating voltage	200-1000 V
Max. power (=>30°C)	66.0 kWac
Pnom ratio (DC:AC)	1.21

Total PV power

Nominal (STC)	218 kWp
Total	544 modules
Module area	1117 m²
Cell area	948 m²

Total inverter power

Total power	180 kWac
Number of inverters	3 units
Pnom ratio	1.21

Array losses

Array Soiling Losses
Loss Fraction 1.5 %

Thermal Loss factor
Module temperature according to irradiance
Uc (const) 29.0 W/m²K
Uv (wind) 0.0 W/m²K/m/s

DC wiring losses
Global array res. 29 mΩ
Loss Fraction 1.5 % at STC

LID - Light Induced Degradation
Loss Fraction 1.5 %

Module Quality Loss
Loss Fraction -0.8 %

Module mismatch losses
Loss Fraction 2.0 % at MPP

Strings Mismatch loss
Loss Fraction 0.1 %

IAM loss factor
Incidence effect (IAM): Fresnel, AR coating, n(glass)=1.526, n(AR)=1.290

0°	30°	50°	60°	70°	75°	80°	85°	90°
1.000	0.999	0.987	0.962	0.892	0.816	0.681	0.440	0.000

AC wiring losses

Inv. output line up to injection point
Inverter voltage 400 Vac tri
Loss Fraction 0.34 % at STC
Inverter: SUN2000-60KTL-M0_400Vac
Wire section (3 Inv.) Copper 3 x 3 x 25 mm²
Average wires length 10 m

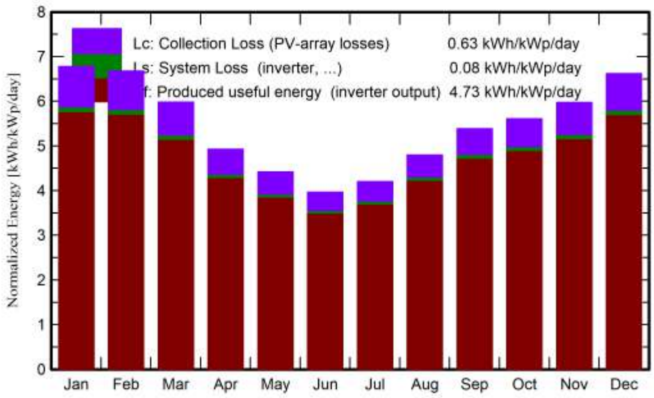
Main results

System Production

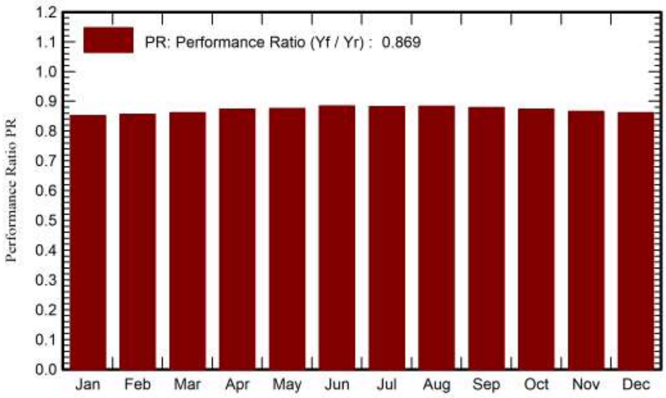
Produced Energy 375.5 MWh/year

Specific production 1726 kWh/kWp/year
Performance Ratio PR 86.92 %

Normalized productions (per installed kWp)



Performance Ratio PR



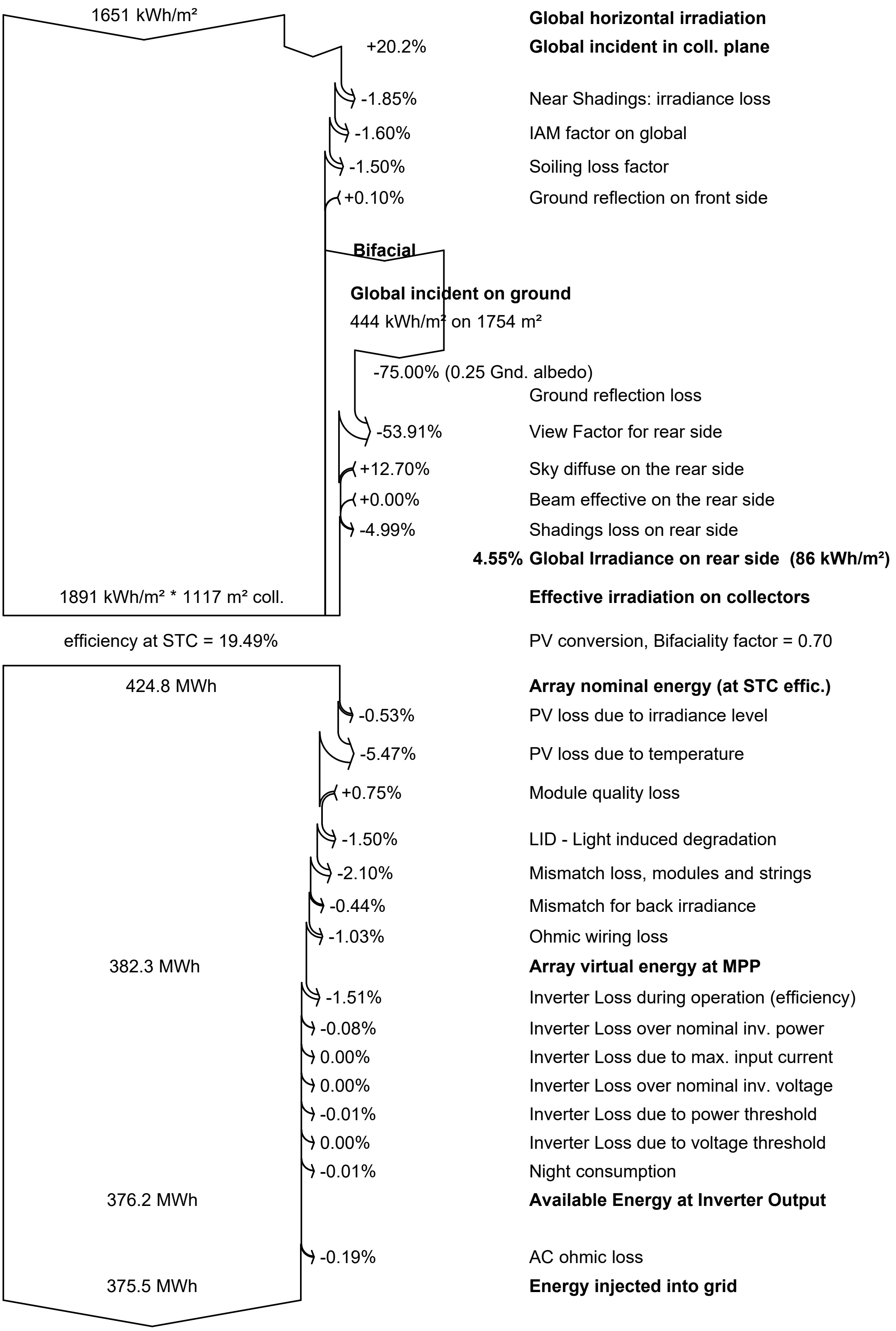
Balances and main results

	GlobHor	DiffHor	T_Amb	GlobInc	GlobEff	EArray	E_Grid	PR
	kWh/m²	kWh/m²	°C	kWh/m²	kWh/m²	MWh	MWh	ratio
January	176.6	69.70	24.80	210.1	201.1	39.69	38.96	0.852
February	155.0	57.90	25.00	187.0	179.0	35.47	34.83	0.856
March	152.7	55.50	24.10	185.4	177.3	35.40	34.77	0.862
April	121.9	43.00	21.80	147.8	140.8	28.57	28.09	0.873
May	111.6	35.60	19.40	137.0	129.3	26.51	26.09	0.875
June	96.5	29.50	17.30	118.9	112.2	23.25	22.88	0.884
July	105.6	34.50	16.70	130.3	122.6	25.43	25.03	0.882
August	123.1	45.30	18.50	148.7	141.1	29.06	28.59	0.884
September	135.0	55.40	19.90	161.7	154.1	31.46	30.92	0.879
October	147.4	65.30	20.80	173.9	165.9	33.66	33.07	0.874
November	153.0	67.50	22.20	179.2	171.0	34.35	33.75	0.866
December	173.1	72.50	23.79	205.3	196.2	39.20	38.50	0.862
Year	1651.5	631.70	21.17	1985.2	1890.6	382.03	375.47	0.869

