TECHNICAL FEASIBILITY STUDY
GILLIMBERG SOLAR ENERGY FACILITY

Forethought Group

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Abbreviations

Reference	Title
AC	Alternating Current
BESS	Battery Energy Storage System
COD	Commercial Operation Date
CNT	Container
DC	Direct Current
EMS	Energy Management System
FESR	Forecast Energy Sales Report
GHI	Global Horizontal Irradiance
GTI	Global Tilted Irradiance
HV	High Voltage
IAM	Incident Angle Modifier
IPP	Independent Power Producer
kV	Kilovolt
kWh	Kilowatt-hour
kWp	Kilowatt-peak
LiD	Light-induced Degradation
LCOE	Levelised Cost of Electricity
LV	Low Voltage
MV	Medium Voltage
MVA	Mega Volt Amperes
MVPS	Medium Voltage Power Station
MW	Mega Watt
MWp	Megawatt-peak
O&M	Operations & Maintenance
p.a.	Per Annum
PCS	Power Conditioning System
PiD	Potential-induced Degradation
POC	Point of Connection
PPA	Power Purchase Agreement
PV	Photovoltaic
REIPPPP	Renewable Energy IPP Procurement Programme
SEF	Solar Energy Facility
S/S	Substation
STC	Standard Testing Conditions

1 Introduction

Forethought Capital has performed a technical feasibility study for the proposed Gillimberg cluster Solar energy facility (SEF) with a total nominal capacity of 400MW (AC), located in the Limpopo province. The SEF would then be connected to the existing transmission grid in the most technically feasible and economical way. This report details the feasibility study undertaken for the proposed SEF.

The project consists of a 605 -ha site earmarked for a 400MW (AC) solar PV installation.

The main technical aspects considered in this study are the following:

- Solar Irradiation and Climatic Study,
- Conceptual Design,
- Energy Yield Assessment.

This report summarises the methodology, assumptions, results and conclusions associated with the feasibility study conducted.

1.1 Project Background

Forethought Capital is proposing to develop a 400MW (AC) to be implemented in two phases of a capacity of 150MW(AC) each (Phase 1 and phase 2) of a Solar Energy Facility situated in the Limpopo province of South Africa. The site is located at -23.899757°, 29.015652° approximately 45 km west of Polokwane, as shown in Figure 1.

Figure 1: Locality map of the proposed SEF

2 Study Area

The proposed project site is situated on farms Gillimberg 861 LR, Jupiter 717 LS, Mars 718 LS, within the Waterberg District Municipality, approximately 5 km west of Mars village, as shown in Figure 2 below. The proposed site can be accessed via a gravel road branching east off the N11 at Witrivier-A, then turning east towards the Borutho Main Transmission Substation.

The following villages are within a 10km radius of the site: Jupiter, Mars, Naledi, Sekuruwe and Ga-Sekhaolelo. The Anglo American Platinum - Mogalakwena Mine is located 12 km south-west of the site.

Taking the middle of the site as reference, the elevation is seen to increase gradually from west to east, with an absolute elevation gain of 85.2m. The average slope of the site is 2.2%. The maximum slope was found to be 5.3%.

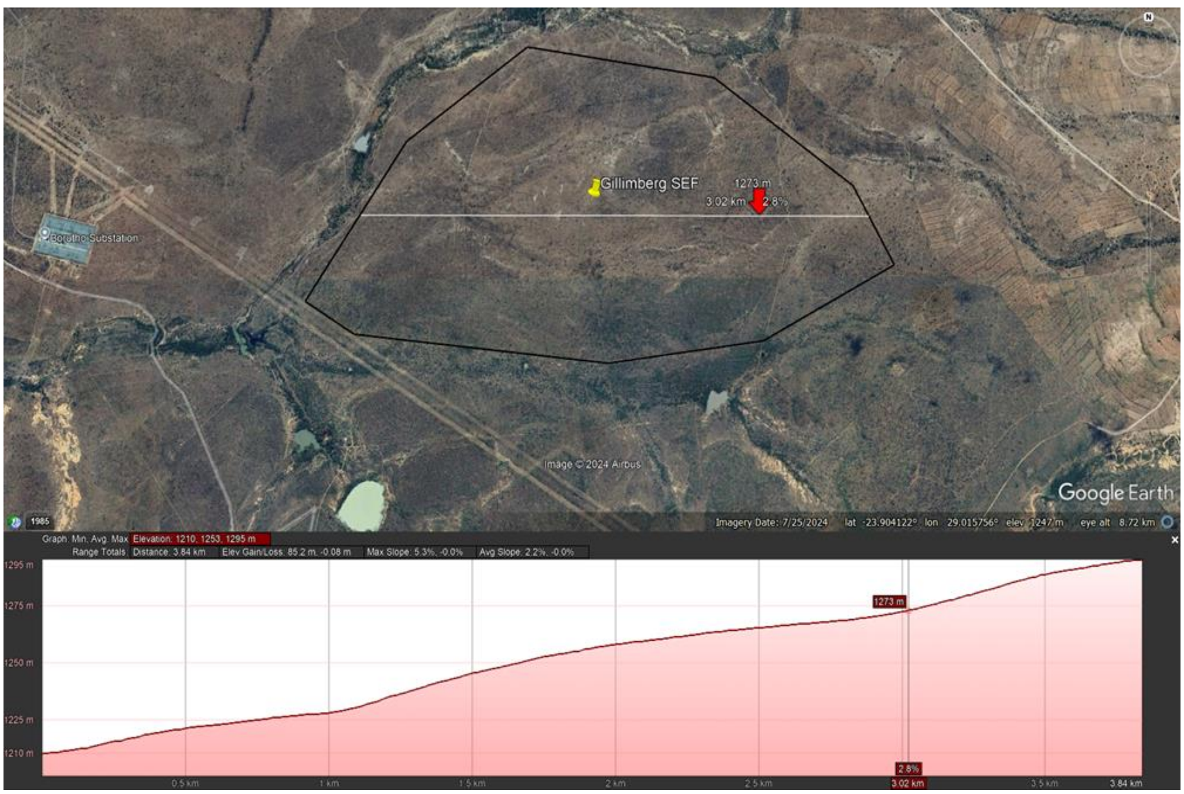

Figure 2: Gillimberg SEF study area

3 Conceptual Design of the SEF

The project site earmarked for the development of a ground-mounted SEF would consist of a peak solar PV capacity of 412 MWp. The SEF is intended to supply energy through a PPA to one or more off-takers.

The proposed Gillimberg cluster solar PV project would consist of a total capacity of 400MW (AC) to be implemented in two phases of 200MW (AC) each. The site terrain is relatively flat, approximately 1 200 meters (m) above sea level, with an average slop of 2.2% from North to South(N–S) and from East to West(E–W), which is highly suitable for the development and construction of SEF

3.1 Description of the Design

Figure 3 below shows the design of the SEF (Phase 1 and Phase 2) within the available land area at the site, which is bound by its dedicated perimeter fence and road. The detailed layout of the SEF can be found in the drawing
Gillimberg Layout.Rev0.

The preliminary design depicted in Figure 3 is based on bifacial solar panels on a single-axis tracker with backtracking system and central inverters to optimise the facility's energy output.

The design considers the key areas to avoid as recommended in the Environmental Impact Assessment (EIA) process thus far. However, there is flexibility for further optimisation during detailed design through discussions with the Client.

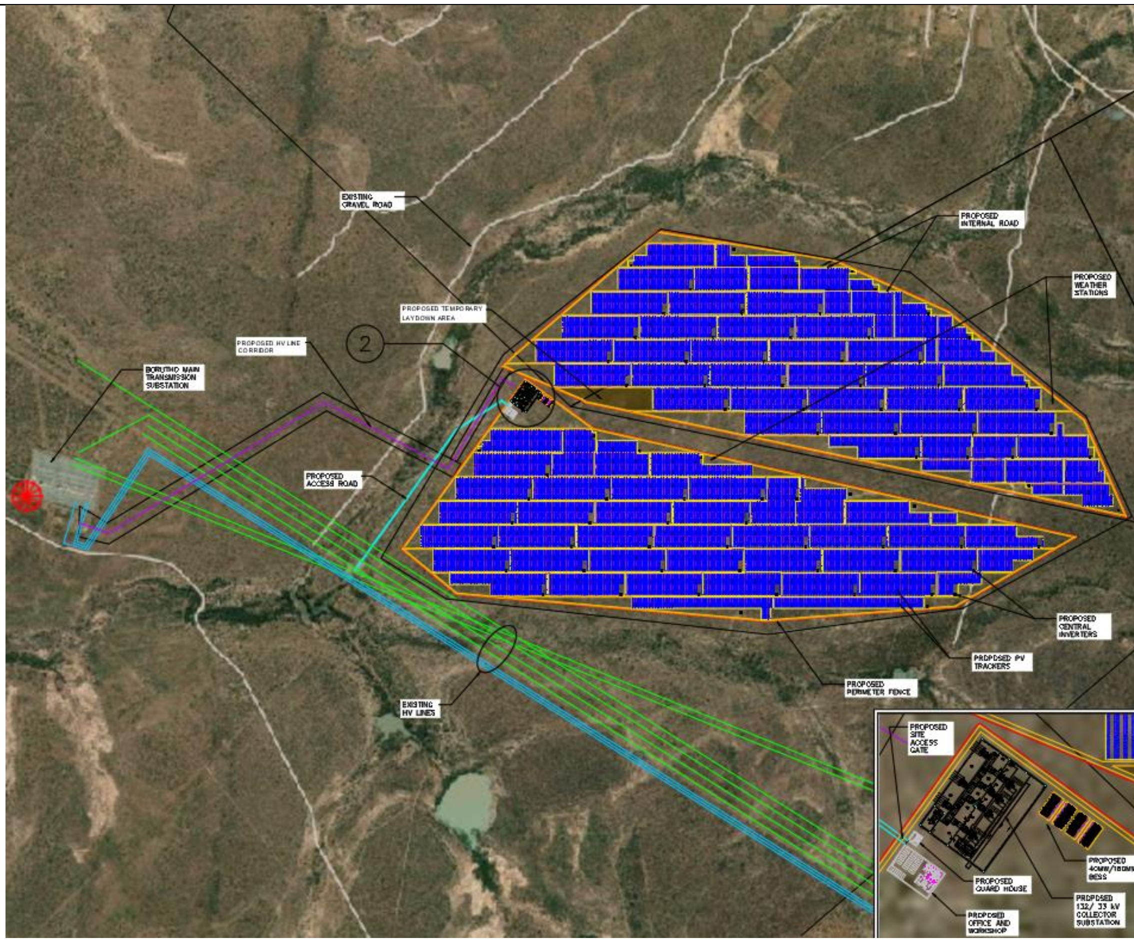

Figure 3: SEF Conceptual layout

4 Environmental Impact Assessment

4.1 Habitat Sensitivity

The following sensitivity map as shown in Figure 4, correlates to the SEI of different habitats in the PAOI was produced.

