Scaling of Solar Rooftop in São Tomé and Príncipe

INTERNATIONAL SOLAR ALLIANCE

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Prepared by:
Global Sustainable Energy Solutions India Pvt. Ltd.
FIEE Complex, A - 46, Upper Ground Floor
Okhla Industrial Area Phase II
New Delhi - 110020, India
www.gses.in

Contact:
Dwipen Boruah
e-mail: dwipen.boruah@gses.in
Ph: +91-11- 41040534
Mobile: +91 9560550075

Front cover photo: Carport PV system in a Government Building in São Tomé and Príncipe.

Back cover photo: Rooftop PV system in a Government Building in São Tomé and Príncipe.

Photo Credit: Dwipen Boruah

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ABBREVIATIONS

AFREC	African Energy Commission
AC	Alternate current
ALER	Associação Lusófona de Energias Renováveis
BOS	Balance of system
CUF	Capacity utility factor
CAPEX	Capital expenditure
CERC	Central Electricity Regulatory Commission
c-Si	Crystalline silicon
°C	Degree Celsius
DPR	Detailed project report
DC	Direct current
DGRNE	Directorate General of Natural Resources and Energy
DISCOM	Distribution company
EE	Energy efficiency
EMAE	Water and Electricity Company (Empresa de Água e Electricidade)
EPC	Engineering, procurement and construction
GW	Giga watt
GWh	Gigawatt hour
GSES	Global Sustainable Energy Solutions
IGEE	Greenhouse gas inventory (Inventário de Gases com Efeito de Estufa)
IP	Ingress protection
IEC	International electrotechnical commission
IRENA	International Renewable Energy Agency
ISA	International Solar Alliance
kW	Kilo watt
kV	Kilovolt
kWh	Kilowatt hour
kWp	Kilowatt peak
MPPT	Maximum power point tracking
MW	Megawatt
MWh	Megawatt hour
MWp	Megawatt peak
m	Meter
NASA - SSE	NASA Surface meteorology and Solar Energy
NEB	National Energy Balance
NEEAP	National Energy Efficiency Action Plan
NREAP	National Renewable Energy Action Plan
O&M	Operation and maintenance
OPEX	Operational expenditure
PR	Performance ratio
PV	Photovoltaic
PPA	Power purchase agreement
RE	Renewable energy

RESCO	Renewable energy service company
STP	São Tomé and Príncipe
Isc	Short circuit current
SRRA	Solar resource radiation assessment
m^2	Square meter
STC	Standard Test Conditions
STP	São Tomé and Príncipe
TWh	Terawatt hour
TES	Total energy supply
UNIDO	United nations industrial development organization
V	Voltage
V_{mp}	Voltage at maximum power
V_{oc}	Voltage at open circuit
W_p	Watt peak

EXECUTIVE SUMMARY

São Tomé and Príncipe (STP) heavily rely on imported fossil fuels. Electricity is primarily generated using diesel generators. The estimated electricity demand for the country is about 108 GWh per year. 94% of electricity is supplied by diesel power plants, 5% from small hydropower plants and 1% from isolated diesel generators. Due to the high dependency on imported fossil fuels for diesel generators, the electricity tariff is very high. Approximately 77% of the population has access to electricity in the country. The STP government set a target to achieve 100% access to electricity by 2030.

The study's objective was to conduct a detailed techno-economic feasibility study and prepare a detailed project report (DPR) for installing solar photovoltaic systems at selected sites to reduce grid electricity consumption and supply reliable power.

This report outlines the potential for rooftop solar PV in selected sites in São Tomé and Príncipe (STP). A comprehensive site assessment and data collection survey was conducted at 31 locations to evaluate their suitability for rooftop solar PV installation. The data collection process involved obtaining crucial information for each building, ensuring a thorough understanding of available shadow-free space for installation of PV arrays on the building roof and open space/carport area in the building premises. The ARKA 360 (Solar Labs) software was used for project design, PV array layout planning, and capacity assessment, with the following considerations: PV module selection, tilt angle, orientation, shadow analysis and inter-row spacing, frame size, provision for maintenance, module spacing and edge clearance for slant roofs.

The table below presents the names of the sites, rooftop PV capacity, estimated energy generation and GHG emission reduction potential:

Site No.	Site name	PV plant capacity (kW_p)	Estimated Energy generation (MWh/year)	GHG emission reduction metric tons (25 years)
	Saõ Tomé Island			
1	Supremo Tribunal de Justiça	107	139	2068
2	Direção do Ensino Primário	32	42	622
3	Procurador/ Ministério publico	14	19	275
4	Ministério da Defesa	86	111	1652
5	Autoridade Geral De Regulaca (AGER)	13	17	257
6	Hospital Dr. Aires de Menezes	211	299	4440
7	Ministério das Finanças e Economia Azul	169	218	3238
8	Liceu Nacional	272	358	5315
9	Ministério da Educação	23	30	445

Site No.	Site name	PV plant capacity (kW_p)	Estimated Energy generation (MWh/year)	GHG emission reduction metric tons (25 years)
10	Tribunal de Contas	34	44	656
11	Liceu Nacional de Santana	93	117	1739
12	Centro Polivalente de Caué	73	104	1543
13	Escola Secundaria de São João dos Angolares	24	31	455
14	Posto de Saúde	53	74	1097
15	Mercado de Bobo Foro	937	1318	19547
16	Escola Secundaria Maria Manuela Margarido (MMM)	208	270	4005
17	Escola Primária de Trindade	132	172	2558
18	Liceu Mé Chinhô	249	321	4763
19	Centro Hospitalar de Lobata	8	11	162
20	Camara Distrital de Lobata	48	62	922
21	Escola Secundária de Neves	96	133	1968
22	Escola Secundária de Santa Catarina	75	106	1567
23	Posto de Saude de Lembá	48	70	1036
24	Camara Distrital de Lembá	47	66	975
25	Fabrica de Chocolate	121	171	2535
	Total for Saõ Tomé Island	3173	4303	63840
	Príncipe Island			
26	Direção Regional de Ambiente e Conservação da Natureza Príncipe	33	48	708
27	Escola de Padrão	114	164	2436
28	Banco Internacional de São Tomé e Príncipe (BISTP)	70	98	1461
29	Casa da Cultura	24	31	461
30	Escola de Santo Antonio	78	110	1632
31	Hospital DR. Manuel Quaresma Dias Da Graça	75	99	1474
	Total for Príncipe	394	550	8172
	Total for Saõ Tomé and Príncipe	3567	4853	72012

This report summarises the site survey findings, plant design and 3-D layout, project capacity, estimated energy generation, and estimated greenhouse gas reduction. Estimations were made using the software for PV array capacity and energy generation potential. The total capacity of the PV array amounted to a total of 3567 kW_p, with 3173 kW_p for São Tomé Island and 394 kW_p in Príncipe Island and the total energy generation of all 31 sites was estimated to be 4853 MWh/year (for the first year). In addition to this, considering the degradation of PV power generation @0.5% per year, the total estimated CO_2 emission reduction during the 25-year project life for all 31 sites is 72012 metric tons.

A life cycle cost-benefit analysis was performed for all the systems proposed for each site, considering the existing grid-connection capacity. Savings from replacing grid electricity, diesel generation fuel consumption reduction, payback period and levelized cost of PV electricity have been calculated using a financial model. Furthermore, since most consumers use diesel generators for backup power supply during power outages, the reduction in diesel consumption based on average savings at lower loading of diesel generator sets and hours of operation during power outages has been calculated after integrating a PV system into their grid network. The upfront capital cost for rooftop PV projects without battery energy storage facilities has been estimated based on established and ongoing projects in the country and the prevailing project development costs of rooftop PV systems in the West African region. There is no import duty and value-added tax (VAT) on renewable energy generation products in the country.

The table below presents inputs and assumptions for financial analysis to determine LCoE and payback period for the rooftop systems in selected sites.

Sl. No.	Particulars	Unit	Value
1	Upfront capital cost for PV systems	US$/$kW_p$	1300
2	Annual power generation	kWh/kW_p/year	1365
3	Cost of battery energy storage systems	US$/kWh	500
4	Electricity tariff used for calculation of savings	US$/kWh	0.25
5	Retail price of diesel used for calculation of savings	US$/liter	1.50
6	Currency conversion ratio	USD : STN	1 : 23.41
7	Escalation of electricity price	% per year	1%
8	Annual reduction of generation due to degradation	%	0.75%
9	Operation and maintenance cost	% of project cost	1.20%
10	Escalation in O & M	%	3%
11	Interest rate for term loan [https://www.bistp.st/inicio/institucional/quem-somos/relatorio-contas/]	%	10%
12	Interest rate on working capital loans	%	10%
13	Viability Gap Funding from Govt/ Donor	% of project cost	0%
14	Plant life assumed for working of depreciation	Year	25
15	Residual Value	%	10%
16	Depreciation of plant (Straight line method)	Percent per year	3.60%

Sl. No.	Particulars	Unit	Value
17	Equity	% of project cost	30%
18	Term loan	% of project cost	70%
19	Term loan period	Years	10.00
20	Discounting Factor	%	10.22%

The LCOE without BESS is found to be US¢ 6.68 per kWh (STN 1.54 per kWh) and US¢ 17.20 per kWh (STN 3.24 per kWh) with 3 hours of full load backup of BESS. These values are much lower than the electricity tariff for commercial and institutional customers, which is STN 6.03 per kWh and STN 7.03 per kWh in São Tome and STN 9.87 per kWh in Príncipe at the time of the site survey.