Legends

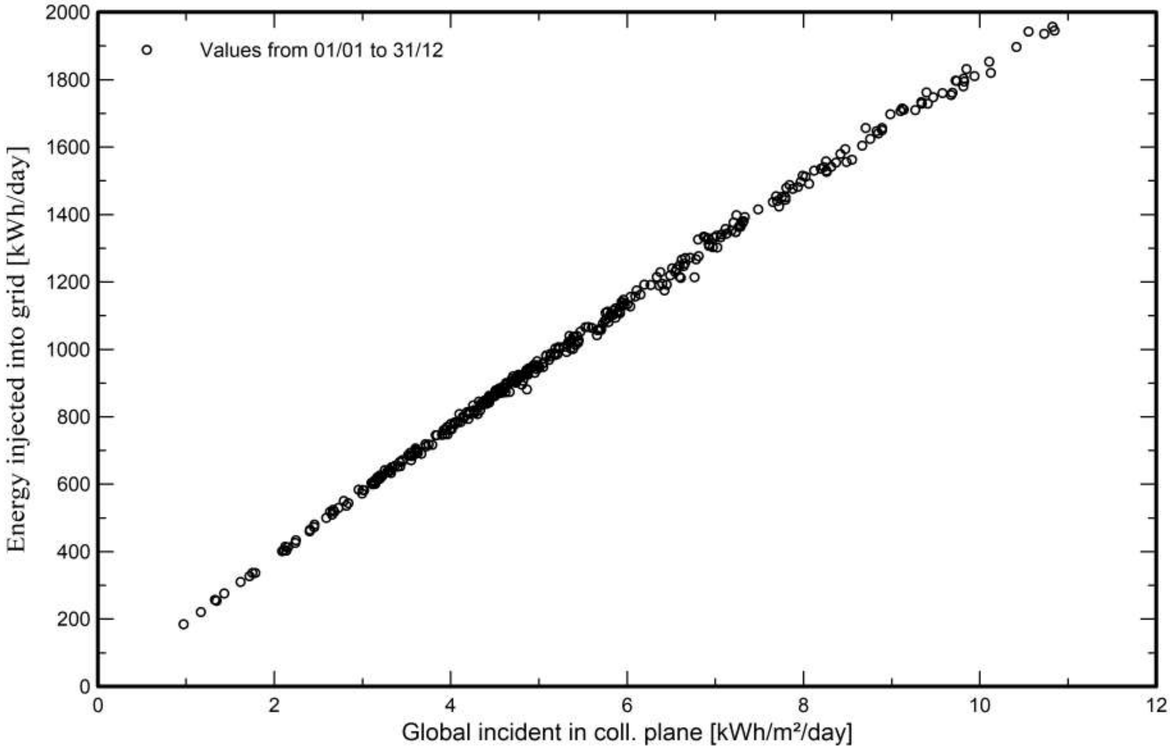
GlobHor	Global horizontal irradiation
DiffHor	Horizontal diffuse irradiation
T_Amb	Ambient Temperature
GlobInc	Global incident in coll. plane
GlobEff	Effective Global, corr. for IAM and shadings
EArray	Effective energy at the output of the array
E_Grid	Energy injected into grid
PR	Performance Ratio

Loss diagram

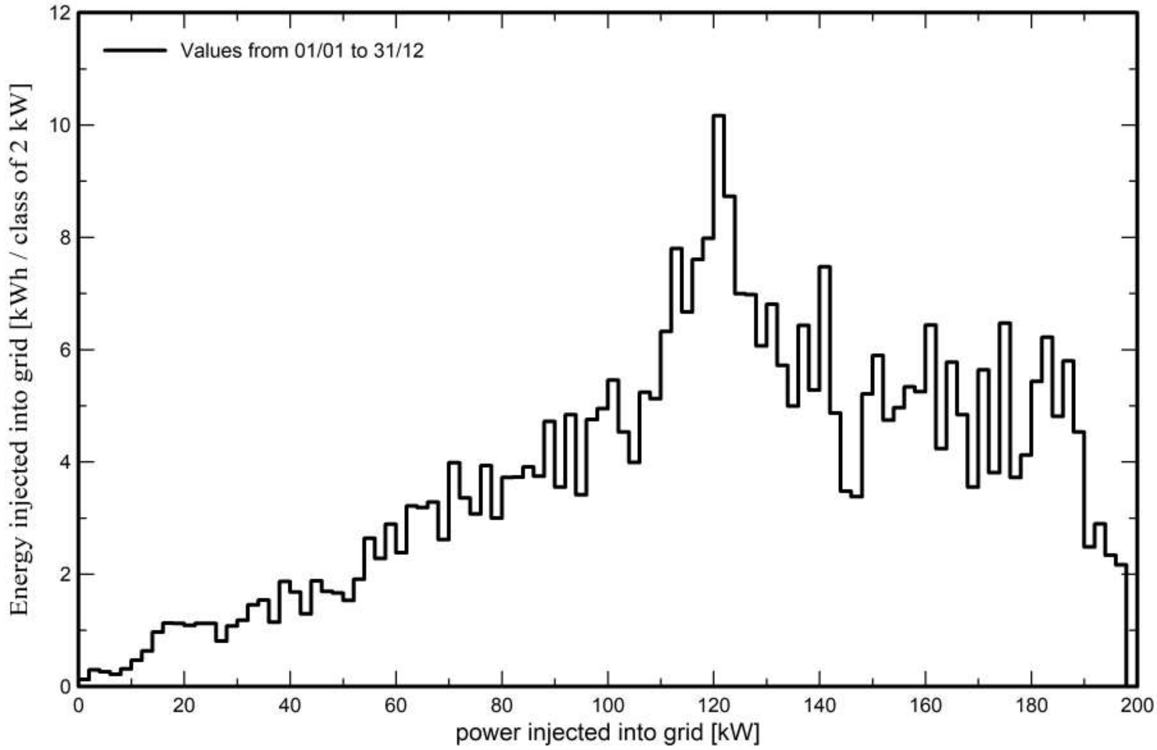


Special graphs

Daily Input/Output diagram



System Output Power Distribution



Version 7.2.19

PVsyst - Simulation report

Grid-Connected System

Project: Sundumbili WTW

Variant: Roof

No 3D scene defined, no shadings

System power: 130 kWp

Mandeni Local Municipality - Sundumbili - South Africa

Author

Arup (Pty) Ltd (South Africa)

Project: Sundumbili WTW

Variant: Roof

Arup (Pty) Ltd (South Africa)

Project summary

Geographical Site
Mandeni Local Municipality - Sundumbili
South Africa

Situation

Latitude	-29.14 °S
Longitude	31.38 °E
Altitude	45 m
Time zone	UTC+2

Project settings

Albedo	0.20

Meteo data
Mandeni Local Municipality - Sundumbili
SolarGIS Monthly aver. , period not spec. - Synthetic

System summary

Grid-Connected System

No 3D scene defined, no shadings

PV Field Orientation
horizontal plane

Near Shadings
No Shadings

User's needs
Unlimited load (grid)

System information

PV Array		**Inverters**	
Nb. of modules	324 units	Nb. of units	2 units
Pnom total	130 kWp	Pnom total	110 kWac
		Pnom ratio	1.178

Results summary

Produced Energy	180.0 MWh/year	Specific production	1389 kWh/kWp/year	Perf. Ratio PR	84.13 %

Table of contents

General parameters

Grid-Connected System — **No 3D scene defined, no shadings**

PV Field Orientation

Orientation	Sheds configuration	Models used	
horizontal plane	No 3D scene defined	Transposition	Perez
		Diffuse	Perez, Meteonorm
		Circumsolar	separate

Horizon	Near Shadings	User's needs
Free Horizon	No Shadings	Unlimited load (grid)

PV Array Characteristics

PV module		Inverter	
Manufacturer	Trina Solar	Manufacturer	Huawei Technologies
Model	TSM-DE15M-(II)-400	Model	SUN2000-55KTL-IN-HV-D1
(Original PVsyst database)		(Original PVsyst database)	
Unit Nom. Power	400 Wp	Unit Nom. Power	55.0 kWac
Number of PV modules	324 units	Number of inverters	2 units
Nominal (STC)	130 kWp	Total power	110 kWac
Modules	12 Strings x 27 In series	Operating voltage	600-1450 V
At operating cond. (50°C)		Max. power (=>30°C)	66.0 kWac
Pmpp	118 kWp	Pnom ratio (DC:AC)	1.18
U mpp	991 V		
I mpp	119 A		

Total PV power		Total inverter power	
Nominal (STC)	130 kWp	Total power	110 kWac
Total	324 modules	Number of inverters	2 units
Module area	658 m²	Pnom ratio	1.18
Cell area	565 m²		

Array losses

Array Soiling Losses
Loss Fraction 3.0 %

Thermal Loss factor
Module temperature according to irradiance
Uc (const) 29.0 W/m²K
Uv (wind) 0.0 W/m²K/m/s

DC wiring losses
Global array res. 138 mΩ
Loss Fraction 1.5 % at STC

LID - Light Induced Degradation
Loss Fraction 1.5 %

Module Quality Loss
Loss Fraction -0.8 %

Module mismatch losses
Loss Fraction 2.0 % at MPP

Strings Mismatch loss
Loss Fraction 0.1 %

IAM loss factor
Incidence effect (IAM): Fresnel, AR coating, n(glass)=1.526, n(AR)=1.290

0°	30°	50°	60°	70°	75°	80°	85°	90°
1.000	0.999	0.987	0.962	0.892	0.816	0.681	0.440	0.000

AC wiring losses

Inv. output line up to injection point

Inverter voltage	800 Vac tri
Loss Fraction	0.15 % at STC

Inverter: SUN2000-55KTL-IN-HV-D1

Wire section (2 Inv.)	Copper 2 x 3 x 25 mm²
Average wires length	20 m

Main results

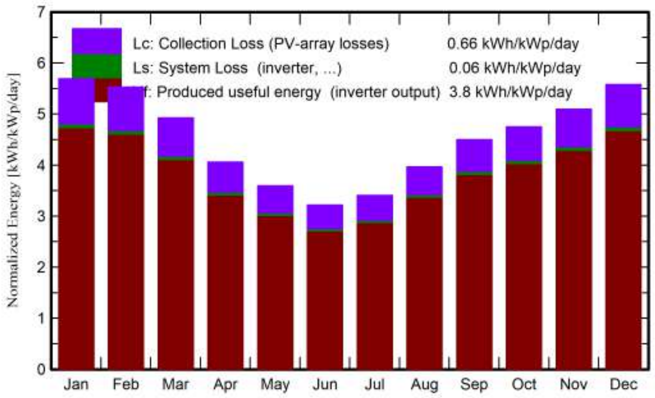
System Production

Produced Energy 180.0 MWh/year

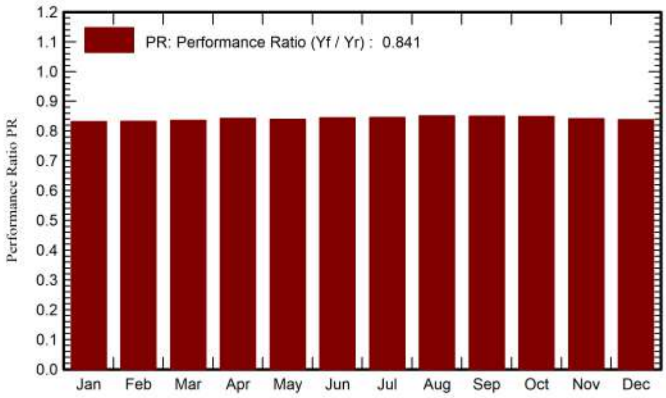
Specific production 1389 kWh/kWp/year

Performance Ratio PR 84.13 %

Normalized productions (per installed kWp)