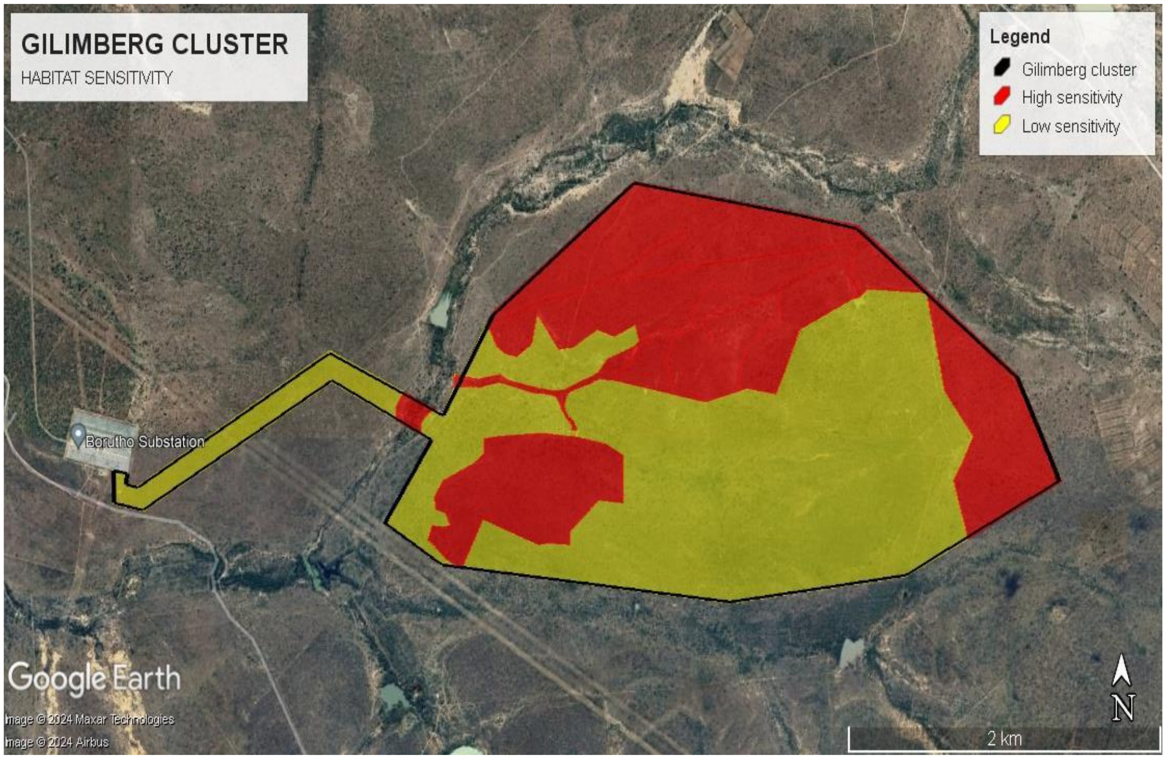

Figure 4: Relative sensitivity for different habitats in the PAOI

Medium sensitivity ratings were assigned to areas where habitat degradation is highly prevalent, and few protected species were observed. High sensitivity ratings relate to areas of less habitat degradation, important ecological functions such as drainage lines, and where more than one species or high numbers of a single species of protected flora was observed.

The terrestrial biodiversity SEI for the proposed development was confirmed to be High or Medium depending on the habitat. Four (4) primary habitat types, referred to as Vegetation Units (VU), were delineated within the PAOI. Due to similarities in floristic species composition, VU1 is described in two sub-units namely VU1a and VU1b.

The PAOI does not fall in or close to any Red Data Ecosystems that are Threatened and in need of protection (Skowno & Monyeki 2021), Protected areas according to the Limpopo Province Map of Critical Biodiversity Areas and Ecological Support Areas (LEDET, 2018), Protected or Conservation Areas or their buffer zones according to the SAPAD and SACAD (DFFE, 2023), NPAES priority focus areas (DEA, 2018), or Important Bird Areas (Marnewick et al., 2015).

It is the specialist's opinion that the proposed developability of different habitats of the PAOI is as follows:

- VU1a (Low SEI areas): Minimisation and restoration mitigation – development activities of medium impact acceptable followed by appropriate restoration activities. Low numbers of protected tree specimens.

- VU1b, VU2, VU3 & VU4 (High SEI Areas) – Avoidance mitigation – no destructive development activities should be considered. Moderate number of protected tree species. Changes to project infrastructure design to limit the amount of habitat impacted, limited development activities of low impact acceptable. VU1a, VU2 & VU3 have high populations of protected tree species and VU4 has low numbers. Offset mitigation may be required for high impact activities.

Three protected tree species were recorded in the PAOI during the site visit. A thorough population assessment of these species will have to be conducted and all protected trees that will need to be destroyed/removed may only be done once the relevant permits have been obtained, avoiding the trees altogether being the favourable option. One medium sensitive mammal species, Dasymys robertsii, may occur in and around aquatic habitats in the PAOI and warrants further investigation.

Low sensitivity ratings were assigned to areas where habitat degradation is highly prevalent, and few protected species were observed. High sensitivity ratings relate to areas of less habitat degradation, important ecological functions such as drainage lines, and where more than one species or high numbers of a single species of protected flora was observed.

It is recommended that all infrastructure be placed outside of High SEI areas. Additionally, the infrastructure layout should consider habitat connectivity to avoid fragmentation, and technology alternatives should opt to retain appropriate indigenous vegetation in the vicinity of and under the proposed PV infrastructure. Offset mitigation may be considered for high impact activities in High SEI areas.

5 Technology Selection

5.1 Solar Modules

5.1.1 Solar Module Key Attributes

The solar cells in modules may be composed of a variety of different semiconductors. The most common type of cell commercially available is crystalline silicon (cSi), which accounts for most global installations of solar PV.

Other commercially available cell types include amorphous silicon (often referred to as thin film), Cadmium-Telluride (Cd-Te thin film), and cells using more exotic materials, collectively referred to as multijunction. Multi-junction modules are currently produced from expensive materials and therefore consist of small cells with concentrating lenses and tracking systems.

Modern cSi modules have conversion efficiencies (efficiency at converting the energy in sunlight into DC electricity) in the 20-21% range, with high-efficiency modules in the order of 22% while thin-film cells are in the 7-18% efficiency range.

A typical installation of solar modules involves 12 to 30 modules wired in series, referred to as a string. Because the modules are in series, string performance relies on the performance of each panel. Shading or soiling of a single panel negatively impacts the performance of the entire string. Issues with string wiring may be overcome with micro-inverters and optimisers. Both technologies are located on each panel and optimise performance panel-by-panel. Micro-inverters and optimisers are not typically used on projects of this scale due to cost/benefit reasons.

5.1.2 Failure and Degradation of Solar PV Modules

The output from a solar PV system degrades over time. Most of the degradation in a well-maintained system is a result of PV panel degradation. Panel manufacturers typically warrant their modules for 10 years against defect and output degradation and provide 25-year and 30-year warranties on panel output.

Currently, the typical industry warranty for output degradation is no greater than a 20% reduction over 30 years. In other words, the panel should be producing at least 80% of the expected first-year output in year 30. While modules continue to degrade past this point, most literature indicates service life for PV modules at 40+ years. Research into the real-world failure of solar PV modules indicates a low but rising incidence of defects and failure industry wide.

Global market pressures have reduced margins and quality concerns have grown in recent years. Real-world studies of panel failure and degradation report 0.005% to 0.1% annual failure rates in modules, however median and average degradation rates are 0.5% and 0.8%/year respectively.