Additionally, the report outlines the financial benefits for consumers from grid electricity savings, diesel consumption reductions, and payback periods for their investments in rooftop PV projects. It has been observed that, in São Tomé Island, the typical payback period is around five (5) years with savings from grid electricity and reduced diesel consumption. The sites with no diesel generator will have a payback period of around six (6) years as there is no additional saving from reduced diesel consumption. Similarly, in Príncipe Island, payback with a diesel generator is around three (3) years; without a diesel generator, the same is around four (4) years.

Diesel saving is calculated based on the specific fuel consumption of diesel generator sets at different loading when rooftop PV is installed. Savings of diesel at different loads are presented in the table below.

Generator Size (kW)	25% Load (l/hour)	50% Load (l/hour)	75% Load (l/hour)	100% Load (l/hour)	Savings at 75% load (l/hour)	Savings at 50% load (l/hour)	Savings at 25% load (l/hour)
20	2.27	3.41	4.92	6.06	1.14	2.65	3.79
30	4.92	6.81	9.08	10.98	1.89	4.16	6.06
40	6.06	8.71	12.11	15.14	3.03	6.44	9.08
60	6.81	10.98	14.38	18.17	3.79	7.19	11.36
75	9.08	12.87	17.41	23.09	5.68	10.22	14.01
100	9.84	15.52	21.96	28.01	6.06	12.49	18.17
125	11.73	18.93	26.88	34.45	7.57	15.52	22.71
135	12.49	20.44	28.77	37.10	8.33	16.66	24.61
150	13.63	22.33	31.80	41.26	9.46	18.93	27.63

The subsequent section of the report also discusses the financial benefits to the utility company EMAE, such as benefits from reduced diesel consumption, avoided generation, and deferred grid upgradation. For São Tomé, it has been estimated that 1080 kW_p rooftop solar power plants will generate 1.47 GWh of electricity annually and save 329,000 litres of diesel annually. Similarly, for Príncipe, 185 kW_p rooftop solar power plants would generate 0.27 GWh of electricity annually and save 61,180 litres of diesel annually. These savings are in addition to diesel savings for individual customers with installed solar systems.

Transitioning to renewable energy generation with battery energy storage will substantially reduce diesel fuel consumption for power generation. This report has demonstrated three scenarios to estimate the potential reduction in diesel consumption, considering the present electricity demand and diesel consumption as the base case. The base case timeline is 2024-25, and the three scenarios were created based on projected electricity demand by 2029-30.

To analyse different power demand and supply scenarios for the country, a load profile with a 15-minute time block basis has been created based on the existing load profile from the ALER 2020 report and project power demand as per NREAP 2022. An Excel sheet-based model has been created to analyse demand and supply profiles 365 days a year with 96 time-blocks per day. Due to the unavailability of real-time load data for the entire year and the minimum variability of weather patterns in the country, the demand profile has been considered similar for the entire year. Power supply profiles with 15-minute time-block power generation have been created for solar, hydro and biomass as planned in the NREAP 2022, creating 3 scenarios until 2030. The gap between demand and supply on a 15-minute time-block basis has been derived by matching the supply profiles of planned RE power projects and the country's demand profile. Diesel savings are calculated based on loading diesel generator plants at different levels of RE integration to the grid.

The energy storage requirement is calculated based on the number of power deficit time blocks when demand is not fulfilled by RE sources. Supply profiles from these projects are added (superimposed) to the projected demand profile to determine the share of renewable energy for all scenarios. The maximum storage power capacity requirement has been calculated based on maximum deficit power. Energy storage energy demand has been calculated based on the number of time blocks having deficit power during a day.

The results of the scenario analysis are presented below:

Parameters	Base Case	Scenario 1	Scenario 2	Scenario 3
Estimated electricity demand (GWh/year)	110	177	177	177
Fraction of electricity demand met by RE (% of total electricity demand)	10.70%	35.23%	50.94%	90.10%
Estimated diesel savings due to solar power generation (kiloliters/year)	1000	5380	10440	15320
Estimated diesel savings due to hydropower generation (kiloliters/year)	1320	6920	9520	22720
Estimated diesel savings due to biomass power generation (kiloliters/year)	-	-	-	4100
Total diesel saving due to RE power generation (kiloliters/year)	2320	12300	19960	42140

Parameters	Base Case	Scenario 1	Scenario 2	Scenario 3
Total amount saved from reduced diesel import for power generation (Million USD/year)	3.48	18.45	29.94	63.21
Government revenue saved from avoided subsidy on diesel for power generation (Million USD/year)	2.32	12.30	19.96	42.14

Note: The government of STP provides a subsidy to EMAE @1.00 USD per litre of diesel

Solar PV projects in São Tomé and Príncipe can be implemented through distributed generation systems and centralised generating plants. This report also reviews how distributed solar systems in São Tomé and Príncipe can be implemented through either the Capital Expenditure (CAPEX) or the Operating Expenditure (OPEX) business model, which is elaborated in section 4 of this report.

The main functional requirements of an EMS (energy management system) and the two types of metering arrangements used to measure the generation and utilisation of energy from a grid-connected solar PV plant, gross metering and net metering, have been elaborated on as well.

Based on the PV project implementation plan in São Tomé and Príncipe, priority capacity-building activities have been laid out in the report. These include –

- Establishing a training centre for practical training, equipping it with essential facilities, and organising technical and project management training for key agency officials.
- Organise workshops and seminars covering renewable energy potential, policy regulations, economic benefits, and project costing.
- Hosting awareness workshops for commercial and institutional electricity customers aims to educate them on technology options and the economic benefits of rooftop PV, while entrepreneurs are to be targeted with sessions on PV technologies, business opportunities, and funding sources.
- Additionally, trainers' training, exposure visits, and technical training sessions could be organised, focusing on various aspects of PV project development, site assessments, system design, installation, operation, and maintenance. This would ensure comprehensive skill-building across stakeholders and facilitate the successful implementation of solar projects in the region.

Successful implementation of solar photovoltaic (PV) projects in São Tomé and Príncipe hinges on effective risk management strategies to ensure a satisfactory return on investment. The main risks potentially impacting solar projects in the two islands have been described as well, which include - quality assurance concerns such as inadequate site planning and equipment selection, which can be mitigated through comprehensive capacity-building initiatives and engaging third-party engineering firms for quality control. Operation and maintenance pose challenges due to environmental factors and require regular cleaning and skilled personnel to maximise system performance. Policy and regulatory frameworks must support grid connectivity and tariff determination for commercial projects, while financial risks arise from high project costs and investor perceptions of risk. Grid infrastructure stability is crucial for uninterrupted operation, particularly for central solar power systems, while harsh climates necessitate measures to combat corrosion and environmental damage to PV modules and infrastructure, emphasising the importance of selecting durable materials and implementing effective drainage and maintenance practices.

The final section of the report outlines recommendations for solar PV projects to be implemented successfully in São Tomé and Príncipe. These comprise measures to be taken regarding the policy and regulatory framework in the islands, implementation of PV projects using suggested business models and sources of funding, selection of technology including codes and standards to be followed, overall techno-economic feasibility, reduction of diesel import, nationally determined emission reduction, electric vehicle infrastructure and capacity building.

1 INTRODUCTION

The International Solar Alliance (ISA) launched the "Scaling of Solar Rooftop" Programme in March 2018. This programme aims to promote, assess potential, harmonise demand, and pool resources for rapid deployment of and scaling up Rooftop Solar (both off-grid and grid-connected) in ISA member countries. "Scaling of solar rooftops in São Tomé and Príncipe" is a part of this programme, and its objective is to conduct feasibility studies and prepare bankable detailed project reports (DPR) for identified sites in the country.

São Tomé and Príncipe is a member country of ISA, which heavily relies on imported diesel to generate generated electricity. Due to the high dependency on imported fossil fuels for diesel generators, the electricity tariff is very high. Approximately 77% of the population has access to electricity in the country. The government set a target to achieve 100% access to electricity by 2030.