Performance Ratio PR



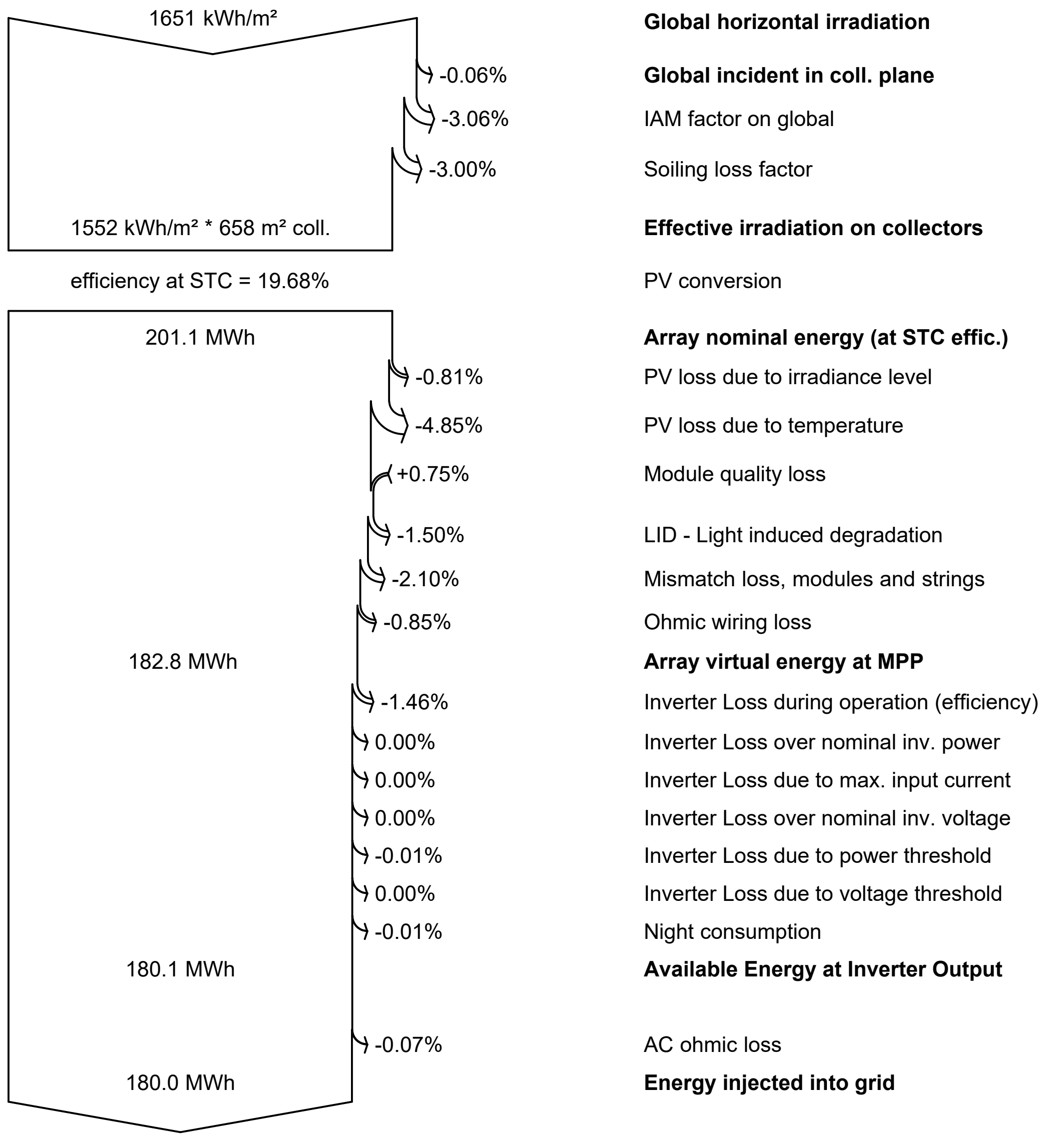
Balances and main results

	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray MWh	E_Grid MWh	PR ratio
January	176.6	69.70	24.80	176.5	167.5	19.34	19.02	0.832
February	155.0	57.90	25.00	154.9	146.7	17.00	16.73	0.833
March	152.7	55.50	24.10	152.7	144.0	16.80	16.54	0.836
April	121.9	43.00	21.80	121.8	114.2	13.50	13.30	0.842
May	111.6	35.60	19.40	111.5	103.1	12.32	12.13	0.839
June	96.5	29.50	17.30	96.5	88.9	10.72	10.56	0.845
July	105.6	34.50	16.70	105.6	97.2	11.74	11.57	0.846
August	123.1	45.30	18.50	123.0	115.0	13.77	13.56	0.851
September	135.0	55.40	19.90	134.9	127.1	15.10	14.87	0.850
October	147.4	65.30	20.80	147.3	139.4	16.46	16.20	0.849
November	153.0	67.50	22.20	152.9	144.9	16.95	16.69	0.842
December	173.1	72.50	23.79	173.0	164.0	19.11	18.80	0.839
Year	1651.5	631.70	21.17	1650.6	1552.0	182.80	179.97	0.841

Legends

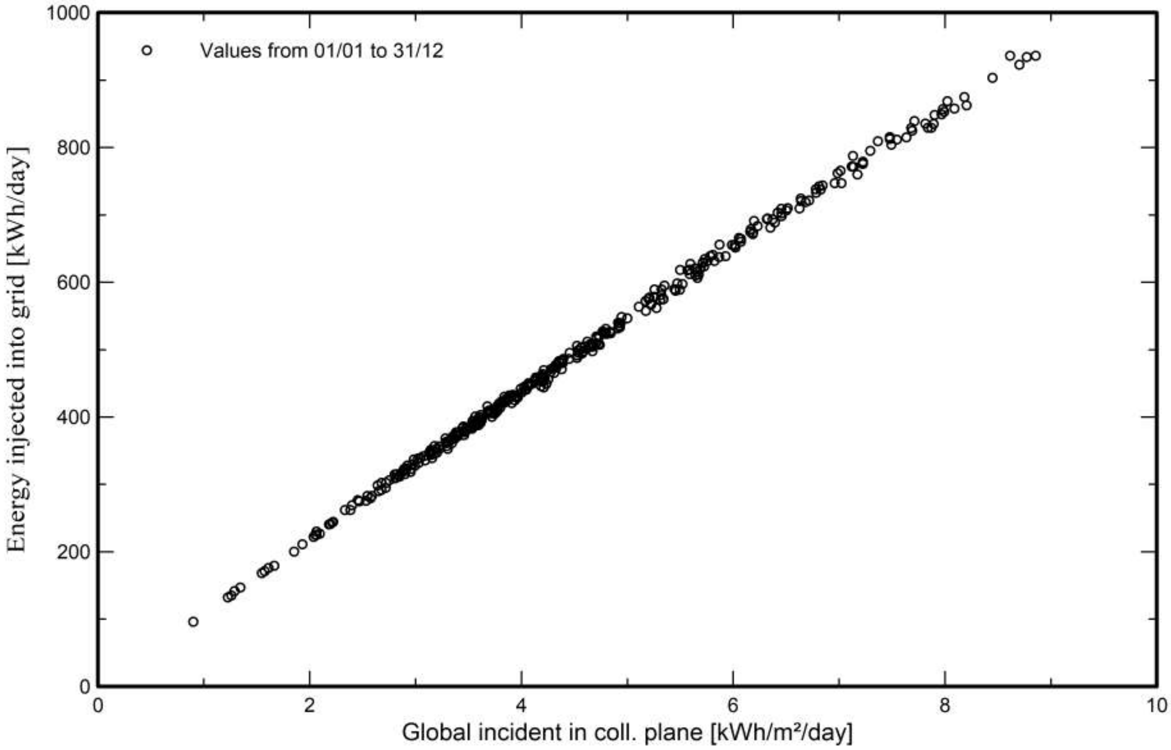
GlobHor	Global horizontal irradiation
DiffHor	Horizontal diffuse irradiation
T_Amb	Ambient Temperature
GlobInc	Global incident in coll. plane
GlobEff	Effective Global, corr. for IAM and shadings
EArray	Effective energy at the output of the array
E_Grid	Energy injected into grid
PR	Performance Ratio