Types of failure and degradation are provided in Table 1 below:

Table 1: Failure and Degradation Modes of Solar Modules

Failure Modes (Leading to immediate warranty returns)	Degradation Modes (Leading to power degradation warranty limit)
• Broken interconnects (leading to arcing, backskin burns, or glass shattering or power loss higher than warranty limit) • Solder bond failure (leading to backskin burns or glass shattering) • Severe corrosion (leading to backskin burns or power loss higher than warranty limit) • Chipped cells (leading to hotspots or power loss higher than warranty level) • Encapsulant delamination (leading to power loss higher than warranty level) • Broken glass (leading to safety issue) • Hotspots (leading to backskin burning and safety issue or power loss higher than warranty limit) • Ground faults (leading to safety issue or power loss higher than warranty limit) • Junction box failures (arcing or ground faults) • Connector failures (leading to safety issue) • Structural failures (leading to safety issue) • Bypass diode failures (leading to safety issue due to hot spot or power loss higher than warranty limit due to string loss)	• Gradual cracking of interconnects (leading to power degradation) • Gradual solder bond failure (leading to power degradation) • Slow corrosion (leading to metallisation discoloration and power degradation) • Gradual cracking of cells (leading to power degradation) • Gradual encapsulant discoloration (leading to power degradation) • Gradual(photo)electrochemical degradation of semiconducting and/or metallic materials (potential induced degradation leading to power degradation) • Gradual back-sheet warping (leading to power degradation) • Gradual increase of module mismatch (leading to power degradation) • Strongly adhering and gradual hardening of soil layer on superstrate (leading to slow cumulative/ permanent increase in annual power degradation) • Weakly adhering and rain/wind cleaning of soil layer (leading to fixed/temporary annual degradation due to non-cumulative reversible annual rain effect)

Source: Accelerated Lifetime Testing of Photovoltaic Modules, Tamizh Mani & Kuitche, PV Reliability Lab, Arizona State University, 2013

The risk of panel failure and degradation may be mitigated by sourcing from experienced manufacturers and through third-party validation and batch testing. Validation involves a review of the manufacturer, certifications, and past testing of modules. Batch testing involves accelerated testing of actual modules from the batch runs to be used on the project. Accelerated testing of modules involves applying higher stress levels than actual use conditions over a short period to induce failures that would normally occur in the field.

5.1.3 Market for Solar PV Modules

A key attribute of solar project components for financed projects is bankability. All components must be specified carefully, and ongoing maintenance/replacement costs factored into project modelling. PV modules and inverters must pass a due diligence review to attract project investment. Due diligence focuses on product technology, testing, and history of performance, as well as company financial history, disposition, diversification, and outlook.

Market factors are also considered. PV modules are commodity items with many bankable, price-competitive options available. The lowest-cost modules are often sourced from China, but competitive modules are also manufactured around the world, including in South Africa. Higher efficiency modules which convert more of the sunlight energy into electricity, are more expensive and often specified for projects where space or power density is a premium. There are several recently settled and pending international anti-dumping and antiincentive trade cases that claim Chinese and EU manufacturers dumped modules on the world market at below cost and/or with illegal government incentive backing.

In 2023 the leading solar module brands currently in the market were: JA Solar, Jinko Solar, Trina, Hanwha Q-Cells, Canadian Solar, LG and LONGi.

5.1.4 Solar Module Selection Criteria

Selection of solar modules was based on the following key criteria:

- Peak power-to-area ratio, due to land constraints on the selected site,
- Bankability - Listed on the Bloomberg New Energy Finance (BNEF) Tier 1 PV module list,
- Compliance with relevant module standards, i.e., IEC 61215, IEC 61730, IEC 62804, etc.

A comparative analysis is provided in Table 2 below.

Table 2: Solar module comparative analysis

Item	Module		
Manufacturer	Canadian Solar	Trina Solar	Jinko Solar
Model Name	HIKU7 CS7N-665MS	VERTEX TSM-DE20-670	JKM-625-78HL4-BDV
Tier 1	Yes	Yes	Yes
Technology	Monocrystalline PERC	Monocrystalline PERC	Monocrystalline N-type TopCON
Power (Wp)	665	670	625
Module efficiency	21.4%	21.6%	22.36%
Complies with quality requirements (Glass, back sheet, EVA, junction box, frame)	Yes	Yes	Yes
Wp/m (2P axis tracker)	1020	1027	970
Compatible with main 2P portrait single axis trackers	Yes	Yes	Yes
Bi-facial option available	Yes	Yes	Yes
Local office/distribution	Yes	Yes	Yes
Product certificates IEC	61215; 61730; 61701; 62716	61215; 61730; 61701; 62716	61215; 61730; 61701; 62716
Management System Certificates ISO	9001:2015 14001:2015 45001:2018	9001:2015 14001:2015 45001:2018 14064:2018	9001:2015 14001:2015 45001:2018

5.1.5 Solar Modules Selected for this Design

Jinko Solar (JKM-625-72HL4-TV) modules were utilised in the design. Jinko is one of the largest manufacturers that produces a substantially different format of cSi panel. While their modules are similar in dimension, Jinko produces significantly larger cells with proprietary technology, allowing for increased power density per panel and high conversion efficiencies which contributes to the reduction of the LCOE and the increase of the project IRR.

5.2 Inverters

5.2.1 Inverter Key Attributes

A solar inverter converts the DC output of the PV modules into utility frequency AC that can be fed into an electrical grid or used by a local electrical network. Inverters consist of solid-state switches, inductors, capacitors, control boards, display panels, and weatherproof housings. Some models include monitoring and transformers. Typical inverter efficiencies range from 95% to 99%. Solar inverters have additional functions adapted for use with photovoltaic arrays, including maximum power point tracking, power factor optimisation, and anti-islanding protection. Figure 5 below shows the top global suppliers of solar PV inverters in 2023.

Figure 5: Inverter price vs performance comparison

Central inverters have several advantages and are typically employed on projects 2MW and larger. Central inverters are typically passively cooled, transformer-less, range from 1MW up to 5MW in size, and are encased (often sealed) in housings. Unlike a series of string inverters, large central inverters are equipped to take on larger amounts of strings thus reducing the DC wiring runs from the arrays. Due to their larger size, a design based on central inverters is likely to have fewer AC wiring losses, this results from the use of fewer inverters.

Central inverters have been assumed for this analysis. Inverters have shorter service lives than PV modules, typically 12-15 years. Warranties are typically 5 or 10 years. For modelling purposes, we assume a 12-year replacement/refurbishment cycle. Inverter replacement, like all O&M, is the responsibility of the PPA provider.

5.2.2 Market for Inverters

In 2023 the leading global inverter manufacturers were:

- **Ingeteam Corp. SA** offers INGECON SUN 3 Power C SERIES which can provide from 3326 kVA up to 3824 kVA in a single power block.

- **SMA Solar Technology AG** operates its business under five segments, which include Residential, Commercial, Utility, Storage, and Digital Energy. The company's key offerings include Sunny Central UP models range from 2660kVA to 4600kVA.

- **Sungrow Power Supply Co. Ltd**. provides a wide range of product offerings SunAccess PV inverters. The company offerings range from 2750kVA to 3,593kVA.

- **ABB Ltd**. owns and operates its business in various segments such as Electrification Products; Robotics and Motion; and Industrial Automation. The company offers PVS800 central inverters, PVS980 central inverters, and PVS980-58BC central inverters.

- **Delta Electronics Inc.** operates its business under four segments, which include Power Electronics, Automation, Infrastructure, and Others. The company's key offerings include C1000 and C1000_1 1000kVA central inverter. The peak efficiency offered by these products, designed mainly for commercial applications is 98.84%, and the wide DC input voltage range is 520-1,000 V.

5.2.3 Inverter Selection criteria

The selection of inverters is based on the following key criteria:

- High operating voltage. A greater number of modules can be connected to an inverter with a high operating voltage, reducing the number of inverters required, ultimately reducing project Capex significantly,

- Efficiency,

- Bankability - Listed in Bloomberg New Energy Finance (BNEF) 2021 PV Module and Inverter Bankability Survey,

- Compliance with relevant local inverter standards, i.e., NRS 097-2-1, etc.,

- Local presence in South Africa. The complexity of inverters makes local support an important bankability criterion Unlike for modules, inverter warranties are around 5-10 years and inverters will require replacement of parts and maintenance throughout their lifetime.

5.2.4 Inverter comparative analysis

Table 3: Inverter comparative analysis

Item	Inverter		
Manufacturer	SMA	INGECOM	SUNGROW
Model name	SUNNY CENTRAL UP (SC 2500-EV)	INGECOM SUN 3800TL C600	SUNGROW HV-20
Power (kVA@25°C)	2,500	3,326	2,750
Max DC Input Voltage	1,500 VDC	1,500 VDC	1,500 VDC
Operating temperature	-25 to 60 °C	-20 to 60 °C	-35 to 60 °C
Efficient cooling	Intelligent air-cooling system OptiCool for efficient cooling	Liquid cooling system and forced air cooling system with temperature control	Temperature controlled forced air cooling
Euro efficiency	98,6%	98,5%	98,7%
Grid support	Yes	Yes	Yes
World leader Inverter manufacturer	Yes	Yes	Yes
Local support	Yes	Yes	Yes
Track record in SA	Yes (since 2012)	Yes	TBC
Bankable	Yes	Yes	Yes
Local office/distribution	Yes	Yes	Yes
Product certificates IEC	CE IEC / EN 62109-1 IEC / EN 62109-2	EC 62116 IEC 61683	CE IEC 62109 IEC 61727 IEC 62116

5.2.5 Inverter Selected for this Design

Sunny Central (SC 2500-EV) central inverters were selected in this design.

SMA inverters have high efficiency, a presence in South Africa that includes a currently operational office with technical support engineers, and a strong track record in South Africa.

5.3 Tracker System

We have determined that a horizontal single-axis tracker (HSAT) is the most feasible solution in this case, taking the techno-economic factors into account.

5.3.1 HSAT Key Attributes

Although the cost of an HSAT system is significantly more than that of a fixed-tilt system, it makes up for the additional cost through the amount of energy it can generate. This generally results in decreased LCOE.

Typical HSAT installations consist of galvanized steel posts supporting a galvanized steel framework of steel and solar modules as shown in Figure 6 below. The structure itself consists of a metal framework, mechanically fastened, and attached to the vertical posts. Mounting structures often include integral grounding and cable management.