ISA has engaged Global Sustainable Energy Solutions India Pvt. Ltd. to conduct a techno-economic feasibility study and prepare a detailed project report for installing solar power projects in thirty-one (31) selected sites in São Tomé and Príncipe under the "Scaling of Solar Rooftop" programme. The objective of the assignment was to carry out a comprehensive energy and power sector assessment and conduct a detailed evaluation of identified sites, their energy demand, infrastructure compatibility, and suitable areas for installing solar PV plants. The other activities under this project were collecting technical, commercial, and financial data, reviewing relevant policies, and carrying out cost-benefit analyses of the proposed solar projects in the selected sites.

This detailed project report (DPR) is the outcome of the study assigned by ISA. This report is presented in eight chapters, as mentioned below:

Chapter 1: Introduction

Chapter 2: Country Energy Profile

Chapter 3: Feasibility study of rooftop projects

Chapter 4: Economic and cost-benefit analysis

Chapter 5: Project implementation roadmap

Chapter 6: Capacity Development Plan

Chapter 7: Risk assessment and mitigation

Chapter 8: Recommendations

2 COUNTRY ENERGY PROFILE

São Tomé and Príncipe (STP) is an island country in Central Africa with a population of 227,380 as of 2022 [1]. The country's energy landscape is characterised by significant challenges and dependencies. As one of the countries in sub-Saharan Africa with one of the highest power generation costs, STP deals with importing all its fossil fuels due to the absence of local production. This reliance on imports renders the country susceptible to international price fluctuations and emphasises its dependency on external sources. The energy sector, marked by subsidies and non-cost-reflective tariffs, further compounds the issue as the national utility company, Water and Electricity Company (EMAE), struggles to recover its costs [2]. The challenges extend to an old transmission and distribution system and a power generation mix heavily reliant on expensive diesel [3]. Decentralised energy generation, particularly in the tourism sector, is common in the country.

2.1 CONSUMPTION

Approximately 77% of the population has access to electricity. The per capita electricity consumption is about 376 kWh/person. São Tomé's energy policy aims to achieve 100% electrification by 2030 [3].

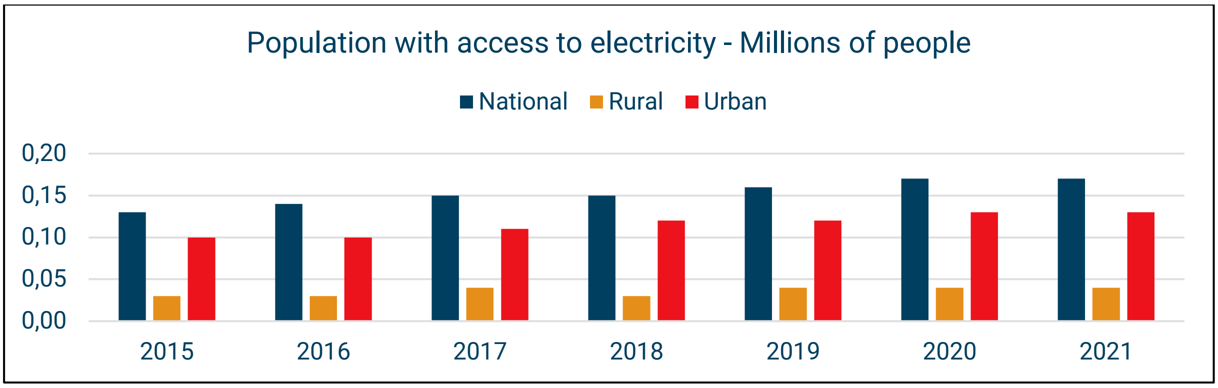


Figure 1: Access to electricity as per popularised areas (Source: African Energy Commission)

The electricity consumption of EMAE's electricity consumers is grouped into four categories, which are mentioned in the table below, which shows estimated electricity consumption per client and share of total consumption.

Table 1: EMAE's electricity consumer category and estimated consumption

Sl. No.	Consumer Category	Consumption (kWh/client)	Total Consumption
1	Residential	970	52 %
2	Small commercial	4423	29 %
3	Large commercial and industrial	11057	15 %
4	Institutional, state and other consumers	10160	4 %

Source: EMAE

São Tomé and Príncipe do not produce fossil fuels. Therefore, all fuels consumed in the country are imported. Due to the absence of an oil refinery, all petroleum products, including jet fuel, gasoline, and kerosene, must be imported. The residential sector has the highest energy demand, followed by the industrial sector and transportation. Based on Greenhouse Gas Inventory (IGEE) data, the transport sector, specifically the land transport subcategory, is the second-largest consumer. This category accounts for 80% of gasoline and 17% of diesel in the overall consumption percentages [3].

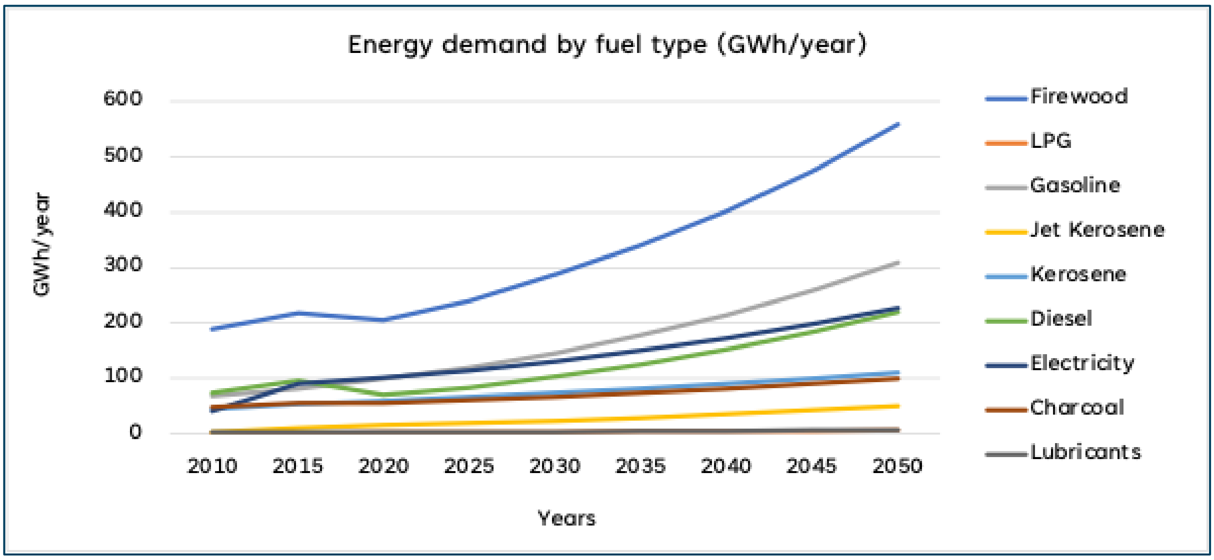


Figure 2: Energy Demand by Fuel Type - Business as usual scenario (Source: NREAP)

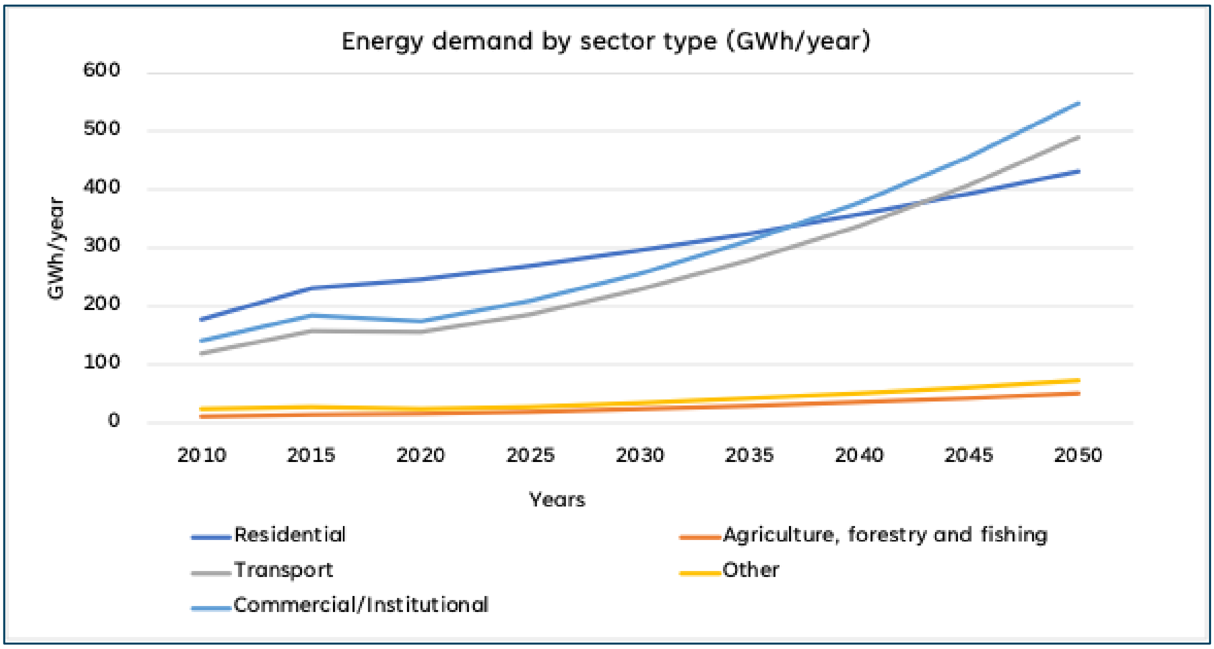


Figure 3: Energy Demand by Sector Type - Business as usual scenario (Source: NREAP)

2.2 LOAD PROFILE

The annual average load profile of São Tomé's primary grid is presented in the figure below. The daily load profile indicates that the peak consumption typically happens between 6 pm and 9 pm, while it remains relatively stable for the rest of the day. The average power demand is 13 MW, and the minimum and maximum power demand during the day are 11 MW and 17 MW, respectively. The maximum peak power demand in the evening is 32% higher than the average power demand during the day.