Loss diagram

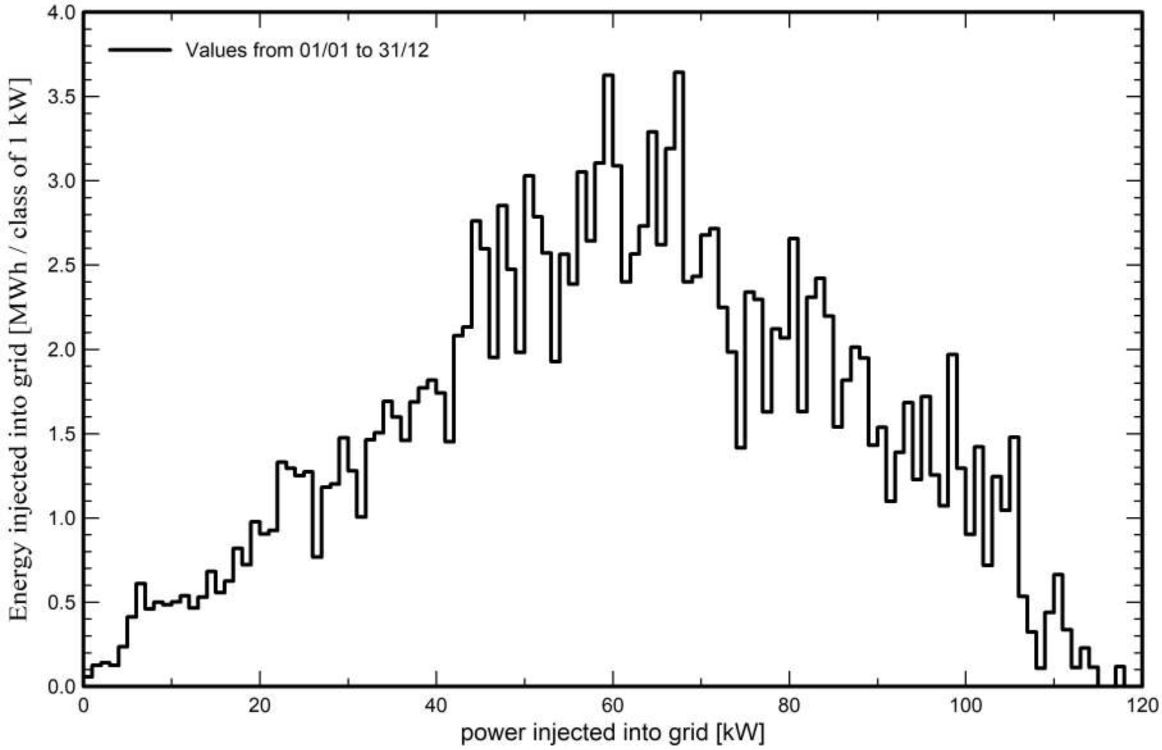


Special graphs

Daily Input/Output diagram



System Output Power Distribution



ANNEXURE 4 – FINANCIAL ANALYSIS

Figure 42 to Figure 46 below provide high-level cashflow of the roof and ground mounted scenarios. These include capital and operation costs as well as energy generation and grid energy saving. Potential savings provided by the roof and ground mounted solar PV facilitys is also highlighted over a 20-year period and the total saving over the lifetime of the plant (25-years) is given. The cashflows below are based on rand per watt value (R/Wp) costs for each system, as summarised in the Table 7 of section 3.2.5.2.

Base case + Rooftop Solar + Fixed Solar System

Years	0	1	2	3	4	5	6	7	8	9	10
Nominal											
PV ground											
Generation (kWh)		339 000	337 305	335 619	333 941	332 271	330 610	328 957	327 312	325 675	324 047
Capital	R3 175 500	R0	R0	R0	R0	R0	R0	R0	R0	R0	R0
O&M	R0	R37 011	R37 011	R37 011	R37 011	R37 011	R37 011	R37 011	R37 011	R37 011	R37 011
PV ground Total	R3 175 500	R37 011	R37 011	R37 011	R37 011	R37 011	R37 011	R37 011	R37 011	R37 011	R37 011
PV Roof											
Generation (kWh)		180 000	179 100	178 204	177 313	176 427	175 544	174 667	173 793	172 924	172 060
Capital	R1 690 000	R0	R0	R0	R0	R0	R0	R0	R0	R0	R0
O&M	R0	R17 550	R17 550	R17 550	R17 550	R17 550	R17 550	R17 550	R17 550	R17 550	R17 550
PV Roof Total	R1 690 000	R17 550	R17 550	R17 550	R17 550	R17 550	R17 550	R17 550	R17 550	R17 550	R17 550
Total	R4 865 500	R54 561	R54 561	R54 561	R54 561	R54 561	R54 561	R54 561	R54 561	R54 561	R54 561
SWTW Grid											
Grid Purchases without PV (kWh)		5 175 335	5 175 335	5 175 335	5 175 335	5 175 335	5 175 335	5 175 335	5 175 335	5 175 335	5 175 335
Grid Purchases with PV (kWh)		4 656 335	4 652 198	4 654 786	4 657 361	4 659 924	4 662 474	4 665 011	4 667 535	4 670 047	4 672 547
Grid Purchases offset by PV (kWh)		519 000	516 405	513 823	511 254	508 698	506 154	503 623	501 105	498 600	496 107
Grid Operating without PV		R5 809 012	R5 809 012	R5 809 012	R5 809 012	R5 809 012	R5 809 012	R5 809 012	R5 809 012	R5 809 012	R5 809 012
Grid Operating Costs with PV		R5 246 268	R5 249 056	R5 251 830	R5 254 590	R5 257 336	R5 260 069	R5 262 788	R5 265 493	R5 268 184	R5 270 863
PV Plant O&M		R54 561	R54 561	R54 561	R54 561	R54 561	R54 561	R54 561	R54 561	R54 561	R54 561
SWTW Grid Total Savings		R508 183	R505 395	R502 621	R499 861	R497 115	R494 382	R491 663	R488 958	R486 267	R483 588

Years	11	12	13	14	15	16	17	18	19	20
Nominal										
PV ground										
Generation (kWh)	322 427	320 815	319 210	317 614	316 026	314 446	312 874	311 310	309 753	308 204
Capital	R0	R0	R0	R0	R0	R0	R0	R0	R0	R0
O&M	R37 011	R37 011	R37 011	R37 011	R37 011	R37 011	R37 011	R37 011	R37 011	R37 011
PV ground Total	R37 011	R37 011	R37 011	R37 011	R37 011	R37 011	R37 011	R37 011	R37 011	R37 011
PV Roof										
Generation (kWh)	171 199	170 343	169 492	168 644	167 801	166 962	166 127	165 297	164 470	163 648
Capital	R0	R0	R0	R0	R0	R0	R0	R0	R0	R0
O&M	R17 550	R17 550	R17 550	R17 550	R17 550	R17 550	R17 550	R17 550	R17 550	R17 550
PV Roof Total	R17 550	R17 550	R17 550	R17 550	R17 550	R17 550	R17 550	R17 550	R17 550	R17 550
Total	R54 561	R54 561	R54 561	R54 561	R54 561	R54 561	R54 561	R54 561	R54 561	R54 561
SWTW Grid										
Grid Purchases without PV (kWh)	5 175 335	5 175 335	5 175 335	5 175 335	5 175 335	5 175 335	5 175 335	5 175 335	5 175 335	5 175 335
Grid Purchases with PV (kWh)	4 675 036	4 677 512	4 679 975	4 682 426	4 684 866	4 687 293	4 689 709	4 692 113	4 694 506	4 696 887
Grid Purchases offset by PV (kWh)	493 626	491 158	488 702	486 259	483 827	481 408	479 001	476 606	474 223	471 852
Grid Operating without PV	R5 809 012	R5 809 012	R5 809 012	R5 809 012	R5 809 012	R5 809 012	R5 809 012	R5 809 012	R5 809 012	R5 809 012
Grid Operating Costs with PV	R5 273 528	R5 276 181	R5 278 820	R5 281 446	R5 284 058	R5 286 658	R5 289 244	R5 291 818	R5 294 379	R5 296 928
PV Plant O&M	R54 561	R54 561	R54 561	R54 561	R54 561	R54 561	R54 561	R54 561	R54 561	R54 561
SWTW Grid Total Savings	R480 923	R478 270	R475 631	R473 005	R470 393	R467 793	R465 207	R462 633	R460 072	R457 523

Potential Saving (Over 25-years)	R 11 899 319
LCOE (R/kWh)	1.08
Internal Rate of Return (IRR) (%)	8.8
Simple Payback (years)	9.8
Net Present Value (NPV)	R 2 831 559

Figure 44: 20-year Cashflow Estimate for Scenario 1

Base case + Rooftop Solar + Tracking System Monofacial

Years	0	1	2	3	4	5	6	7	8	9	10
Nominal											
PV ground											
Generation (kWh)		365 010	363 185	361 369	359 562	357 765	355 976	354 196	352 425	350 663	348 909
Capital	R3 504 000	R0	R0	R0	R0	R0	R0	R0	R0	R0	R0
O&M	R0	R42 048	R42 048	R42 048	R42 048	R42 048	R42 048	R42 048	R42 048	R42 048	R42 048
PV ground Total	R3 504 000	R42 048	R42 048	R42 048	R42 048	R42 048	R42 048	R42 048	R42 048	R42 048	R42 048
PV Roof											
Generation (kWh)		180 000	179 100	178 204	177 313	176 427	175 544	174 667	173 793	172 924	172 060
Capital	R1 690 000	R0	R0	R0	R0	R0	R0	R0	R0	R0	R0
O&M	R0	R17 550	R17 550	R17 550	R17 550	R17 550	R17 550	R17 550	R17 550	R17 550	R17 550
PV Roof Total	R1 690 000	R17 550	R17 550	R17 550	R17 550	R17 550	R17 550	R17 550	R17 550	R17 550	R17 550
Total	R5 194 000	R59 598	R59 598	R59 598	R59 598	R59 598	R59 598	R59 598	R59 598	R59 598	R59 598
SWTW Grid											
Grid Purchases without PV (kWh)		5 175 335	5 175 335	5 175 335	5 175 335	5 175 335	5 175 335	5 175 335	5 175 335	5 175 335	5 175 335
Grid Purchases with PV (kWh)		4 630 325	4 652 198	4 654 786	4 657 361	4 659 924	4 662 474	4 665 011	4 667 535	4 670 047	4 672 547
Grid Purchases offset by PV (kWh)		545 010	542 285	539 573	536 875	534 191	531 520	528 863	526 218	523 587	520 969
Grid Operating without PV		R5 809 012	R5 809 012	R5 809 012	R5 809 012	R5 809 012	R5 809 012	R5 809 012	R5 809 012	R5 809 012	R5 809 012
Grid Operating Costs with PV		R5 218 328	R5 221 255	R5 224 168	R5 227 066	R5 229 949	R5 232 818	R5 235 673	R5 238 514	R5 241 340	R5 244 153
PV Plant O&M		R59 598	R59 598	R59 598	R59 598	R59 598	R59 598	R59 598	R59 598	R59 598	R59 598
SWTW Grid Total Savings		R531 086	R528 159	R525 246	R522 348	R519 465	R516 596	R513 741	R510 900	R508 074	R505 261