Foundation design includes geotechnical studies and a review of seismic and wind loading, and some manufacturers also perform pull-out tests. Support columns are typically installed directly into the soil with no concrete foundation using a hydraulic ram. Hydraulic rams can install up to 200 posts in a day depending on soil conditions and layout. The low point of the racking holding the modules is typically about 1 meter off the ground.

Design of HSATs is typically performed by the manufacturer, which may provide turnkey services, including stamped drawings and installation. Warranties are typically on the order of 10 years.

Figure 6: Typical HSAT

5.3.2 Market for HSATs

In 2023 the leading global inverter manufacturers were:

- **NEXTracker -** NX Horizon is one of the most installed single-axis trackers in the world. The NX Gemini has a two-in-portrait (2P) independent-row architecture with an optimized design for bifacial modules.

  "The NX Gemini™ two-in-portrait (2P) solar tracker optimises lifetime value and performance, helping project developers and asset owners get the most from their power plant. Ideally suited for sites with challenging soils, high winds, and irregular boundaries, the ruggedized 2P tracker features a patent-pending distributed drive system for maximum stability in extreme weather, eliminating the need for dampers and producing virtually zero energy losses associated with stowing."

- **STI Norland -** STI Norland, manufacturer of solar trackers for large-scale projects, has become the fifth largest supplier of these structures.

  "Developed in 2017, the STI-H250TM is the first dual-row solar tracker on the market and consists of two torsion beams oriented in a North-South direction on which the PV modules are supported. Both beams are linked and rotate simultaneously following the path of the sun in the sky. They are moved by just one motor, cutting supply and maintenance costs."

- **GENIUS TRACKER. GameChange Solar -** The model Genius Tracker 2P has extensive experience and is optimised for bifacial modules.

5.3.3 HSAT Selection criteria

Selection of HSATs is based on the following key criteria:

- Quick and easy assembly,
- Quality of materials, galvanizing methodology, fasteners, wind/geotechnical, and vegetation management under structures is a common issue with ground-mount systems,
- Available in individual parts. Manual tools are required for mounting. No welding work is required,
- Structural design adapted to the use of bifacial panels,
- Structural design adapted to the largest panels, with maximum performance,
- Approximate table dimensions: 80m (length) x 5m (width),
- Robust actuator stainless steel & aluminium with locking technology,
- Operating wind load 90 km/hour,
- Tracking range: +/-60 °,
- 1 drive per tracker (decentralised configuration),
- Powering system: preferably on-board solar module with battery,
- Maximum admissible ground slope East-West: 15%,
- Maximum admissible ground slope North-South: up to 10%,
- Backtracking (anti-shading) mechanism,

- Adjustable to the potential different types of foundations (to be confirmed after pull-out test 7 detailed geotechnical studies),
- The ground-mount plant within one structure is always parallel to the terrain topography beneath it. Height differences of the subsoil under a structure can be equalized with the foundation posts. The tolerance of the anchoring depth is ±100 mm and
- Manufacturer track record and local presence in South Africa.

5.3.4 HSATs Selected for this Design

NEXTracker Gemini was the most suitable for this study due to its compliance with the criteria listed in paragraph 5.3.3.

5.4 Battery Modules

5.4.1 Market for Battery Modules

Amidst the global surge in electrification and the rise of the energy storage market, lithium batteries, which play a pivotal role, are experiencing explosive demand growth.

Overall, the global lithium-ion battery production capacity surpassed 2,000GWh in 2022 and is expected to maintain a 33% compound annual growth rate over the next four years, achieving over 6,300GWh of production capacity by 2026.

In terms of distribution, Asia's lithium battery production capacity took an absolute lead in 2022, accounting for 84% of the total capacity, and is anticipated to continue this dominant position over the next four years.

Meanwhile, Europe and the Americas, as the other two major consumer markets for new energy vehicles, are fostering domestic battery industry chain development through encouraging policies.

In 2023 the leading solar module brands currently in the market were:

CATL (Contemporary Amperex Technology Co., Limited)
CATL is a global leader in lithium-ion battery development and manufacturing for electric vehicles and energy storage systems, as well as battery management systems (BMS). CATL is the biggest lithium-ion battery manufacturer for EVs in the world, producing 96.7 GWh of the global 296.8 GWh, up 167.5% year on year.

LG Energy Solution, Ltd.
LG Energy Solution, Ltd is a battery company headquartered in Seoul, South Korea, which is the only one of the world's top four battery companies with a background in chemical materials. LG Chem produced Korea's first lithium-ion battery in 1999 and succeeded in supplying automotive batteries for General Motors, Volt in the late 2000s. Then, the company became a battery supplier to global car makers, including Ford, Chrysler, Audi, Renault, Volvo, Jaguar, Porsche, Tesla and SAIC Motor.

Panasonic Corporation
Panasonic is one of the world's three largest lithium batteries. Due to NCA positive electrode and complex battery management system, their batteries are more efficient and safety. Panasonic is the supplier of Tesla.

SAMSUNG SDI Co., Ltd.
Different from other leading lithium battery supplier, SDI mainly engaged in small-scale lithium-ion batteries and the packaging form of Samsung SDI Power Battery is mainly prismatic. Compared with cylindrical cell, prismatic cell can provide more protection, and safety. However, the disadvantage of prismatic cells is that there are too many models, and the process is difficult to unify.

BYD Company Ltd.

BYD Energy is World's Biggest Iron-Phosphate Battery Factory, with more than 24 years Battery Manufacturing Experience. BYD is the world's leading manufacturer of rechargeable batteries. BYD mainly produces two kinds of batteries, including NCM lithium-ion battery and lithium iron phosphate battery.

Pylon Technologies Co., Ltd. (PylonTech)

The PylonTech name is one of the most well-known and popular brands of Lithium-ion Batteries for sale in South Africa. They are known as one of the best solar batteries available due to their excellent quality.

5.4.2 Battery Module Selection criteria

Selection of batteries was based on the following key criteria:

- Bankability - Listed on the Bloomberg New Energy Finance (BNEF) Energy Storage Tier 1 list.
- Compliance to relevant module standards, i.e., UL 1973, IEC 62619, UL 9540A, IEC 63056, VDE, etc.

A comparative analysis is provided in Table 2 below.

Table 4: Battery cell technology comparative analysis

Chemistry	Lithium Cobalt Oxide	Lithium Manganese Oxide	Lithium Nickel Manganese Oxide	Lithium Iron Phosphate	Lithium Nickel Cobalt Aluminium Oxide
Short form	Li-cobalt	Li-manganese	NMC	Li-phosphate	Li-aluminium
Abbreviation	$LiCoO_2$ (LCO)	$LiMn_2O_4$ (LMO)	$LiNiMnCoO_2$ (NMC)	$LiFePO_4$ (LFP)	$LiNiCoAlO_2$ (NCA)
Nominal voltage	3.60V	3.70V (3.80V)	3.60V (3.70V)	3.20, 3.30V	3.60V
Full charge	4.20V	4.20V	4.20V (or higher)	3.65V	4.20V
Full discharge	3.00V	3.00V	3.00V	2.50V	3.00V
Minimal voltage	2.50V	2.50V	2.50V	2.00V	2.50V
Specific Energy	150–200Wh/kg	100–150Wh/kg	150–220Wh/kg	90–120Wh/kg	200-260Wh/kg
Charge rate	0.7–1C (3h)	0.7–1C (3h)	0.7–1C (3h)	1C (3h)	1C
Discharge rate	1C (1h)	1C, 10C possible	1–2C	1C (25C pule)	1C
Cycle life (ideal)	500–1000	300–700	1000–2000	1000–2000	500
Thermal runaway	150°C (higher when empty)	250°C (higher when empty)	210°C (higher when empty)	270°C (safe at full charge)	150°C (higher when empty)
Packaging (typical)	18650, prismatic and pouch cell	prismatic	18650, prismatic and pouch cell	26650, prismatic	18650
History	1991 (Sony)	1996	2008	1996	1999
Comments	High energy, limited power. Market share has stabilized.	High power, less capacity; safer than Li-cobalt; often mixed with NMC to improve performance.	High capacity and high power. Market share is increasing. Also, NCM, CMN, MNC, MCN	Flat discharge voltage, high power low capacity, very safe; elevated self-discharge.	Highest capacity with moderate power. Like Li-cobalt.

5.4.3 Batteries Selected for this Design

PylonTech (POWERCUBE40HM5) containerised units were utilised in the design. PylonTech is one of the largest manufacturers and has a strong presence and history in South Africa. Other criteria considered are:

- The operational parameters including discharge rates, grid requirements, DOD, etc.
- Maturity of the proposed option as well as the availability of the various options modelled (only proven utility-scale technologies to be considered).
- Fast response battery storage.

5.5 Balance of System (BOS) Components

Every component of a PV system must be designed to handle anticipated loads, comply with local, provincial, and national regulations and codes, perform for the duration of the project lifetime, and be maintainable. Of particular importance are the weather rating of exposed components and the accuracy of metering and measuring equipment. Most of this equipment is not unique to PV installations and is very mature. Procuring from major suppliers with a proven track record and bankable warranty is recommended. Typical BOS components include:

- Switchgear
- Transformers
- Non-Export Equipment
- AC and DC Disconnects
- Metering and Monitoring Equipment
- Junction boxes
- Wiring and conduit

5.6 Conclusion on Technology Selection

Components selected for this study are top global module, inverter, and tracker manufacturers Jinko, SMA, and NEXTracker respectively. Note, this equipment was only used as an example and would not be specified in the Engineering, Procurement & Construction (EPC) procurement RFP, rather a performance specification would be used to solicit high-quality, industry-standard equipment. Crystalline silicon modules are assumed to be the common industry standard. The Client may choose to utilise higher efficiency modules which require a smaller footprint, however, increase build cost. The inverters utilised were “central” type inverters. The trackers utilised were HSATs. selected Performance specifications for soliciting proposals would allow the vendor to select the preferred inverter types.