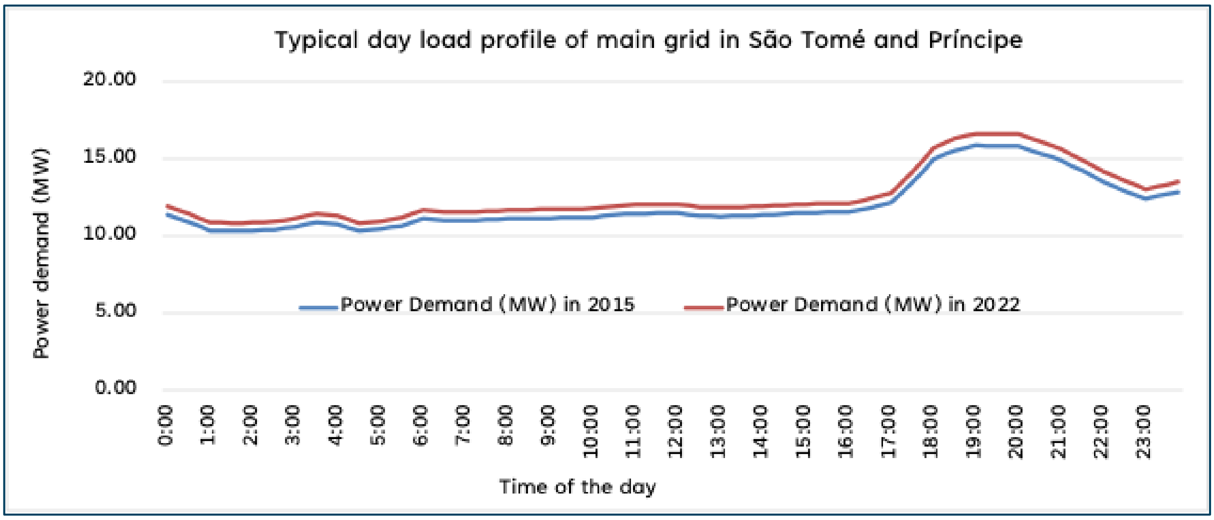


Figure 4: Annual average load profile of São Tomé's main grid [4]

2.3 GENERATION

The installed electricity generation capacity in São Tomé and Príncipe was 30.22 MW, with an available capacity of 19.24 MW. Details of generation capacity and available capacity are presented in Table 2. All the power plants are operated from imported diesel fuel. The average plant load factor of the generating stations is 41%.

EMAE's total electricity generation is 108.15 GWh, with 101.77 GWh (94%) generated from diesel power plants, 5.83 GWh (5%) from hydroelectric plants, and 0.551 (1%) GWh from isolated diesel generators. Energy generation from the solar power plants is estimated at 0.051 GWh per year.

Table 2: Installed Capacity of Power Plants in São Tomé and Príncipe

São Tomé					
Power Plant Type	Installed Power (MW)	Available capacity (MW)	Availability of Installed Power (%)	Energy Produced (MWh)	Capacity Utilization Factor
Diesel Power Plant	24.96	16.89	67.7%	96605	44%
Hydropower Plant	1.92	1.22	63.6%	5833	35%

Isolated diesel generator	0.54	0.18	32.7%	551	12%
Total	27.42	18.29	66.7%	102990	43%
Principe					
Diesel Power Plant	2.80	1.82	65.1%	5160	21%
São Tomé & Príncipe					
Total	30.22	20.11	66.5%	108149	41%

Source: EMAE

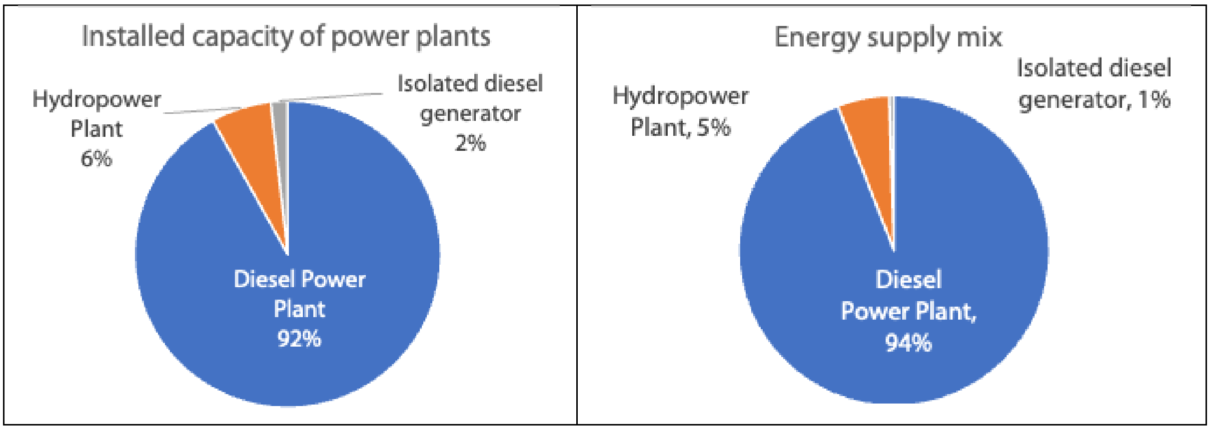


Figure 5: Installed capacity of power plants and energy supply mix

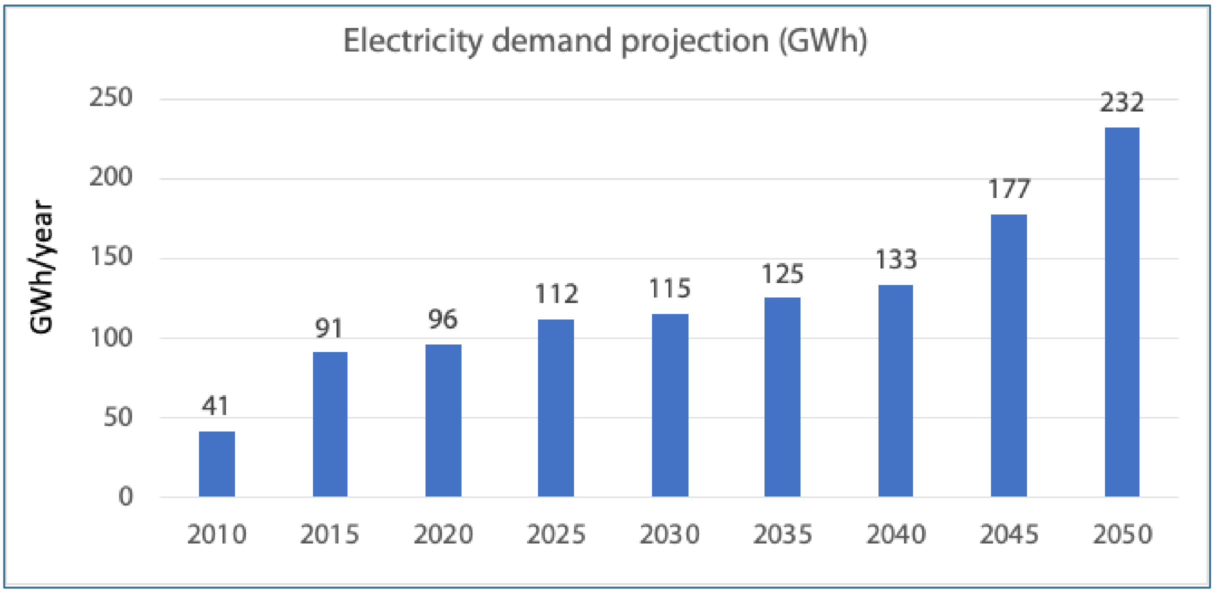


Figure 6: Electricity generation growth in GWh (Source: NREAP)

2.4 INSTITUTIONAL FRAMEWORK

The energy sector in São Tomé and Príncipe comes under the jurisdiction of the Ministry of Infrastructure and Natural Resources (MIRN – Ministério das Infraestruturas e Recursos Naturais). The Directorate General of Natural Resources and Energy (DGRNE – Direcção Geral dos Recursos Naturais e Energia) looks after all activities in São Tomé island the Regional Secretariat for Environment and Sustainable Development (SRADS – Secretaria Regional de Ambiente e Desenvolvimento Sustentável) looks after the activities in the Autonomous Region of Príncipe (RAP – Região Autónoma do Príncipe). The district authorities have regulatory powers in the energy field and actively participate in the design of public policies and the sector's regulation.