Years	11	12	13	14	15	16	17	18	19	20
Nominal										
PV ground										
Generation (kWh)	347 165	345 429	343 702	341 983	340 274	338 572	336 879	335 195	333 519	331 851
Capital	R0	R0	R0	R0	R0	R0	R0	R0	R0	R0
O&M	R42 048	R42 048	R42 048	R42 048	R42 048	R42 048	R42 048	R42 048	R42 048	R42 048
PV ground Total	R42 048	R42 048	R42 048	R42 048	R42 048	R42 048	R42 048	R42 048	R42 048	R42 048
PV Roof										
Generation (kWh)	171 199	170 343	169 492	168 644	167 801	166 962	166 127	165 297	164 470	163 648
Capital	R0	R0	R0	R0	R0	R0	R0	R0	R0	R0
O&M	R17 550	R17 550	R17 550	R17 550	R17 550	R17 550	R17 550	R17 550	R17 550	R17 550
PV Roof Total	R17 550	R17 550	R17 550	R17 550	R17 550	R17 550	R17 550	R17 550	R17 550	R17 550
Total	R59 598	R59 598	R59 598	R59 598	R59 598	R59 598	R59 598	R59 598	R59 598	R59 598
SWTW Grid										
Grid Purchases without PV (kWh)	5 175 335	5 175 335	5 175 335	5 175 335	5 175 335	5 175 335	5 175 335	5 175 335	5 175 335	5 175 335
Grid Purchases with PV (kWh)	4 675 036	4 677 512	4 679 975	4 682 426	4 684 866	4 687 293	4 689 709	4 692 113	4 694 506	4 696 887
Grid Purchases offset by PV (kWh)	518 364	515 773	513 194	510 628	508 075	505 534	503 007	500 491	497 989	495 499
Grid Operating without PV	R5 809 012	R5 809 012	R5 809 012	R5 809 012	R5 809 012	R5 809 012	R5 809 012	R5 809 012	R5 809 012	R5 809 012
Grid Operating Costs with PV	R5 246 951	R5 249 736	R5 252 506	R5 255 263	R5 258 006	R5 260 735	R5 263 450	R5 266 152	R5 268 840	R5 271 516
PV Plant O&M	R59 598	R59 598	R59 598	R59 598	R59 598	R59 598	R59 598	R59 598	R59 598	R59 598
SWTW Grid Total Savings	R502 463	R499 678	R496 908	R494 151	R491 408	R488 679	R485 964	R483 262	R480 574	R477 898

Potential Saving (Over 25-years)	R 12 431 681.00
LCOE (R/kWh)	1.08
Internal Rate of Return (IRR) (%)	8.5
Simple Payback (years)	10
Net Present Value (NPV)	R 2 847 831

Figure 45: 20-year Cashflow Estimate for Scenario 2

Base case + Rooftop Solar + Tracking System Bifacial											
Years	0	1	2	3	4	5	6	7	8	9	10
Nominal											
PV ground											
Generation (kWh)		375 026	373 151	371 285	369 428	367 581	365 743	363 915	362 095	360 285	358 483
Capital	R3 569 700	R0	R0	R0	R0	R0	R0	R0	R0	R0	R0
O&M	R0	R42 048	R42 048	R42 048	R42 048	R42 048	R42 048	R42 048	R42 048	R42 048	R42 048
PV ground Total	R3 569 700	R42 048	R42 048	R42 048	R42 048	R42 048	R42 048	R42 048	R42 048	R42 048	R42 048
PV Roof											
Generation (kWh)		180 000	179 100	178 204	177 313	176 427	175 544	174 667	173 793	172 924	172 060
Capital	R1 690 000	R0	R0	R0	R0	R0	R0	R0	R0	R0	R0
O&M	R0	R17 550	R17 550	R17 550	R17 550	R17 550	R17 550	R17 550	R17 550	R17 550	R17 550
PV Roof Total	R1 690 000	R17 550	R17 550	R17 550	R17 550	R17 550	R17 550	R17 550	R17 550	R17 550	R17 550
Total	R5 259 700	R59 598	R59 598	R59 598	R59 598	R59 598	R59 598	R59 598	R59 598	R59 598	R59 598
SWTW Grid											
Grid Purchases without PV (kWh)		5 175 335	5 175 335	5 175 335	5 175 335	5 175 335	5 175 335	5 175 335	5 175 335	5 175 335	5 175 335
Grid Purchases with PV (kWh)		4 620 310	4 623 085	4 625 846	4 628 594	4 631 328	4 634 048	4 636 754	4 639 447	4 642 126	4 644 792
Grid Purchases offset by PV (kWh)		555 025	552 250	549 489	546 741	544 008	541 288	538 581	535 888	533 209	530 543
Grid Operating without PV		R5 809 012	R5 809 012	R5 809 012	R5 809 012	R5 809 012	R5 809 012	R5 809 012	R5 809 012	R5 809 012	R5 809 012
Grid Operating Costs with PV		R5 207 571	R5 210 550	R5 213 514	R5 216 464	R5 219 400	R5 222 321	R5 225 228	R5 228 121	R5 231 000	R5 233 863
PV Plant O&M		R59 598	R59 598	R59 598	R59 598	R59 598	R59 598	R59 598	R59 598	R59 598	R59 598
SWTW Grid Total Savings		R541 843	R538 864	R535 900	R532 950	R530 014	R527 093	R524 186	R521 293	R518 414	R515 551

Base case + Rooftop Solar + Tracking System Bifacial										
Years	11	12	13	14	15	16	17	18	19	20
Nominal										
PV ground										
Generation (kWh)	356 691	354 907	353 133	351 367	349 610	347 862	346 123	344 392	342 670	340 957
Capital	R0	R0	R0	R0	R0	R0	R0	R0	R0	R0
O&M	R42 048	R42 048	R42 048	R42 048	R42 048	R42 048	R42 048	R42 048	R42 048	R42 048
PV ground Total	R42 048	R42 048	R42 048	R42 048	R42 048	R42 048	R42 048	R42 048	R42 048	R42 048
PV Roof										
Generation (kWh)	171 199	170 343	169 492	168 644	167 801	166 962	166 127	165 297	164 470	163 648
Capital	R0	R0	R0	R0	R0	R0	R0	R0	R0	R0
O&M	R17 550	R17 550	R17 550	R17 550	R17 550	R17 550	R17 550	R17 550	R17 550	R17 550
PV Roof Total	R17 550	R17 550	R17 550	R17 550	R17 550	R17 550	R17 550	R17 550	R17 550	R17 550
Total	R59 598	R59 598	R59 598	R59 598	R59 598	R59 598	R59 598	R59 598	R59 598	R59 598
SWTW Grid										
Grid Purchases without PV (kWh)	5 175 335	5 175 335	5 175 335	5 175 335	5 175 335	5 175 335	5 175 335	5 175 335	5 175 335	5 175 335
Grid Purchases with PV (kWh)	4 647 445	4 650 085	4 652 711	4 655 324	4 657 924	4 660 511	4 663 085	4 665 646	4 668 195	4 670 731
Grid Purchases offset by PV (kWh)	527 890	525 251	522 624	520 011	517 411	514 824	512 250	509 689	507 140	504 605
Grid Operating without PV	R5 809 012	R5 809 012	R5 809 012	R5 809 012	R5 809 012	R5 809 012	R5 809 012	R5 809 012	R5 809 012	R5 809 012
Grid Operating Costs with PV	R5 236 713	R5 239 548	R5 242 370	R5 245 177	R5 247 970	R5 250 750	R5 253 515	R5 256 267	R5 259 004	R5 261 729
PV Plant O&M	R59 598	R59 598	R59 598	R59 598	R59 598	R59 598	R59 598	R59 598	R59 598	R59 598
SWTW Grid Total Savings	R512 701	R509 866	R507 044	R504 237	R501 444	R498 664	R495 899	R493 147	R490 410	R487 685

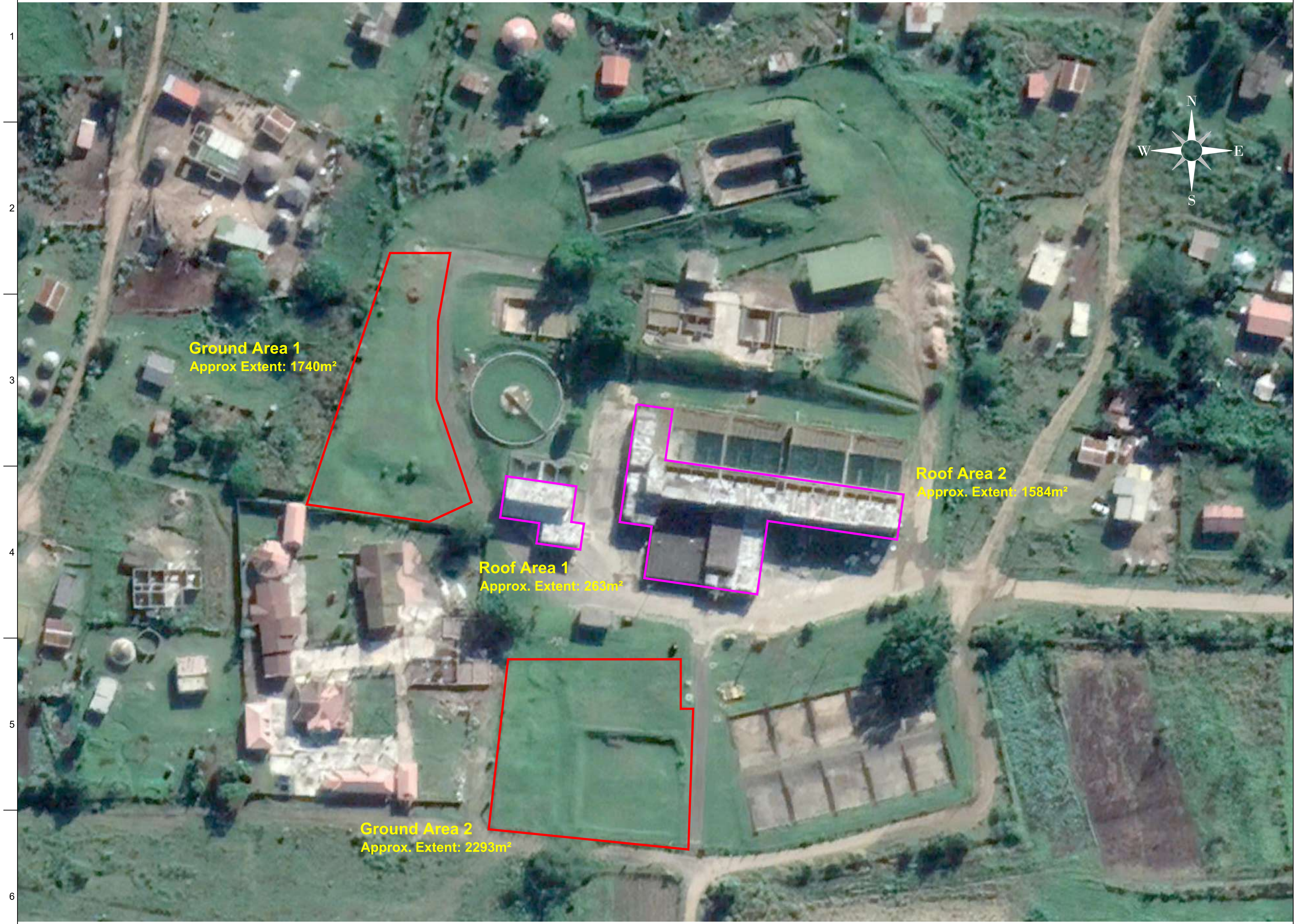
Potential Saving (Over 25-years)	R 12 685 241
LCOE (R/kWh)	1.07
Internal Rate of Return (IRR) (%)	8.60
Simple Payback (years)	10
Net Present Value (NPV)	R 2 945 977