6 Layout Design Proposal of the SEF

6.1 Assessment of Shading for the SEF

The most obvious (and disruptive) type of shading on a PV module is the blocking of direct irradiance, which results in a visible shadow on the module. Since the direct component of irradiance comprises most of the solar energy, this reduces the array output by the most significant amount. Blocking of a portion of diffuse irradiation can also reduce array output but is not as readily apparent as blocking direct irradiation.

To avoid this phenomenon, we must consider the shadows that may cause elements surrounding the solar installation and shadows that may occur between the rows of different modules.

Therefore, the shading analysis is a very important step when designing the location of the panels in a solar photovoltaic installation. The extent of the area required by a photovoltaic solar power plant is a factor in the efficiency of the panel and the extent of shading. As mentioned above, any type of shading is detrimental to the performance of the entire photovoltaic solar power plant. A shadow on a panel not only reduces the efficiency of that panel but also cuts off the supply of the entire chain.

A shadow that falls on a panel blocks the flow of solar energy and can cause the dreaded hot spot effect, in which the panel gets damaged due to heating. This can cause irreversible damage to the sometimes, even the panels that are not in the shadow zone can get heated while trying to compensate for the loss of energy.

Shadows created by moving objects, such as trees and similar objects, can be avoided by removing them to create an area without shadow. However, in the case of immovable objects such as fixed structures, they should be avoided in the design of the plant.

When arranging the panels, care also needs to be taken with the shading between rows caused by the panels themselves, and, therefore, the panels are placed at appropriate inter-row distance.

6.1.1 Sun Path

To perform the shadow analysis, we must start by obtaining data on the position of the sun throughout the year with respect to the geographical position of our project.

Our facility is in Blouberg, Limpopo. The approximate coordinates of the plot are Latitude -23.899757°, and Longitude 29.015652°, but to speed up the calculations we will take as reference the position 24º S, 29º E. We will also need to know the time zone, in our case GMT +2.

The first step will be obtaining the Sun Path Chart for our location. We have downloaded the chart from SunEarthTools.com.

Sun path charts plot the sun's elevation angle and azimuth angle over a day, as seen from a given location. The elevation angle measures the height of the sun in the sky from the horizon; it is the complement of (90 degrees minus) the zenith angle of the sun. The azimuth angle indicates the direction of the sun in the horizontal plain from a given location. North is defined to have an azimuth of 0° and south has an azimuth of 180°.

In addition to depicting the path of the sun in terms of its elevation and azimuth angles, sun path charts indicate sun positions at times of the day. It plots the time, for all hours during which the sun is visible for the given location. We have chosen local solar time. Local solar time is based on the sun's position and is independent of longitude. Noon in solar time occurs when the sun is at its highest point in the sky for the day, and it is either due south or due north of the observer depending on the latitude and time of year.

We have obtained Polar Coordinates and Cartesian Coordinates, and we reproduced them in Figure 7 below:

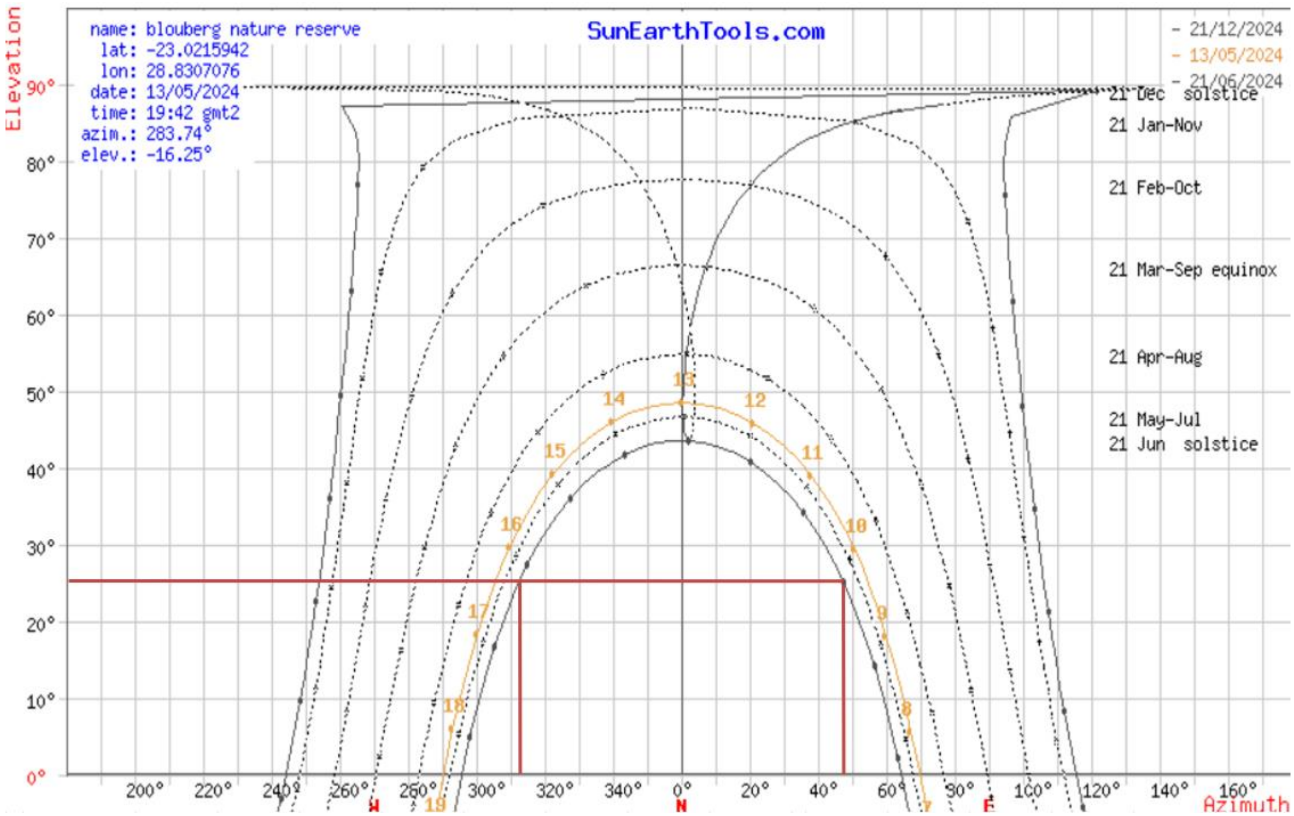

Figure 7: Sun path chart

However, for the analysis of the shadows, the data corresponding to the winter solstice is used, in our case on June 21. It is the time of the year when the sun is at its lowest, therefore it is the worst case of use in the study. If mutual shading of rows is avoided on this day, we are sure that it will be avoided for the rest of the year. Therefore, we will look at the previous charts in the lines labelled as June 21. This data can also be calculated analytically using complex formulas or convenient solar calculators. For our study, we used the solar calculator from SunEarthTools.com.

The standard shadow analysis uses the criterion of guaranteeing that on the worst day of the year, June 21, there will be a minimum of 4 hours with no shadows. However, for increased performance and to avoid the possible technical problems of the maintenance of the panels, all our studies will be carried out with the premise of guaranteeing a minimum of 6 hours free of shadows on the worst day of the year.

Let us analyse what happens within a 6-hour period centered on solar noon, that is, from 10:00 a.m. to 4:00 p.m. in Solar Time. We used a solar calculator to analytically determine the position of the sun every hour.

6.1.2 Calculation of Minimum distance between Tracker Axes

In this case of the HSAT structure, the rows of panels are in the north-south direction and with rotation 0º at midday, that is, horizontal panels in an east-west direction. The tracker rotates on its axis tilting the panels to the right or left to get a better incidence of the radiation following the sun.

This complicates the calculation, since in the different hours in which we calculate the shadow, the panels do not have the same position because of the tracking movement they have.

We made the elevation drawing with the relative position of two contiguous trackers to evaluate the behaviour of the shadows at 10:00 on June 21. This situation is analogous to that which occurs at 4:00 pm solar time. We have also entered the value of the inclination of the recommended tracker for this hour which is 60º. This position is the most extreme since it is the maximum turning angle of most trackers.

This drawing allows us to evaluate what the minimum distance between the axes of the trackers should be so that no shadows are produced in the proposed period of 6 hours a day during the worst day of the year.