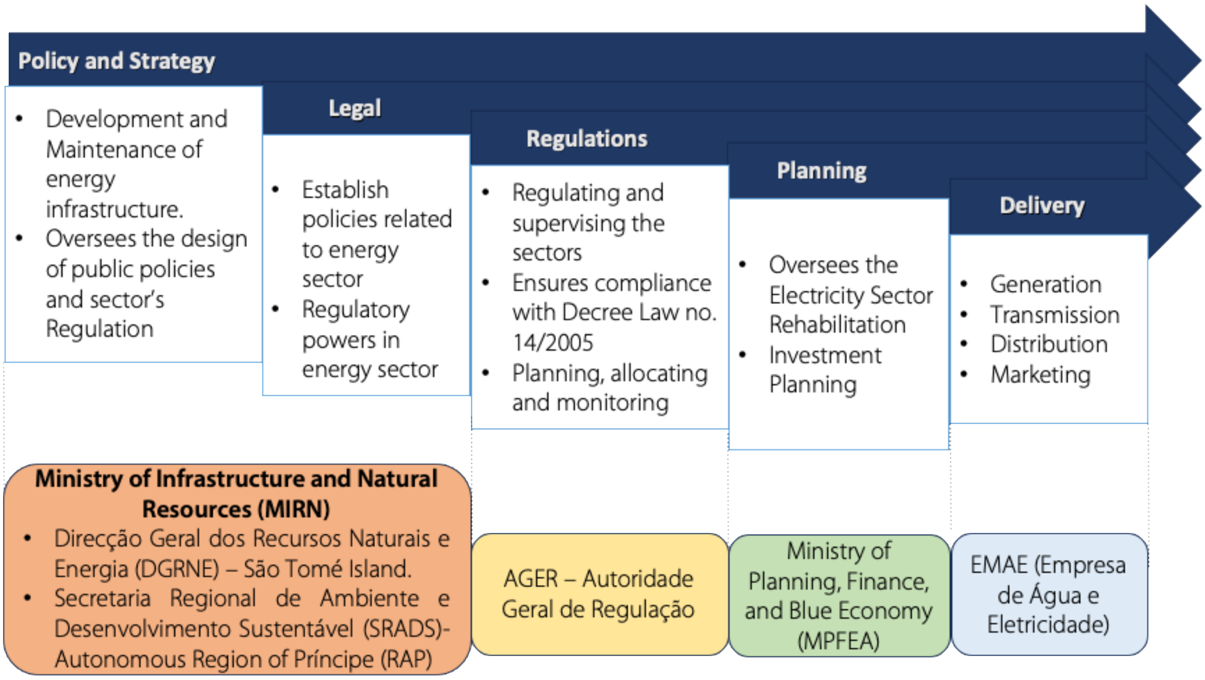


Figure 7: Institutional Framework of Electricity Sector in STP

The General Regulation Authority (AGER – Autoridade Geral de Regulação) regulates the electricity sector, created by Decree Law no. 14/2005. The public company EMAE (Empresa de Água e Eletricidade) performs electricity generation, transmission, distribution and marketing in a vertically integrated monopoly. It is the only public entity that distributes and sells electricity in the country.

In addition to the aforementioned institutions, the energy sector also includes the STP National Oil Agency (ANP – Agência Nacional do Petróleo), which is the public body that regulates and promotes the activities of the oil and gas industry in the national territory and the Directorate General of the Environment (DGA – Direcção Geral do Ambiente), which is linked to the MIRN and is the body through which the Government exercises its environmental policy. The DGA has a broad and transversal competence that addresses the energy sector.

AFAP (Agência Fiduciária de Administração de Projectos) is an autonomous body under the Ministry of Planning, Finance and Blue Economy (MPFEA—Ministério do Planeamento, Finanças e Economia Azul) which manages the Electricity Sector Rehabilitation Project in the country.

A Coordination Committee for the Electricity Sector Transformation Program (CC- PTSE – Comité de Coordenação do Programa de Transformação do Sector Eléctrico) and the Technical Group supporting the Electricity Sector Transformation Program (GT- PTSE – Grupo Técnico de apoio ao Programa de Transformação do Sector Eléctrico), support the Government in implementing the Electricity Sector Transformation Program.

A Steering Committee in the Ministers of Finance and the Blue Economy has been formed for the Electricity Sector Transformation Program (CP-PTSE – Comité Piloto do Programa de Transformação do Sector Eléctrico).

The National Sustainable Energy Platform (PNES) was established under the UNIDO/GEF project. The PNES includes representatives from public and private institutions that operate/participate directly and indirectly in the STP energy sector.

2.5 POLICY AND REGULATIONS

São Tomé and Príncipe do not have a legal framework for renewable energy incentives or specific access rules for independent generation under a specific regime. The National Renewable Energy Action Plan (NREAP) recommends updating the current regulations and policies to achieve the desired goals. The following measures are necessary to achieve the goals mentioned in these development plans:

- Regulations for low-voltage installations should be established.
- Regulations for the quality of material used in low, medium, and high-voltage electrical installations are to be established.
- Regulations for grid connections, model contracts and tariffs are to be established.
- Regulations for incorporation of solar energy in real estate infrastructure projects.

Decree-Law no. 26/2014 is the Basic Law for the Electricity Sector in STP. It outlines state policies, planning, management, granting generation licenses, concessions, and sanctioning legal regulations. The Electricity Sector Legal Regime (RJSE) was developed for three main reasons: to clarify regulations to address sector challenges such as power supply issues, to encourage private investment alongside the main producer, EMAE, and to strengthen the sector's technical and economic regulations. The RJSE outlines the overall regulations for the electricity sector, including renewable energy generation, in Article No. 50 and the proceeding items.

However, existing frameworks in Decree-Law no. 26/2014 serve as policy enablers for RE generation. The current market organisation still needs to align with the RJSE fully, indicating a need to enhance the legal framework, support stakeholders, and attract private investment. Further development of the RJSE is required through supplementary legislation, especially regarding renewable energy generation and grid integration.

Article No. 52 promotes the generation of self-consumption in the country. It defines the following framework for the generation of self-consumption/captive consumption and generation in isolated locations:

- Licenses are not required, which enables simplified access to generation from such plants

- Access is not restricted to delivery points. This excludes producers who want to sell part of their generated energy to the grid. However, such producers must consume at least 60 % of their generated energy.
- No limit is set on the maximum power to be installed for self-consumption.

Under Article No. 53, a producer in an isolated location can generate up to 150 kVA of electricity. However, the system must not be connected to the national electricity grid and must sell the generated electricity in the local area [2].

2.6 RENEWABLE ENERGY INITIATIVES

São Tomé and Príncipe have showcased a robust dedication to achieving their Nationally Determined Contributions (NDC) targets. The country actively implements renewable energy projects in various regions to pursue these objectives. This initiative aims to diminish reliance on diesel-based power plants, the costs of which are subject to fluctuations in diesel prices imported from other countries.

The Directorate General of Natural Resources and Energy (DGRNE), the government of São Tomé and Príncipe, in collaboration with UNIDO, has set renewable energy targets outlined in the National Renewable Energy Action Plan (NREAP) published in 2022. The NREAP lays out various targets and actions to be achieved by 2030 and 2050.

The primary aim of the NREAP is to increase the use of renewable energy sources for electricity generation through grid-connected and off-grid systems. The NREAP targets 72% of the total installed capacity from renewable energy by 2030. This includes 49% from solar, 18% from hydropower, and 5% from biomass. The NREAP aims to maintain these targets until 2050. The goal is to ensure 100% access to electricity by 2030 and to continue sustaining this indefinitely.

The NREAP plans to achieve the following renewable energy installed capacity by 2030.

1) Solar power plant capacity: 49.35 MW
2) Hydropower plant capacity: 17.30 MW
3) Biomass power plant capacity: 4.68 MW

Table 5 presents the details of solar energy installation targets as per NREAP, and Table 6 presents the details of non-solar renewable energy installation targets.