Figure 46: 20-year Cashflow Estimate for Scenario 3

ANNEXURE 5 – CONCEPT LAYOUT DRAWINGS

A3

A	B	C	D	E	F	G



Aerial Photo Source: Google Earth Pro (imagery date: May 2022)

Issue	Date	By	Chkd	Appd
1	26/10/22	SB	DM/TM	JL

ARUP

Arup (Mauritius) Ltd
Bagatelle Office Park
Bagatelle - Mauritius
Tel - (230) 601 9800 Fax - (230) 468 8338
www.arup.com

Client

Vuthela ILEMBE LED PROGRAMME

Job Title

Sundumbili Water Treatment Works - Proposed Solar Farm

Drawing Title

Identification of Areas for Solar PV implementation

Scale at A3 1:1000

Discipline Infrastructure

Drawing Status **Draft.**

Arup Job No **287825-00**

Issue **P0**

Drawing No

287825-ARUP-99-XX-DR-C-0001

C:\Users\Saleem.Bundhoo\Arup\SUNDUMBILI WATER TREATMENT WORK - Concept Design\CAD Infra\WIP\287865-ARUP-99-XX-DR-C-0001 Site Layout.dwg

Do not scale

Issue	Date	By	Chkd	Appd
1	26/10/22	SB	DM/TM	JL

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Arup (Mauritius) Ltd
Bagatelle Office Park
Bagatelle - Mauritius
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www.arup.com

Client

Vuthela ILEMBE LED PROGRAMME

Job Title

Sundumbili Water Treatment Works - Proposed Solar Farm

Drawing Title

Roof Areas 1 & 2 Proposed Solar Panels Arrangement

Scale at A3: 1:500

Discipline: Infrastructure

Drawing Status: **Draft.**

Arup Job No: **287825-00**

Issue: **P0**

Drawing No: **287825-ARUP-99-XX-DR-C-0004**

Do not scale

C:\Users\Saleem.Bundhoo\Arup\SUNDUMBILI WATER TREATMENT WORK - Concept Design\CAD Infra\WIP\287865-ARUP-99-XX-DR-C-0004 Roof Areas 1&2.dwg

A3 | A | B | C | D | E | F | G

Issue	Date	By	Chkd	Appd
1	26/10/22	SB	DM/LM	JL

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Client

Vuthela
ILEMBE LED PROGRAMME

Job Title

Sundumbili Water Treatment Works - Proposed Solar Farm

Drawing Title

Ground Area 1
Proposed Solar Panels Arrangement

Scale at A3: 1:500

Discipline: Infrastructure

Drawing Status: **Draft**

Arup Job No: **287825-00**

Issue: **P0**

Drawing No: **287825-ARUP-99-XX-DR-C-0002**

C:\Users\Saleem.Bundhoo\Arup\SUNDUMBILI WATER TREATMENT WORK - Concept Design\CAD Infra\WIP\287865-ARUP-99-XX-DR-C-0002 Ground Area 1.dwg

Do not scale

Issue	Date	By	Chkd	Appd
1	26/10/22	SB	DM/TM	JL

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Client

Vuthela
ILEMBE LED PROGRAMME

Job Title

Sundumbili Water Treatment Works - Proposed Solar Farm

Drawing Title

Ground Area 2
Proposed Solar Panels Arrangement

Scale at A3: 1:500

Discipline: Infrastructure

Drawing Status: **Draft**

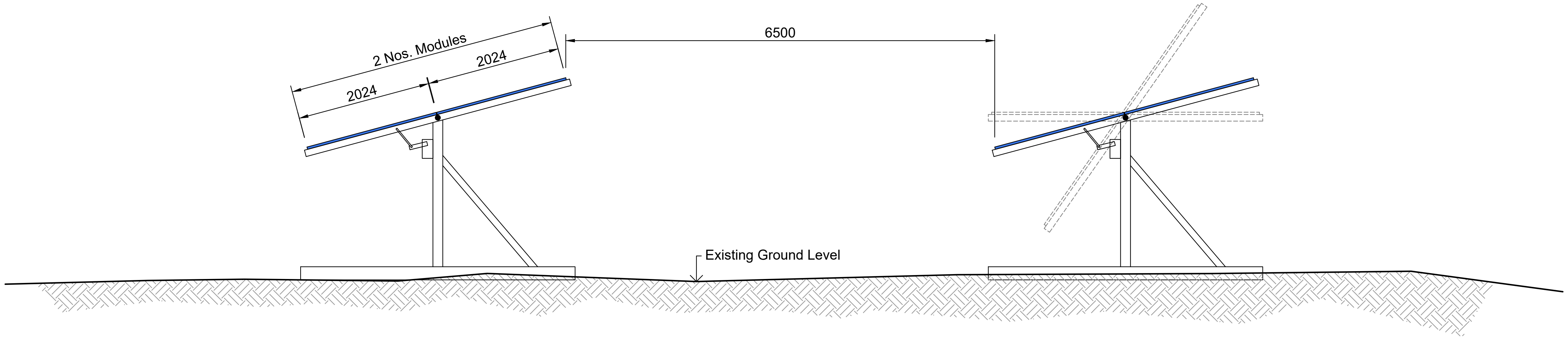
Arup Job No: **287825-00**

Issue: **P0**

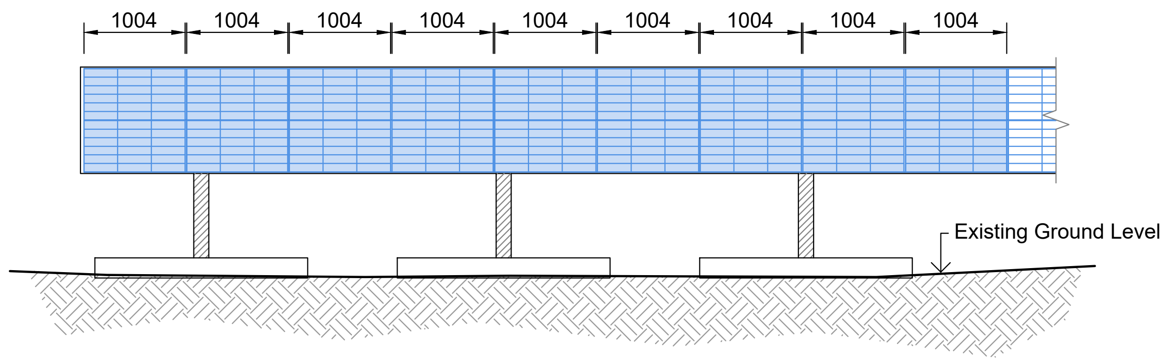
Drawing No: **287825-ARUP-99-XX-DR-C-0003**

C:\Users\Saleem.Bundhoo\Arup\SUNDUMBILI WATER TREATMENT WORK - Concept Design\CAD Infra\WIP\287865-ARUP-99-XX-DR-C-0003 Ground Area 2.dwg

Do not scale



Solar Panels Modules - Side Elevation



Solar Panels Modules - Front Elevation

Issue	Date	By	Chkd	Appd
1	26/10/22	SB	DM/TM	JL

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Client

Vuthela iLEMBE LED PROGRAMME

Job Title

Sundumbili Water Treatment Works - Proposed Solar Farm

Drawing Title

Panels Arrangement Details

Scale at A3: 1:75

Discipline: Infrastructure

Drawing Status: **Draft.**

Arup Job No: **287825-00**

Issue: **P0**

Drawing No: **287825-ARUP-99-XX-DR-C-0004**

C:\Users\Saleem.Bundhoo\Arup\SUNDUMBILI WATER TREATMENT WORK - Concept Design\CAD Infra\WIP\287865-ARUP-99-XX-DR-C-0005 Panels Arrangement Details.dwg

Do not scale

ANNEXURE 6 – INDICATIVE PROGRAM

Program

An indicative project program is presented below for the rooftop and ground-mounted systems. The procurement stage may be subject to internal municipality processes and requirements that may be longer than what is presented below. Project kick-off timelines closer to December and January should consider the construction shutdown period between 15 December to 8 January. Equipment procurement times will vary depending on availability and market conditions. These timelines exclude permits and approvals that may be required at detailed design stage.