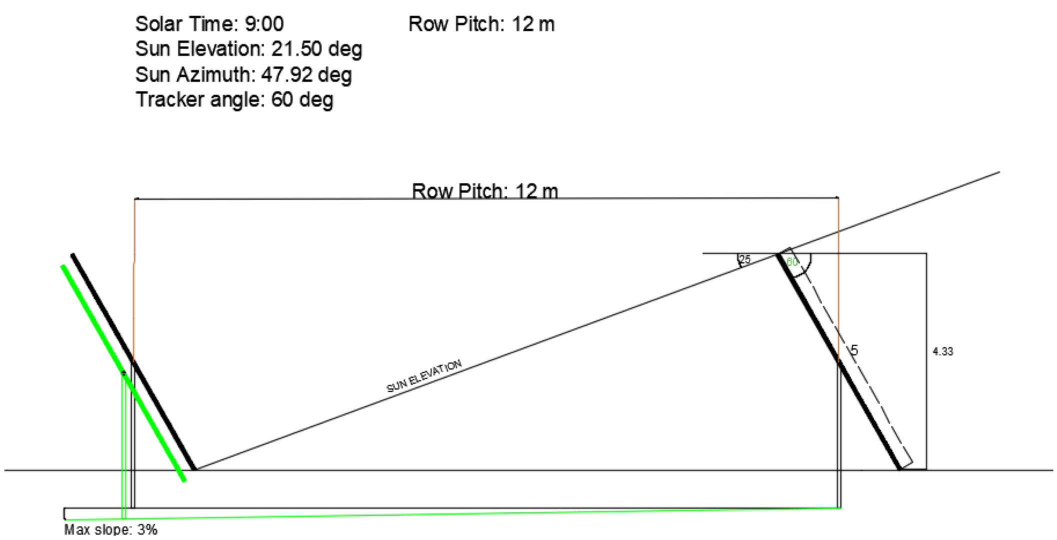

Figure 8: Minimum distance between tracker axes at most adverse terrain conditions

The minimum distance between axis trackers must be 11.67 m as we can see in the drawing. As per the previous site assessment, we found some areas that can reach 5.3% and if there is any greater, they are very specific areas that can be corrected. Considering this most adverse terrain condition, the minimum distance between trackers' axes must be 12 meters.

Below is the Pitch Length calculation:

$$\text{Interrow spacing} = \frac{Corridor\ height.\sin(azimuth)}{Tan(Altitude)}$$

$$\text{Pitch Length} = (Table\ length.Cos(tilt\ angle))$$

6.1.3 Additional notes on shading

A backtracking system avoids row-to-row shading while deviating as little as possible from the true-tracking angle to still optimise the capture of direct irradiance. This is achieved by orienting the row such that the shadow cast from the top edge of one row is exactly tangent to the bottom edge of the row beside it.

Equivalently, when the solar vector is projected onto the tracker rotation plane, it passes through a point on the upper edge of one row to a point on the lower edge of the previous row. This mechanism will prevent losses due to shading but as the module plane does not follow the sun, and deviates from the best-performing angle causing some energy losses (but optimises the energy output).

6.2 DC Electrical Design

It is critical to know the minimum and maximum number of PV modules that can be connected in series, referred to as a string. PV modules produce more voltage in low temperatures and less voltage in high temperatures. If too many modules are connected in a string, the maximum input voltage of the inverter may be exceeded, and the electrical equipment connected to that string could be damaged. If too few modules are in a string, then the inverter may shut off when the ambient temperature is high, resulting in underperformance during the summer months.

The minimum string size is the minimum number of PV modules, connected in series, required to keep the inverter running during hot summer months. That is considered a performance issue, not a safety issue.

The module minimum voltage is calculated using the high temperature for the installation site when the modules would produce the lowest expected voltage. This is because as a PV module gets hotter it is less efficient and produces less voltage.

The maximum string size is the maximum number of series-connected modules that can maintain a maximum voltage below the maximum allowed input voltage of the inverter. This is considered a safety concern.

When designing a solar PV system, it is also critical to know the maximum number of PV series that can be connected in parallel. Maximum DC current, Max Short Circuit DC currents, and Max number of DC inputs per inverter are the values required to figure the maximum number of strings per inverter.

From the inverter datasheets, the critical voltage, and current values for the correct operation of the PV inverters are known.

The specifications for inverters and solar modules are shown below in Table 5 and Table 6 respectively.

Table 5: Inverter specification

Item	SUNNY CENTRAL 2500-EV
Power (kVA@25°C)	2,500 kVA
Max DC Input Voltage (VDC	1,500 V
Min DC voltage	778
MPP voltage range	850 - 1,425
Max DC current	3,000 A
Max SC current	4,300 A

Item	SUNNY CENTRAL 2500-EV
Number of DC inputs	24
Operating temperature	-25 to 60 C

Considering the electrical parameters of the selected modules at STC:

Table 6: Solar module specification

Item	78HL4-BDV 625 Watt
Nominal Power	625 Wp
Voc	55.72 V
Vmp	46.10 V
Imp	13.56 A
Isc	14.27 A
Temperature Coefficient (Pmax)	-0.30%/C
Temperature Coefficient (Voc)	-0.25%/C
Temperature Coefficient (Isc)	0.046%/C
Nominal Module operating Temperature	45±2 C

The minimum and maximum number of panels per string is 18-24. We take the median number to reduce the cable losses while remaining within the MPPT range.

The design considers a total number of 164 inverters and 29,970 strings of 22 modules each.

6.2.1 Preliminary Cable Calculation

The preliminary cable calculation considers the following:

- The maximum current carrying capacity of the cables,
- Average MV power losses of the system.

During the detailed design stage temperature coefficients, installation type, and number of cables or cable systems will be considered, but no major changes in the current carrying capacity of the cables are expected. The string cable section has been sized to 6mm^2, with a current-carrying capacity of 59A when installed on surfaces with opposite contacts.

Consequently, the chosen 6mm^2 solar cable can withstand 1.25 times of the short circuit current (1.25 x 8.91A) as well as the current at the maximum power point, which means that the cable meets the requirements given by the applicable standards. To protect each of the PV strings, DC fuses have been rated as 20A.

The maximum voltage drop in the strings has been limited to 0.6%. This allows a maximum cable length of 98 meters, which is longer than the maximum cable length of the PV arrays (86 meters). DC cables connect the string boxes to the inverters. The DC cables are installed on the structures as well as in cable trenches inside cable conduits. The average DC voltage drop is a maximum of 1.0%.

6.2.2 PV Module String Cables

String DC cables will be attached to the fixed module structure and tied with cable ties. String cables will be placed in conduits in DC trenches when not attached to the structure. The string cables with connect each string to its related sting monitor box.

The string cables must be specified for use in a solar facility, e.g., appropriate UV protection, Class II insulation rating, and so forth.

The cable cross sections have been calculated so that the maximum losses of the complete PV system will be a maximum of 1.3%. The string cable size is specified as 6 mm2 and with this section, the maximum voltage drop from the PV generator to the string box will be 1%.

6.2.3 DC Cables

DC cables, 150 mm^2 Al XLPE/PVC 0.6/1kV type NAYY or equivalent, will be used to connect the string boxes and the inverters.

The DC cable will be installed in trenches inside 63 mm diameter corrugated PVC cable conduits or directly in soil depending on the exact location and detailed design.

The average power losses on the DC side of the facility have been calculated as 1%, from the PV generator to the DC inputs of the inverters.

6.2.4 DC Combiner Boxes

DC combiner boxes will be installed to collect the PV strings and connect these to the inputs in the inverters. DC Protection (fuses) for strings will be supplied by the string monitor manufacturer and DC fuses for inverter protection will be supplied by the inverter manufacturer.

Two types of string boxes are proposed for this installation:

Type 1: String Combiner box with 16-Inputs, including all mounting accessories:

- IP 54 or higher
- 16 fuses 20 Amps
- 1 Isolator 150 Amps with external knob
- 1 SPD Type 2 + Earth Clamp
- Monitoring System to be DC-powered
- Monitoring System:
  - Current Measurement
  - Voltage Measurement

Type 2: String Combiner boxes 8-Input (only 4 inputs to be connected—if a 4-input product is available this may be used), including all mounting accessories:

- IP 54 or higher
- fuses 20 Amps
- 1 Isolator 80 Amps with external knob
- 1 SPD Type 2 + Earth Clamp
- Monitoring System to be DC-powered
- Monitoring System
    - Current measurement
    - Voltage Measurement

Please refer to *Gillimberg Layout.Rev0* for the location of the combiner boxes in a typical block layout and refer to *Gillimberg SLD.Rev0* for electrical details of the combiner boxes.

6.2.5 Cable Electrical Protection

Switchgear used in all the switchboards shall comply with IEC 60947 and IEC 62271 standards, and relevant SANS standards such as listed in the “Standards” section of this document. DC cables will be protected using fuses located inside the DC combiner boxes as well as at the inputs of the inverters.

6.2.6 Weather Stations

Meteorological Station 1

- Plane-of-Array (POA) Pyranometer (ISO 9060 First class)
- Three PV module temperature sensors with an accuracy of +/- 1 degree or better
- Ambient Temperature sensor installed in a naturally aspirated radiation shield at a height like the PV array (Tolerance margin: +/- 1 degree)
- Anemometer installed at average array height, accurate to 1m/s or better.
- 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 interface
- Weather Station backup power (15 days). It is also advised that each weather station has a permanent power feed from the nearest Power Station to ensure continuity of power.

Meteorological Station 2

- Plane-of-Array (POA) Pyranometer (ISO 9060 First class)
- Three PV module temperature sensors with an accuracy of +/- 1 degree or better
- 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 interface
- Weather Station backup power (15 days). It is also advised that each weather station has a permanent power feed from the nearest Power Station to ensure continuity of power.

6.3 Block Design

Following the technical design criteria established in the choice of trackers, the study of the shadows, the electrical configuration, and the optimisation of the plant, a typical design block has been defined for this project.

It consists of a rectangle with dimensions 449.00 m by 131.00 m. In it, 38 axes of trackers are defined on the long row and 35 on the short row, in direction N-S, separated by 1m between them as shown in Figure 9 below.