A 550 kW_p solar PV plant was commissioned in 2022, and another 1.6 MW_p solar PV plant is under construction and scheduled to be commissioned in 2024. Both PV power plants are located in the diesel power generating station in Santo Amaro on São Tomé Island.

There are plans to install grid-connected rooftop PV systems at the two airports in São Tomé and Príncipe. However, these projects are not yet implemented. At the time of this report, no grid-connected rooftop PV systems were installed in the country. Off-grid systems with battery storage are installed in a few government buildings to provide a backup power supply. These systems are new and in working condition. One such system installed in a school on Príncipe Island has been lying idle due to the lack of maintenance. Many solar home systems and solar lanterns are used in rural areas for lighting and mobile charging.

Table 3: Solar energy installation target as per NREAP [2]

Period	Planned projects	Capacity (MW)	Location
2020-2022	Hybridization of the Santo Amaro photovoltaic plant 1st phase 0.54 MW	0.54	São Tomé
2020-2023	Hybridization of the Santo Amaro photovoltaic plant 2nd phase 1.66 MW	1.66	São Tomé
2020-2025	Construction of the 15 MW Água Casada Lobata Solar PV Plant, with a 2 MW battery bank	15	São Tomé
2020-2025	Construction of the 15 MW Água Casada Lobata Solar PV Plant, with a battery bank for backup	15	São Tomé
2021-2025	Construction of the 10 MW Água Casada Lobata Solar PV Plant	10	São Tomé
2021-2024	Construction of the Solar PV Plant - 4.75 MWp with 3.5 MWh of storage	4.75	Principe
2021-2030	Installation of domestic solar PV plant (800 households / 3 kW) (including rooftop PV and RE for industrial prosumers)	2.4	São Tomé
	Total	49.35	

Table 4: Non-solar renewable energy installation target as per NREAP [2]

Period	Planned projects	Capacity (MW)	Location
2020-2024	Rehabilitation with power increase of the Contador 2 MW mini-hydropower plant	2	São Tomé
2020-2025	Rehabilitation with power increase of the Papagaio 1.1 MW mini-hydropower plant	1.1	São Tomé
2020-2023	Rehabilitation of the Agostinho Neto 1.2 MW mini-hydropower plant	1.2	São Tomé
2020-2024	Rehabilitation of the Guegué mini-hydropower plant with an increase of 1 MW	1	São Tomé
2020-2025	Construction of the 4.68 MW Biomass Power Plant	4.68	São Tomé
2020-2030	Construction of hydropower plants on the Iô Grande River and in Bombaim, total of 10 MW	10	São Tomé
2021-2030	Construction of a 2 MW mini-hydropower plant in Claudino Faro	2	São Tomé
	Total	21.98	

2.7 TRANSMISSION AND DISTRIBUTION

São Tomé and Príncipe's electricity transmission and distribution grid consists of various voltage levels, including 30 kV and 6 kV for medium voltage (MV), 0.4 kV for low voltage (LV), and 30/6 kV substations, as presented in Table 5.

Table 5: Grid Details of São Tomé and Príncipe Island [4]

Sl. No.	Island	Grid Infrastructure Details	Grid voltage level	Route length
1	São Tomé	Medium Voltage	30 kV and 6 kV	203 km
		Low Voltage	0.40 kV	300 km
		Substations and Switching Stations	30 kV/6 kV	
2	Príncipe	Medium Voltage	6 kV	25 km
		Low Voltage	0.40 kV	25 km

São Tomé's grid features aerial and underground components, with the MV grid covering most of the island. Príncipe, on the other hand, has an entirely 6 kV MV grid comprising both aerial and underground sections. EMAE served about 70,000 customers by supplying electricity and water. There is different tariff categories classified by EMAE, which are outlined as follows:

- Tariff categories ranged from the subsidised rate of STN 1.67/kWh (US0.071US/kWh) (social tariff for consumers using up to 100 kWh/month) to STN 3.84 /kWh (US0.16US/kWh) (also subsidized) for commercial customers and services.
- The highest tariff, STN 9.87 /kWh (US0.42US/kWh), applied to customers categorized as "Public Administration", "Regional Administration", "Autonomous Region (State)", and "Local Authorities".
- The average electricity tariff in São Tomé and Príncipe was STN 5.5/kWh (US$0.23 $US/kWh)

Customers are also categorised based on post-paid billing and pre-paid billing facilities. The tariff structure for post-paid billing and pre-paid billing is presented in Table 6 and Table 7.

Table 6: EMAE Post-paid energy tariff structure

Customer categories	Price per kWh in STN (US$)		
	≤ 100 kWh	≤ 300 kWh	> 300 kWh
Domestic	1.67 (0.071)	2.45 (0.10)	3.84 (0.16)
Industrial	3.43 (0.15)		
Commercial and Services	3.84 (0.16)		
Companies and State Institutions	6.03 (0.26)		
Embassies and International Organizations	7.03 (0.30)		
Inst. Finance. (Banks and Insurance Companies)			

Customer categories	Price per kWh in STN (US$)		
	≤ 100 kWh	≤ 300 kWh	> 300 kWh
Telecommunications Companies			
Travel Agencies			
Autonomous Region	9.87 (0.42)		

Table 7: EMAE Prepaid energy tariff structure

Customer categories	Price per type of counter in STN	
	Single-phase	Three-phase
Domestic	2.75 (0.12)	3.35 (0.14)
Industrial	3.43 (0.15)	
Commercial and Services	3.84 (0.16)	
Companies and State Institutions	6.03 (0.26)	
Embassies and International Organizations	6.56 (0.28)	
Inst. Finance. (Banks and Insurance Companies)		
Telecommunications Companies		
Travel Agencies		
Autonomous Region	9.87 (0.42)	

1 STN = 23.41

Figure 8: Electrical distribution network of São Tomé (Source: Ricardo Energy & Environment, 2018)

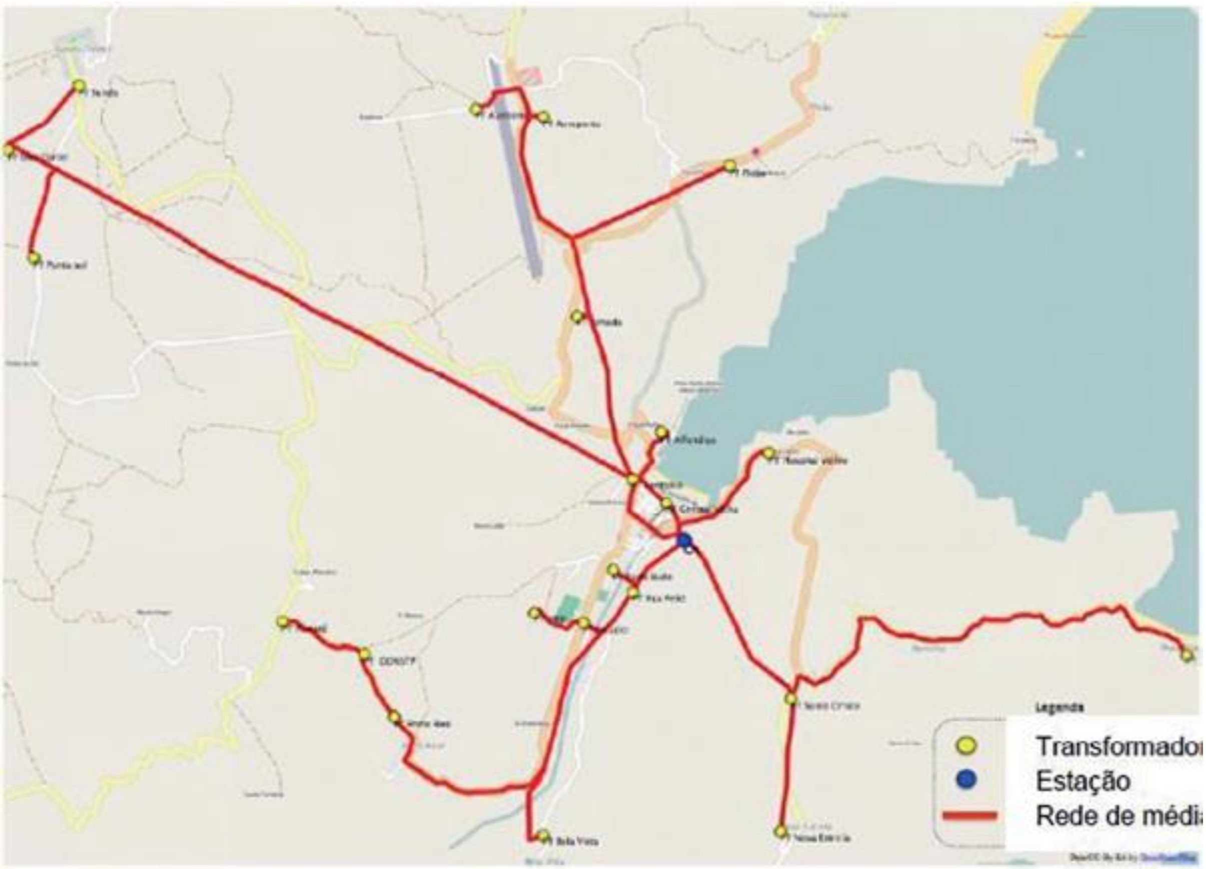


Figure 9: Electrical distribution network of Príncipe (Source: Ricardo Energy & Environment, 2018)

2.8 DEMAND AND SUPPLY GAP

There is a considerable gap in the demand and supply of electricity in São Tome and Príncipe due to various reasons, such as losses in the power system, a shortage of diesel, and a failure of the distribution system. Many commercial and institutional consumers use standby diesel power generators as their standby power supply.