Rooftop solar

ID	Task Name	Duration	Month 1	Month 2	Month 3	Month 4	Month 5	Month 6	Month 7	Month 8
1	Procurement	**100 days**								
2	Tender circulation and submissions	30 days								
3	Tender adjudication	30 days								
4	Tender and contract negotiations	30 days								
5	Appoint preferred contractor	1 day								
6	**Construction and commissioning:**	**234 days**								
7	Notice to Proceed	0 days								
8	EPC detail design	30 days								
9	Site preparation	14 days								
10	Detail design approval by Client	30 days								
11	Procurement and Delivery	90 days								
12	Construction to start immediately after Client approval	56 days								
13	Testing and commissioning	14 days								
14	Commercial Operation Date (COD)	0 days								

Ground-mounted PV

ID	Task Name	Duration	Month 1	Month 2	Month 3	Month 4	Month 5	Month 6	Month 7	Month 8	Month 9	Month 10	Month 11	Month 12
1	Procurement	**100 days**												
2	Tender circulation and submissions	30 days												
3	Tender adjudication	30 days												
4	Tender and contract negotiations	30 days												
5	Appoint preferred contractor	1 day												
6	**Construction and commissioning:**	**328 days**												
7	Notice to Proceed	0 days												
8	EPC detail design	30 days												
9	Site preparation	14 days												
10	Detail design approval by Client	30 days												
11	Procurement and Delivery	120 days												
12	Construction - Earthworks, Installation and Electrical	120 days												
13	Testing and commissioning	14 days												
14	Commercial Operation Date (COD)	0 days												

ANNEXURE 7 – BILL OF QUANTITIES

ARUP

JOB TITLE	VILP/I/036 - Sundumbili WTW Renewable Energy Study
JOB NUMBER	287865-00
MADE BY	DM / TM
CHECKED BY	JL / KK
DATE	04/11/2022
Description of spreadsheet	Ground-mount solar PV system BOQ

CONTENTS OF SPREADSHEET

Sheet	Description
0	Cover
1	Preliminaries and General
2	Modules
3	Inverters
4	Mounting Structure
5	LV (DC) Collector Network
6	LV (AC) Collector Network
7	Performance Monitoring
8	Site Preparation
9	Trenches
10	Fire & Security System
11	Summary
12	Spare Parts

AUTHORISATION OF LATEST VERSION

Notes

This BOQ provides indicative quatities and measurements based on initial assessments. A more accurate BOQ will need to be developed at basic and detailed design stages. Please note that this is high-level pricing and quantities with an accuracy level of ~60%. An updated and comprehensive BoQ will need to be developed at detailed design stage by an EPC Contractor.

This BOQ also only caters for works within the plant boundary. All drainage and road works are excluded from the BOQ. The appointed EPC Contractor will have to price this section of works subject to the preliminary investigations. Any infrastructure that may affect the project during construction can be quoted as variation order, eg., access road maintenace (gravel road outside).

The P&G costs in this BOQ also cater for the Roof-mounted solar PV BOQ.

Signatures & dates:

Made by: Derrick Makhathini & Thapelo Mumba

Checked: Justin Lotter & Kausar Khan

REVISIONS Current Revision: 1

Rev.	Date	Made by	Checked	Description
1		DM/TM	JL/KK	Draft for Comment

ARUP	Job No.	Sheet No.	Rev.
	287865-00	1	1
	Member/Location		
Job Title: VILP/I/036 - Sundumbili WTW Renewable Energy Study	Drg. Ref.		
Document: Ground-mount solar PV system BOQ	Made by: DM / TM	Date: 04/11/2022	Chd.: JL / KK

Item Ref	Description	Unit	No. Units	Cost/Unit (ZAR)	Total Cost (ZAR)
	Bill No. 1 : PRELIMINARY & GENERAL				
	Allow for Fixed-Charge and Value-related items:				
	Establishment of Facilities on Site:				
	Facilities for Contractor:				
1	Allowance for preliminary and general costs across both projects should projects be run in parallel i.e. rooftop and ground-mount installations. Costs will cover items such as site establishment, dust and stormwater control during construction, office and storage sheds, waste management and general site housekeeping.		6%	R 5 274 715,86	R 316 482,95
	TOTAL CARRIED FORWARD TO SUMMARY				**R 316 482,95**

ARUP		Job No.	Sheet No.	Rev.
		287865-00	2	1
		Member/Location		
Job Title	VILP/I/036 - Sundumbili WTW Renewable Energy Study	Drg. Ref.		
Document	Ground-mount solar PV system BOQ	Made by DM / TM	Date 04/11/2022	Chd. JL / KK

Item Ref	Description	Unit	No. Units	Cost/Unit (ZAR)	Total Cost (ZAR)
	Bill No. 2 : Modules				
1	**Supply and transportation**				
1,1	Supply and installation of Trina TSM-DE15M-400 400W PV Modules or similar. - The modules will have output cables of 6 mm² and have leads of 2m in length for both anode and cathode	No.	546	R 2 850,00	R 1 556 100,00
1,2	Sample testing of at least 10% of supplied PV modules to be certified by an independent laboratory (e.g. TUV). This is optional and can be done at the clients discretion if required.	No.	55	-	-
	TOTAL CARRIED FORWARD TO SUMMARY				**R 1 556 100,00**

Item Ref	Description	Unit	No. Units	Cost/Unit (ZAR)	Total Cost (ZAR)
	Bill No. 3 : Inverters				
1	**Supply and transportation**				
1,1	Supply and installation of Huawei SUN2000-60KTL-M0 60kW Inverters or similar. - Input: 1,100 Vmax, 22 Amax, 12 Inputs - Output: 60 kW, 400 V, 50 Hz.	No.	3	R 44 556,00	R 133 668,00
	TOTAL CARRIED FORWARD TO SUMMARY				**R 133 668,00**

ARUP		Job No. 287865-00	Sheet No. 4	Rev. 1
		Member/Location		
Job Title	VILP/I/036 - Sundumbili WTW Renewable Energy Study	Drg. Ref.		
Document	Ground-mount solar PV system BOQ	Made by DM / TM	Date 04/11/2022	Chd. JL / KK

Item Ref	Description	Unit	No. Units	Cost/Unit (ZAR)	Total Cost (ZAR)
	Bill No. 4 : Mounting Structure and Tracking System				
1	**Design, supply, transportation, installation and commissioning**				
1,1	Supply of mounting structure and tracking system as follows @ 0.2$/Wp:				
1,2	10 tracker blocks	No.	10	R80 808,00	R808 080,00
1,3	Detailed design to comply with site specific requirements and project requirements. All sensitive electrical equipment and terminations to be placed at least 300mm a.g.l.	Lot	1	-	-
1,4	Transportation of all equipment and associated construction materials to site to be determined upon appointment of EPC contractor.	Lot	1	-	-
1,5	Installation (including all works required for foundations, mounting structure, actuators, and control system) and commissioning of the system. To be priced upon appointment of the EPC contractor.	Lot	1	-	-
	TOTAL CARRIED FORWARD TO SUMMARY				**R 808 080,00**

Item Ref	Description	Unit	No. Units	Cost/Unit (ZAR)	Total Cost (ZAR)
	Bill No. 5 : LV (DC) Collector Network				
	Supply, Transportation & Installation				
	Conductors & Cable Trays:				
1	**DC String Cables**				
1,1	900/1500 V Solardac Aberdare or equivalent - 6mm² Tin-plated Cu PVC insulated single core UV protected Solar Cables	m	1 500	R 12,70	R 19 050,00
1,2	1500 V DC Solar Connectors (Male & Female Pair)	No.	68	R 22,35	R 1 519,94
2	**Earthing and DC cable accessories**				
2,1	10mm diameter galvanised steel rod used as earthing conductor for PV mounting structures.	m	500	R 50,80	R 25 400,00
2,2	Galvanised cable tray, including cover, nuts, bolts and other clamps, brackets and mounting accessories. Cable tray to be mounted on top of moulded concrete blocks at an interval of 2.5m, and fixed to concrete block.	m	5	R 317,50	R 1 587,50
	TOTAL CARRIED FORWARD TO SUMMARY				**R 47 604,99**

Item Ref	Description	Unit	No. Units	Cost/Unit (ZAR)	Total Cost (ZAR)
	Bill No. 6 : LV (AC) Collector Network **Supply, Transportation & Installation** **Conductors & Cable Trays:**				
1	**AC CABLING MATERIAL**				
1,1	Inverter LV cabling to AC Combiner - 3-core, Cu, PVC/SWA/PVC.	m	60	R 174,28	R 10 456,80
1,2	AC Combiner Box connection to DB. 4-Core, Cu, PVC/SWA/PVC.	m	20	R 174,28	R 3 485,60
1,3	Permanent Earth Cable, Grey/Yellow PVC.	m	80	R 99,00	R 7 920,00
2	**LV Distribution Board:**				
2,1	Panel for AC combiner to be tied in to the main LV panel in the main plant room: - IP 54 or higher with lockable doors and applicable warning signs - 1 x AC on-load isolator, 100A - 1 x SPD Type 1/2 combination with status contact - 1 x DC Power supply (12V - 48V, depending on data logger) - 3 x 3P Moulded Circuit Breaker (MCB) - Monitoring System (RS485 output) DC Bus Voltage Measurement Surge Protection Status One additional analogue input for RS485 conversion - Cable terminations and equipment to be located at least 1200mm a.g.l. - Energy and power quality meter	No.	1	R 126 961,00	R 126 961,00
	TOTAL CARRIED FORWARD TO SUMMARY				**R 148 972,22**