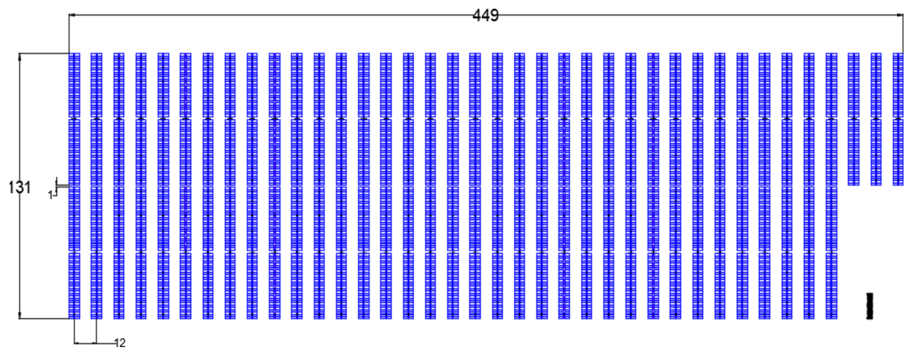

Figure 9: Block Design

Each axis has a length of 65.00 m, which is driven by a motor, and supports 110 panels (2 x 55) in a 2-panel portrait configuration.

The total of the block is made up of 8,140 panels. Each block will be connected to an Inverter / Transformer set known as a Medium Voltage Power Station (MVPS).

6.4 Block Distribution

An extract of the block distribution is shown in Figure 10 below. To distribute the design blocks, we have started in the western area and moved eastwards. To guarantee good accessibility during the construction and maintenance of the plant, one block has been concatenated in a north-south direction. This implies that spaces for roadways in an east-west direction have been created for every row of blocks.

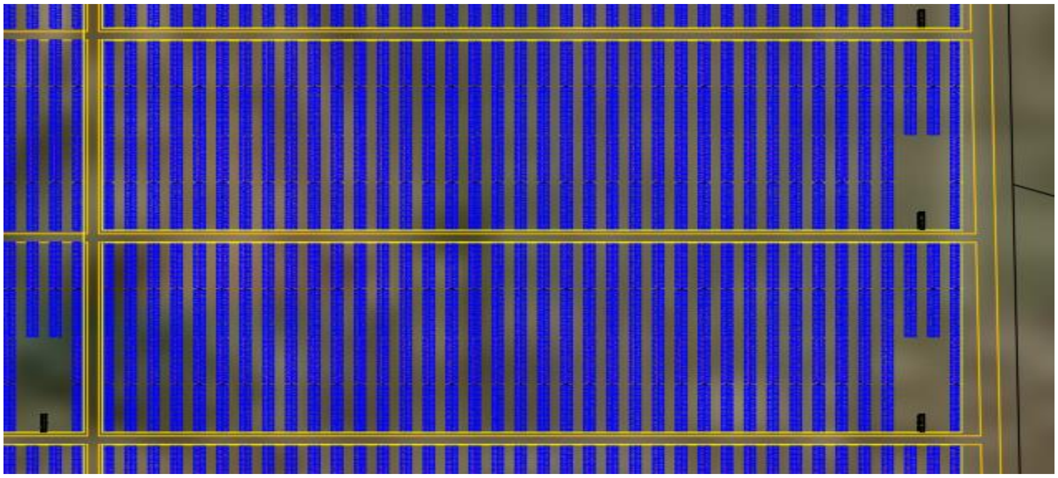

Figure 10: Block distribution

Within each block, space has been reserved to house the Transformer/Inverter assemblies. The roads must allow the passage and work of the necessary vehicles for the construction and maintenance of the plant. An allowance of 8.35m has therefore been provided as shown in Figure 11 below.

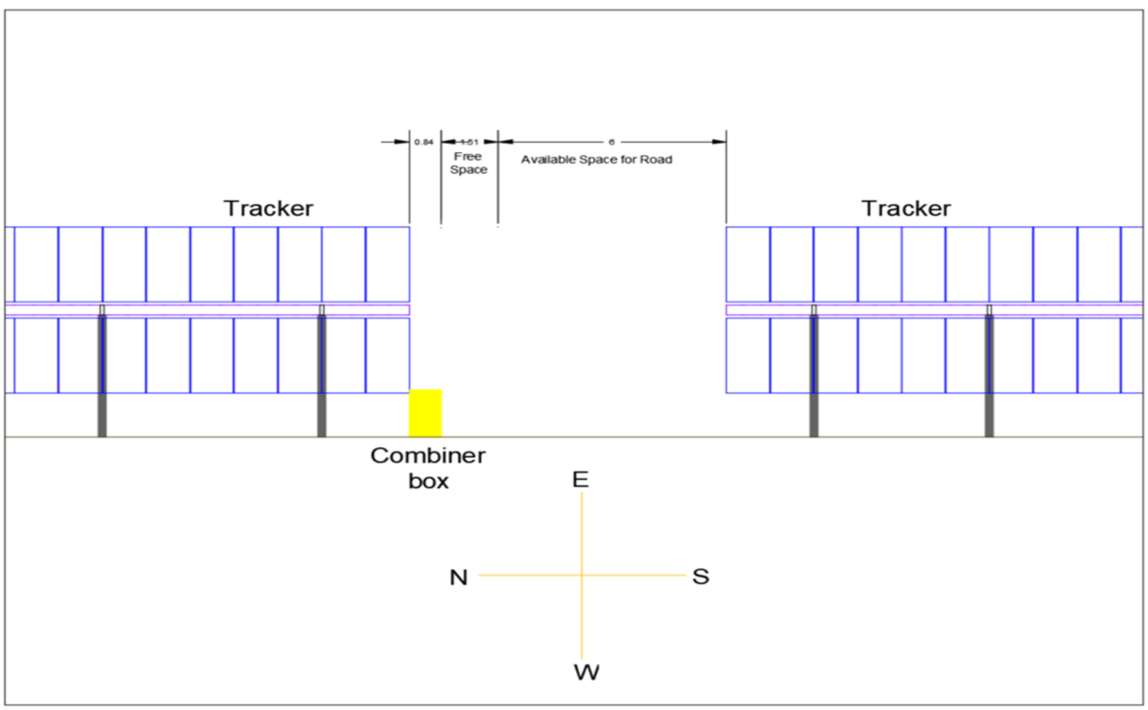

Figure 11: Space reserved for roads

6.5 BESS Design

This design includes a 4-hour BESS to optimise the integration of the SEF. The BESS will store the excess solar energy generated during curtailment periods. The BESS will also provide auxiliary grid services such as voltage regulation and reactive energy injection and absorption as-and-when required by Eskom. The battery cell technology chemical composition used is Lithium Iron Phosphate ($LiFePO_4$).

6.5.1 BESS Sizing

The BESS is sized at 41 MW/ 164 MWh to achieve a power capacity approximately 10% that of the SEF. Table 7 provides a summary of the sizing.

Table 7: BESS Sizing

Item	Units	Value
BESS Array sizing		
Proposed BESS power rating	kW	41,000
Proposed BESS energy rating	kWh	164,000
Proposed CNT size	kWh	5,268
No. of CNTs	no	32
Nominal PCS size	kW	1,305
Nominal Transformer size	kVA	1,305
Battery Module Sizing		
Module current	Ah	148
Module voltage	V	38.4
Module energy	kWh	5.6832
Battery String Sizing		
Modules per string	no	29
Total string voltage	V	1,114
Total string energy	kWh	164.81
BESS Container Sizing		
Strings per container	no	16
Total string voltage	V	17,818
Total CNT energy	kWh	2,637
Total CNT power	kW	1,305
Cabling		
DC Cabling (String to PCS)	m	1,398
AC Cabling (PCS to Transformer)	m	128
AC Cabling (Transformer to S/S)	m	14,784
Communication cable (BESS CNT to EMS)	m	14,784

6.5.2 Interconnection Architecture

The system architecture of this design is: Co-located PV + Battery (AC-coupled), meaning the PV and BESS systems are located at the same site and interconnected behind the same electricity meter. The SEF and the BESS connect to a common AC bus. Separate power electronics are required to connect the SEF and the BESS to the main AC bus as shown below on Figure 12.

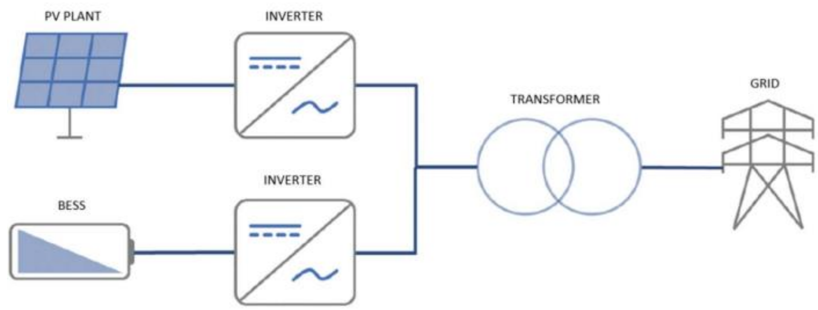

Figure 12: PV-BESS Interconnection Architecture

6.5.3 General Conceptual Layout

DC power flows from the SEF to an inverter, which converts the DC power into AC power. The output AC power from the PV inverter then flows to the PCS that converts the electricity back to DC for charging the BESS and converts the DC power from the BESS to AC power to export to the grid when there is excess energy from the SEF. In other words, the output from the SEF is fed through a PV or interactive inverter before it reaches the BESS. This means that the output AC power from the PV inverter must be converted to DC power before charging the BESS, and the DC power from the BESS must be converted once again to AC power.