The consumers of the utility company EMAE face acute power cuts in São Tomé and Príncipe mainly due to the fuel shortage to run the diesel power plants and the failure of the distribution network. The duration and frequency of power outages are unpredictable in São Tomé Island, which may extend from 1-2 hours to serval hours depending upon the availability of fuel. There is a scheduled power cut in Príncipe Island for 6– 7 hours daily from midnight to morning. Diesel generators are common for commercial and institutional electricity consumers as a backup power supply system to cope with power outages. However, it was observed that many diesel generators are not functioning due to a lack of maintenance or spare parts to replace.

2.9 SOLAR RESOURCE

Solar radiation data has been collected and analysed from satellite-based sources, namely NASA, Meteonorm, and Global Solar Atlas (World Bank). Solar data collected from these sources has been compared.

NASA-POWER (Prediction of Worldwide Energy Resources): The NASA-POWER data archive can produce data on a "1/2 x 1/2" degree global grid through GIS-enabled Data Access Viewer, ArcGIS image services, etc.

Solar Meteonorm 7.3: The Meteonorm database comprises more than 8,000 weather stations, 5 geostationary satellites, and globally calibrated aerosol climatology. It uses a standard period from 1991-2010 or 1996-2015 for irradiation data and 2000-2009 for other parameters. Figure 10 presents global irradiation at a 10° tilted surface (kWh/m^2/day).

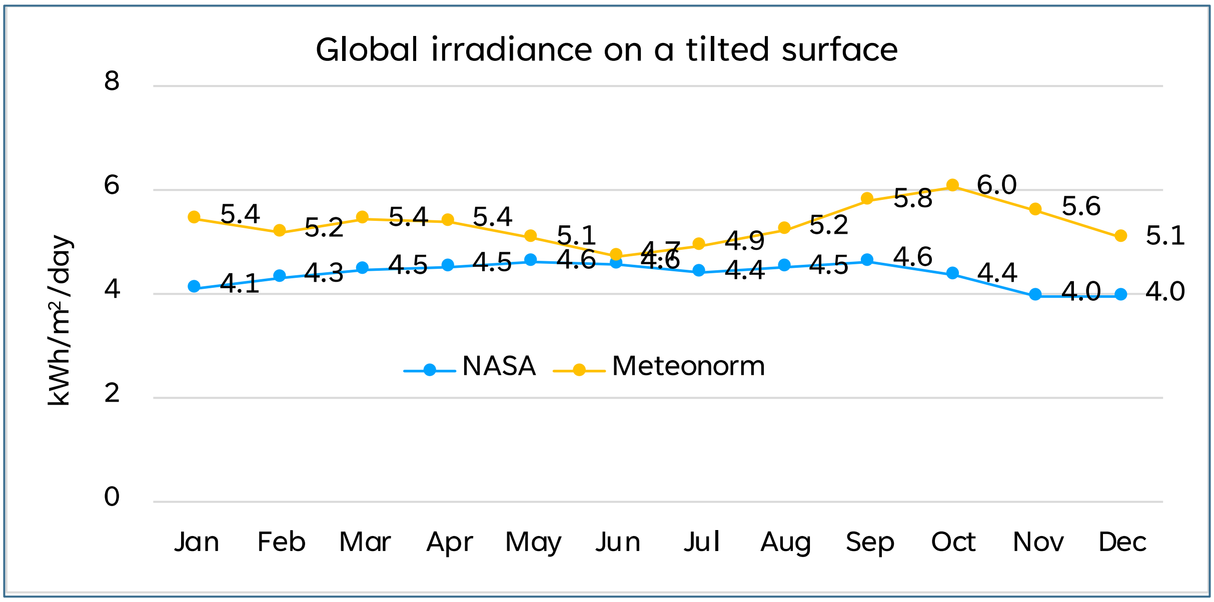


Figure 10: Global irradiance on a tilted surface in kWh/m^2/day

Global Solar Atlas (World Bank): Solargis, funded by the World Bank, provides country-wise solar resource maps to support the global scale-up of solar power. This work is funded by the Energy Sector Management Assistance Program (ESMAP). The solar resource map of São Tomé and Príncipe is given in Figure 11.

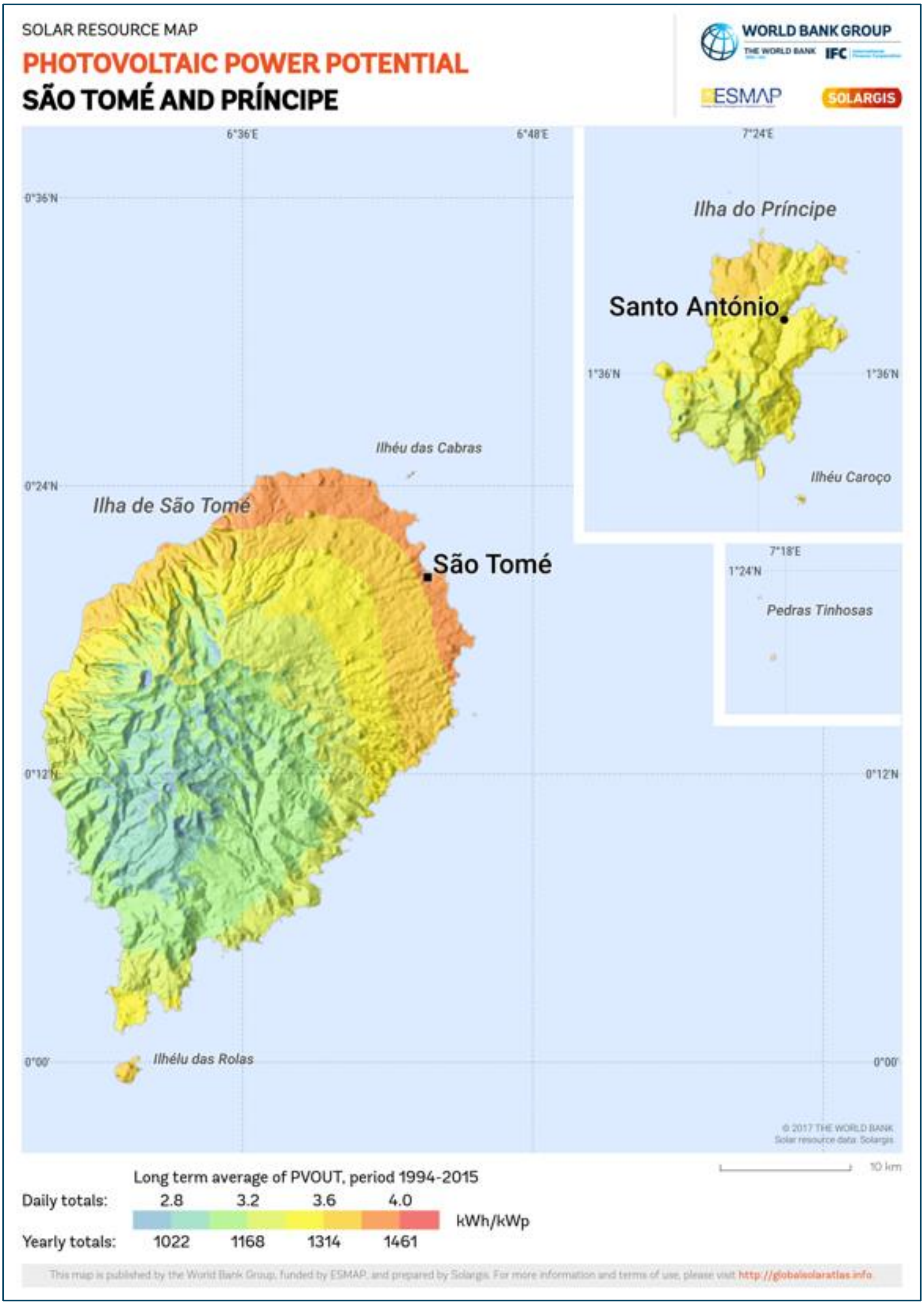


Figure 11: Solar potential in STP [https://globalsolaratlas.info/download/sao-tome-and-principe]

2.10TEMPERATURE AND WIND SPEED

The maximum and minimum ambient temperatures in São Tomé and Príncipe and the maximum wind speed were taken from the NASA-POWER data archive. The values are given in Table 8. The annual average of the maximum ambient temperature is 28.3°C, and the annual average of the minimum ambient temperature is 24°C, indicating very low variation in temperature throughout the year. The maximum wind speed occurs in October with a value of 10 m/s, while the average maximum wind speed is 8.6 m/s.