Item Ref	Description	Unit	No. Units	Cost/Unit (ZAR)	Total Cost (ZAR)
	Bill No. 7 : Weather & Performance Monitoring				
1	**Meteorological stations (In PV field)**	No.	1	R 228 600,00	R 228 600,00
1,1	These units will be mounted on the tracking structure. These stations shall include the following equipment:				
1,2	2 x Calibrated reference PV cells				
1,3	1 x Plane-of-Array (POA) Pyranometer (ISO 9060 Secondary Standard)				
1,4	1 x Horizontal pyranometer (ISO 9060 Secondary Standard)				
1,5	2 x PV module temperature sensor with accuracy of +/- 1 degree or better mounted on the back of the closest PV module				
1,6	1 x ambient temperature sensor				
1,7	1 x Anemometer including datalogger/RS485 interface, cable glands and mounting pole/structure mounted in ground. Anemomenter mounted 1.5m a.g.l.				
1,8	Weather Station data logger (log 15 days' data at 1 minute intervals, 5 minute averages of 1 minute samples to be recorded every 5 minutes) and SCADA/RS485 or Fibre interface				
1,9	Installation (including mounting plates, platforms, nuts, bolts) and commissioning of Weather station works				
2	**Transportation**				
2,1	Transport and delivery to site of Weather monitoring equipment. Transportation of all equipment and associated construction materials to site to be determined upon appointment of EPC contractor.	Sum	1	-	R 0,00
	TOTAL CARRIED FORWARD TO SUMMARY				**R 228 600,00**

Item Ref	Item Type	Description	Unit	No. Units	Cost/Unit (ZAR)	Total Cost (ZAR)
		BILL No. 8: Site Preparation & Laydown Area				
1	SANS 1200 C	**Site Clearance**				
1,1	8.2.1	Clear and grub area of all trees and large bushes for whole site area to allow installation of equipment.				
		Phase 1	Ha	0,5	R 19 050,00	R 9 747,89
2		**Laydown Area Preparation (to be assesssed by appointed EPC)**				
	SANS 1200 DM					
2,1		**Earthworks**				
	8.3.4	Cut to fill 150mm layer				
	(a)	Compact to 90% mod AASTHO maximum dry density	m^3	0	R 120,00	R 0,00
		Assumption based on site visual inspection is that significant laydown area preparation is not required. EPC to confirm upon appointment.				
	TOTAL CARRIED FORWARD TO SUMMARY					**R 9 747,89**

Item Ref	Description	Unit	No. Units	Cost/Unit (ZAR)	Total Cost (ZAR)
	Bill No. 9 : Trenches				
1	**Control Building LV Supply Trench**				
1,1	Trench containing LV cables: - Excavate all material other than hard rock for cable trenches, including bedding, laying cables, blanket layer, backfill and placement of warning tape	m	60	R 90,00	R 5 400,00
1,2	Excavate hard rock for cable trenches - 20% of total volume estimated to be hard rock	m^3	6	R 317,50	R 1 828,80
2	**DC cable trenching**				
2,1	DC trenches: - Excavate all material other than hard rock for cable trenches, including bedding, laying cables, blanket layer, backfill and placement of warning tape	m	60	R 90,00	R 5 400,00
2,2	Excavate hard rock for cable trenches - 20% of total volume estimated to be hard rock	m^3	6	R 317,50	R 1 828,80
3	**Weather station LV supply and communication cable trenching**				
3,1	Weather Station trenches containing connecting cables from Inverter to weather station: - Excavate all material other than hard rock for cable trenches, including bedding, laying cables, blanket layer, backfill and placement of warning tape	m	20	R 90,00	R 1 800,00
3,2	Excavate hard rock for cable trenches - 20% of total volume estimated to be hard rock	m^3	2	R 317,50	R 609,60
	TOTAL CARRIED FORWARD TO SUMMARY				**R 16 867,20**

Item Ref	Description	Unit	No. Units	Cost/Unit (ZAR)	Total Cost (ZAR)
	Bill No. 10 : Fire & Security System				
1	**Perimeter Fencing (Client to decide if PV fields will be fenced)**				
1,1	Fencing (3m high) system around PV facilities should be erected as a perimeter barrier to create a no-mans land. Supply, transportation, installation and commissioning of perimeter fence as follows:				
1,2	- 3m high welded wire mesh fence (inside)	m	0	R 851,00	R 0,00
1,3	- A secondary electrified fence to be erected within the fencing system, adding protection and early warning to possible intrusion attempts.	m	0	R 431,80	R 0,00
1,4	Including all foundations, posts, trenching, cables or communications as required				
2	Supply, transportation, installation and commissioning of perimeter gates as follows:				
2,1	- Main Fence Gate - 6m wide, with a pedestrian gate, built into the main fence near the raw water works access point.	No.	1	R 14 674,00	R 14 674,00
3	**CCTV Camera**				
3,1	CCTV Camera to be mounted on post or Control Building to provide view of the facility entrance and external access road. - Entry level infrared-thermographic camera for cable connection and DB infrared thermography, such as the HIKVISION 4 MP IP Bullet - To be powered and operated by proposed control building or main plant.	No.	9	R 2 600,00	R 23 400,00
4	**Laydown Area Security**				
4,1	Supply, transportation, installation and commissioning of perimeter fence as follows: - Fence with 1.8m high diamond mesh fence (outside). - Including all foundations, posts, trenching, as required - Include allowance for gate(s) for equipment delivery and to access site as per Contractor requirements.	m	50	R 800,00	R 40 000,00
5	**Fire Protection**				
5,1	Fire Extinguishers and other protection equipment as per OHSACT.	Sum	2	R 1 003,30	R 2 006,60
	TOTAL CARRIED FORWARD TO SUMMARY				**R 80 080,60**

Item Ref	Item Type	Description		Page No.		Amount (ZAR)
		SUMMARY				
	Bill No. 1	Preliminaries and General		1		R 316 482,95
	Bill No. 2	Modules		2		R 1 556 100,00
	Bill No. 3	Inverters		3		R 133 668,00
	Bill No. 4	Mounting Structure		4		R 808 080,00
	Bill No. 5	LV (DC) Collector Network		5		R 47 604,99
	Bill No. 6	LV (AC) Collector Network		6		R 148 972,22
	Bill No. 7	Performance Monitoring		7		R 228 600,00
	Bill No. 8	Site Preparation		8		R 9 747,89
	Bill No. 9	Trenches		9		R 16 867,20
	Bill No. 10	Fire & Security System		10		R 80 080,60
		Subtotal				**R 3 346 203,85**
		Provide the sum of 10% for contingencies to be used at the discretion of the Project Manager and deducted in whole or in part if not required				R 334 620,39
		Sub-total				**R 3 680 824,24**
		Add 15% VAT				R 552 123,64
		Grand Total to Tender				**R 4 232 947,87**
		Exclusions: - Control room structure to be specified at detailed design stage				
		- LV infrastructure in the contol room to be specified at detailed design stage.				

Item Ref	Description	Unit	No. Units
	Bill No. 15 : Spare Parts (Recommended spare parts list to be costed by EPC)		
	Sufficient allowance to be made and agreed. Preliminary suggestion below.		
1	**Modules**		
1,1	Trina TSM-DE15M-400 400W PV Modules PV Modules or similar.	No.	55
	Inverters		
	Huawei SUN2000-60KTL-M0 60kW Inverters or similar.	No.	1
2	**LV Collector Network**		
2,1	1000/600 V 6mm² Tin-plated Cu PVC insulated single core UV protected Solar Cables	m	150
2,2	1000/600 V DC Solar Connectors (Male & Female Pair)	No.	20
2,5	Galvanised steel rod used as earthing conductor for PV mounting structures	m	10
2,6	Galvanised cable tray, including cover, nuts, bolts and other clamps, brackets and mounting accessories	m	50
2,9	Type 1/2 Surge Arrestor	No.	2
2.10	Cable ties 200mm (Solar Grade)	No.	50
3	**Performance Monitoring**		
3.1	Anemometer	No.	1
3.2	Calibrated reference PV cells	No.	2
3.3	Pyranometer (ISO 9060 Secondary Standard)	No.	1
3.4	Module temperature sensor with accuracy of +/- 1 degree or better	No.	2
4	**Security System**		
4.1	Wire mesh fence	m	50
5	**Mounting + Tracker Structure**		
5.1	Drive unit	No.	1
5.2	Bearings and all other rotating parts (to be discussed and confirmed with supplier)	No.	40
5.4	Complete tracker block components	No.	1
	TOTAL CARRIED FORWARD TO SUMMARY		

EEDSM 2021/22 - Renewable Energy Technology

Name of Municipality:	iLembe District Municipality (IDM)
Municipal Manager:	Ms. Xolelwa Mazibuko
Project Manager:	Kausar Khan
Date:	31.10.2022
Version:	1

ARUP

Vuthela
ILEMBE LED PROGRAMME

Site			Planned Renewable Technology Technology Data						
Site ID	**Site Description**	**Price per Installed Capacity (ZAR/kW)**	**Proposed System Size (kWp)**	**Mounting Option**	**Estimated Annual Energy Output (kWh/year)**	**Product Warranties**	**Annual Energy Perfomance Warranties**	**Proposed System Cost (ZAR)**	**Proposed System Cost (USD)**
	Ground-mounted bifacial tracking system	R16 300,00	219	Ground Mounted Grid-tie systems	180 000	See list below	25 year linear performance warranty	3 504 000	192 254
	Rooftop solar system	R13 000,00	130	Rooftop PV systems	365 000	See list below	25 year linear performance warranty	1 690 000	92 725

Product warranties

Item	Equipment	Warranty period
1	PV modules	10 years product warranty 25 years linear performance warranty
2	Inverters	5 years standards plus 5 years warranty extension
3	Mounting structure	12 years
4	Plant controller and monitoring system	5 years
5	Pyranometer	5 years
6	Irradiance sensors, ambient temperature sensor, module temperature sensor and wind speed and direction sensor	1 year
7	Meter	3 years
8	AC cables	1 year
9	DC cables	2 years
10	MC4 connectors	1 year

Rates are included in USD in for the benefit of international funding applications that might require USD rates. Exchange rate of 1 USD = 18.2259 ZAR is applied based on data accessed at 25.10.2022 from https://www.exchangerates.org.uk/Dollars-to-South-African-Rands-currency-conversion-page.html