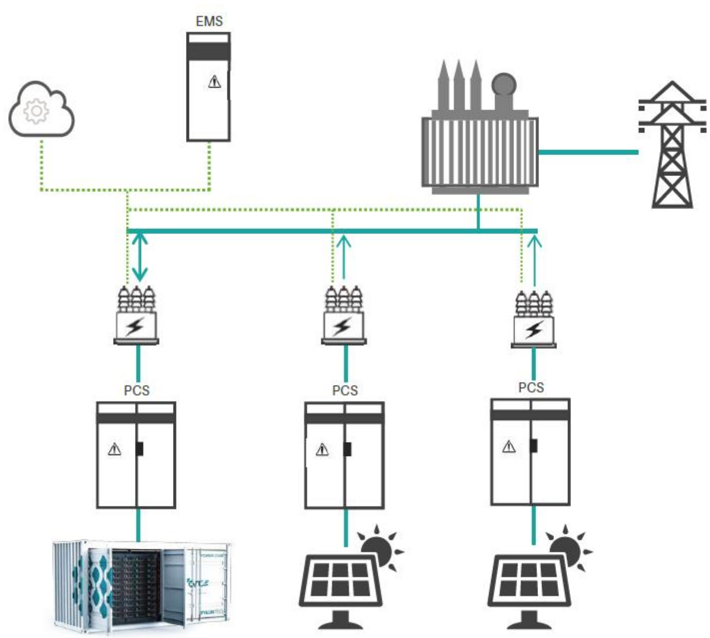

Figure 13: BESS Conceptual Layout

6.5.4 Charging and Discharging of Energy

Solar Energy Facility: The BESS will receive power both from the grid and SEF simultaneously. When there is excess energy produced by the SEF, the DC energy is converted to AC power by the PV inverter. This excess power from the SEF will charge the BESS.

Battery Power Supply: When there is insufficient energy from the SEF, and the BESS has sufficient energy stored in it, and there is a need for additional energy beyond what the SEF is generating, the BESS will discharge to supply power via the PCS.

The coordination of power supply to between these two power sources will be managed by the energy management systems (EMS) and the control strategies, as well as monitoring the charging and discharging of the BESS by the Battery Management System (BMS), to ensure that the power is supplied efficiently.

7 Technology Specifications

7.1 PV Technology Specification

A summarised technical specification of the SEF is provided in Table 8 below.

Table 8: Summary of technology specification

Description	Value
$P_{Nom\ (STC)}$	412.088 MWp
Nominal AC power at cos φ = 1 at 25°C	404.007 MVA
Number of central Inverters	162
P_{Nom} array/Inv ratio	102%
Proposed Inverter	Sunny Central 2500-EV
Alternative Inverters	Ingecom Sun 3800TL C600 SUNGROW HV-20
Strings/ Inverter	370
Modules/ String	22
Proposed Module	JKM-625-78HL4-BDV
Alternative modules	HIKU7 CS7N-665MS VERTEX TSM-DE20-670 DEEP BLUE 3.0 JAM72030-550
Design	81 Modular blocks
Block dimensions	104 x 80.05 m
Structure	Horizontal Single-axis Tracker (HSAT)
Structure layout	2 modules portrait
Distance between axis (trackers)	12 m
Space available for access roads (N-S)	6 m
Proposed Tracker	NX Gemini Next Tracker
Alternative tracker	Horizon L:TEC® IDEEMATEC
DC Cable Routes	Attached under tracker structure. Underground
Plant Communication	SMA PPM
Energy Yield Assessment Tool	PVsyst

7.2 BESS Technology Specification

A summarised technical specification of the BESS is provided in Table 9 below.

Table 9: Summary of technology specification - BESS

Description	Value
Nominal AC power	41 MVA
Nominal energy	164 MWh
Number of PCSs	32
Proposed PCS	Sinexcel PWS1-1500/1725KTL-H
Alternative PCS	SMA SCS-1900-10
Strings/ PCS	16
Modules/ String	29
Proposed Battery Module	PylonTech HM3A180
Alternative modules	LG M48126P3S
Design	32 Modular containers
Typical container dimensions	12.192 x 2.438 x 2.896 mm
Interconnection Architecture	Co-located, AC-coupled
Plant Communication	CANBUS/Modbus TCP/IP

8 Energy Yield Assessment

A detailed Forecast Energy Sales Report (FESR) is provided as part of the feasibility study package.

The global horizontal irradiation (GHI) data used in the yield simulations was obtained from the PVGIS SARAH 2 database and was generated using 15 years of irradiation data (2005 – 2020).

Industry-standard software, PVsyst, was used to perform the yield simulation. Certain post-processing was also conducted to account for inverter and tracking system self-consumption, PV module degradation, and plant and grid availability. PVsyst has been developed at the University of Geneva (Switzerland) and is the solar industry's preferred software simulation tool for bankability analyses and acceptance testing. This incumbent status is both a function of the platform's capabilities and stakeholder confidence in its results. Accurate energy modeling is essential to photovoltaic system financial models, capacity tests, and performance reports.

This FESR analysis has considered the intended Contracted Capacity of 400 MW (AC) and the analysis assumes a mechanism will be in place to limit the capacity exported from the Facility to exclude the possibility of exporting capacity above the intended Contracted Capacity of 400 MW (AC).

8.1 Yield Summary

A 20-year generation forecast was calculated and the probability of exceedance yields (P50, P90). A summary of these results is shown in the table below.

Importing the solar resources data recorded by PVGIS into PVsyst software, the team has run a preliminary simulation for the Project.

The results of the simulations are shown in Table 10 below.

Table 10: Energy yield summary

Description	Units	Value
Nominal Power	MWp	412.1
Specific Yield [P50]	kWh/kWp·yr	2,550
Total Energy [P50]	GWh/yr	1,050.65
Specific Yield [P90]	kWh/kWp·yr	2,376
Total Energy [P90]	GWh/yr	979.04

9 Maintenance

Solar project maintenance can help maximise uptime and extend the life of the SEF. The delivery of solar power without any disruption maintains the stream of economic value generated by each kilowatt-hour of production. Proper service is a critical component to ensuring optimal performance while minimising the risks of downtime. A well-maintained SEF can perform 10 to 30% better than one that is not. Without proper operation and maintenance, system components could be void of all warranties.

A good operations and maintenance firm will have a dedicated team of field-service engineers and technicians to actively oversee the quality and performance of an SEF with effective maintenance. Typically, this will involve signing maintenance contracts.

Plant availability is key to getting the expected IRR. A 98% availability ratio is the required goal.

9.1 Maintenance Schedule

The proposed maintenance schedule is shown in Table 11 below.

Table 11: Maintenance schedule

Maintenance Item	Frequency
Solar Modules	
Cleanliness (accumulation of debris around/ under array)	4 months
Verify cleanliness (dust or fungus)	12 months
Check for visual defects including: • Fractures • Browning • Moisture Penetration • Frame Corrosion	12 months
Inspect junction boxes for: • Water accumulation/build-up • Integrity of lid seals, cable entrance, glands and/or conduit sealing	12 months
Wiring installation / Array boxes	
Verify mechanical integrity of conduits	24 Months
Verify insulation integrity of cables installed without conduit	24 Months
Check Array boxes for: • Tightness of connections • Water accumulation/build-up • Integrity of lid seals, cable entrance and/or conduit sealing • Verify surge arresters for degradation • Tightness of connections	12 Months

Maintenance Item	Frequency
• Corrosion • Verify integrity of fuses • Verify operation of solar array isolation device • Verify tightness and integrity of bolts and other fastening devices	
Measure open circuit voltages	2 Months
Measure short circuit currents	2 Months
Inverter	
Clean the air duct and ventilation grids	2 Months
Maintain the key switches and seals	2 Months
Perform visual inspection	2 Months
Clean the interior	2 Months
Backup the operating data of the inverter	2 Months
Check the labels	24 Months
Check the fuse of the DC surge arrester for continuity	24 Months
Check the fans.	24 Months
Check the functioning of the indicator lights	24 Months
Maintain the DC load-break switch	24 Months
Clean the AC disconnection unit	24 Months
Check the AC connection contact resistors	24 Months
Maintain the AC disconnection unit circuit	24 Months
Replacing the remote GFDI fuse	4 years
Replace the fuse of the DC surge arrester	When triggered
Check the optional sound absorber	24 Months
Tracking System	
Check corrosion damage on all components.	12 months
Check for dirt on the system parts (geared motor, etc.)	12 months
Check electrical components (drive control box, motor, interconnection, tilt-sensor, wind sensor)	12 months
Recurring checks of main mechanical components	12 months
Check of the oil level of the geared motor	12 months
Standard oil exchange for gear	4 years
Cleaning and lubrication	12 months

9.3 Estimation of the required resources for maintenance

The annual maintenance and operation (O&M) resources are estimated as follows:

- 2 cleaning services per year (during dry season)
- 3,827 m^3 of water for module cleaning (2 services per year during dry season)
- 7-17 staff in the field at any given time:
    - 2 - 12 for cleaning, washings, housekeeping, vegetation control
    - 4 technicians for electric and mechanical maintenance works and repairs
    - 1 site manager
- 1 control room operator to monitor and control plant performance and energy production
- 1 service engineer/project manager

The annual O&M works of the SEF are estimated to cost 0,8 to 1% of total project CAPEX.

The basic schedule of activities, to be discussed during the design works with technology suppliers and relevant stakeholders is shown in Table 12 below:

Table 12: Maintenance on-site staff requirements

Maintenance Staff					
Month	**Vegetation control/ module cleaning**	**General cleaning**	**Mechanical/ Electrical**	**Site Manager**	**Total field staff**
Jan		2	4	1	7
Feb		2	4	1	7
Mar		2	4	1	7
Apr	10	2	4	1	17
May	10	2	4	1	17
Jun	10	2	4	1	17
Jul	10	2	4	1	17
Aug	10	2	4	1	17
Sep	10	2	4	1	17
Oct		2	4	1	7
Nov		2	4	1	7
Dec		2	4	1	7