Table 8: Temperature and wind speed data from NASA-POWER

Months	Max ambient temperature °C	Min ambient temperature °C	Max wind speed (m/s)
January	29.2	24.7	9.0
February	29.5	25.1	9.0
March	29.7	25.5	9.5
April	29.3	25.1	8.4
May	28.9	23.9	8.1
June	27.4	22.7	8.4
July	26.9	21.9	8.1
August	26.8	22.4	8.3
September	27.3	23.0	8.3
October	27.7	24.4	10.0
November	28.3	24.4	8.1
December	28.5	24.9	8.0
Average	28.3	24.0	8.6

3 FEASIBILITY STUDY OF ROOFTOP PROJECTS

In consultation with the Directorate General of Natural Resources and Energy, São Tomé and Príncipe, 31 sites across two islands have been shortlisted for survey and assessment. These sites are located in six districts of São Tomé and the Autonomous Region of Príncipe. Table 9 presents the types of institutions covered in each district.

Table 9: Summary of shortlisted sites

Sl. No.	Island	District	Number of sites shortlisted	Types of institution
1	São Tomé	Agua Grande	10 sites	Government office: 8, Hospital: 1, School: 1
2	São Tomé	Cantagalo	1 site	School: 1
3	São Tomé	Caué	3 sites	Government office: 1, Hospital: 1, School: 1
4	São Tomé	Mé Zochi	3 sites	Market: 1, School: 2
5	São Tomé	Lobata	3 sites	Government office: 1, Hospital: 1, School: 1
6	São Tomé	Lembá	5 sites	Government office: 1, Hospital: 1, School: 2, Private company: 1
7	Príncipe	Região Autónoma do Príncipe	6 sites	Government office: 2, Hospital: 1, School: 2, Bank: 1
			31 sites	

A comprehensive methodology was adopted to conduct the site survey and feasibility assessment of rooftop solar PV installation in the shortlisted sites. The data collection process involved obtaining information for each building, ensuring a thorough understanding of available shadow-free space for installation of PV arrays on the building roof and open space/carport area in the building premises. Structural conditions and suitability of building roofs for installation of PV arrays were verified during the site visit. The data was gathered via physical examination and stakeholder consultation at the site. The approach for site assessment and the data collection results for each site is given in Section 3.1. The subsequent sections include summaries of all surveyed sites, including PV capacity, project design, grid integration, diesel fuel savings, greenhouse gas emission reduction, project cost, and financial analysis.

3.1 SITE ASSESSMENT AND DATA COLLECTION

The following methodology has been followed to carry out this task.

Step 1: Ste survey

A site survey checklist was prepared for data collection. The following particulars were gathered for each site during the site survey:

- The number of buildings surveyed was noted, along with their precise geographical coordinates and the names and addresses of the sites.
- The type of building roof and roofing materials were observed along with building age, and the structural conditions of the building and roof were observed and recorded.
- The type of roof and slope were observed for buildings with slanted roofs. The material composition of the roof and supporting structure, alongside the age of the building/roof, were assessed to gauge their durability and potential impact on installation feasibility.
- The presence of nearby objects capable of casting shadows, such as trees, neighbouring buildings, or any objects on the building roof, was recorded and considered for conducting shadow analysis.
- Accessibility to the roof was examined to ensure practicality for installation purposes while confirming whether the roof space was unobstructed and suitable for accommodating PV arrays.
- The location of the main electrical panel and the current-carrying capacity of the existing electrical panel were observed, and grid connection points were identified.
- The optimum locations for installing inverters were identified based on the main electrical panel and PV array location.
- Grid connection type (single phase or three phase), connected load and electricity consumption/demand data were gathered to assess compatibility and system capacity for grid connectivity.
- The reliability of the electricity supply and the incidence and duration of power outages were enquired and recorded. The availability and capacity of the backup power supply during power outages were also recorded.

Step 2: PV array capacity determination

The capacity of the PV plant for a specific building premises was estimated based on the following:

(1) Type of building and roof
(2) Dimension and orientation of the building roofs
(3) Shadow-free area suitable for PV array installation
(4) Optimum layout of PV arrays for maximum performance and operational convenience

Step 3: Annual Energy yield estimation

Once the PV array layout is finalised, the appropriate and available make and model of the inverter are selected from the software database. Inverters are selected based on PV array layout planning to minimise mismatch loss. DC capacity oversizing to inverter capacity is kept at less than 10%. Monthly and annual energy generation reports were generated through simulation in the software, adjusting the loss parameters per the site conditions.

Step 4: Creation of Data Room

A web-based data room has been created in One Drive, containing the following information for each site. Separate folders will be created for each project site.

1. Geographical coordinates and .kmz file for each site
2. Solar lab simulation report
3. 3-D PV array layout
4. Estimated PV Plant capacity
5. Estimated annual energy generation
6. Estimated CO_2 emission reduction
7. Photos of buildings/sites

3.2 CAPACITY ASSESSMENT OF PROPOSED ROOFTOP PV PLANTS

The PV array capacity for all sites was estimated using Solar Lab software and site survey data, as shown in Table 10. The estimated aggregated PV capacity for all 31 sites is 3567 kW_p.

Table 10: Summary of estimated PV plant capacity of surveyed sites

Site No.	Site name	District	Coordinates	PV plant capacity (kW_p)
	São Tomé Island			
1	Supremo Tribunal de Justiça	Agua Grande	0.339007, 6.736160	107
2	Direção do Ensino Primário	Agua Grande	0.340270, 6.734672	32
3	Procurador/ Ministério publico	Agua Grande	0.340045, 6.734872	14
4	Ministério da Defesa	Agua Grande	0.344186, 6.736427	86
5	Autoridade Geral De Regulaca (AGER)	Agua Grande	0.343074, 6.736117	13
6	Hospital Dr. Aires de Menezes	Agua Grande	0.356086, 6.722450	211
7	Ministério das Finanças e Economia Azul	Agua Grande	0.345539, 6.737110	169
8	Liceu Nacional	Agua Grande	0.339048, 6.739914	272
9	Ministério da Educação	Agua Grande	0.340066, 6.735176	23
10	Tribunal de Contas	Agua Grande	0.340502, 6.735445	34
11	Liceu Nacional de Santana	Cantagalo	0.263781, 6.743511	93
12	Centro Polivalente de Caué	Caué	0.133876, 6.648637	73
13	Escola Secundaria de São João dos Angolares	Caué	0.133062, 6.648472	24
14	Posto de Saúde	Caué	0.133114, 6.648135	53
15	Mercado de Bobo Foro	Mé Zochi	0.324577, 6.705579	937

Site No.	Site name	District	Coordinates	PV plant capacity (kW_p)
16	Escola Secundaria Maria Manuela Margarido (MMM)	Mé Zochi	0.295383, 6.668566	208
17	Escola Primária de Trindade	Mé Zochi	0.296825, 6.680038	132
18	Liceu Mé Chinhô	Lobata	0.375658, 6.650231	249
19	Centro Hospitalar de Lobata	Lobata	0.378000, 6.636840	8
20	Camara Distrital de Lobata	Lobata	0.379155, 6.637134	48
21	Escola Secundária de Neves	Lembá	0.357505, 6.545040	96
22	Escola Secundária de Santa Catarina	Lembá	0.270007, 6.472640	75
23	Posto de Saude de Lembá	Lembá	0.357927, 6.553228	48
24	Camara Distrital de Lembá	Lembá	0.358654, 6.544597	47
25	Fabrica de Chocolate	Lembá	0.389749, 6.629590	121
			Total in São Tomé	3173
	Príncipe Island			
26	Direção Regional de Ambiente e Conservação da Natureza Príncipe	Príncipe	1.622401, 7.402924	33
27	Escola de Padrão	Príncipe	1.641298, 7.419496	114
28	Banco Internacional de São Tomé e Príncipe (BISTP)	Príncipe	1.641208, 7.421017	70
29	Casa da Cultura	Príncipe	1.637300, 7.418969	24
30	Escola de Santo Antonio	Príncipe	1.634786, 7.416313	78
31	Hospital DR. Manuel Quaresma Dias Da Graça	Príncipe	1.645163, 7.421525	75
			Total in Príncipe	394
			Grand Total	3567

3.3 PROJECT DESIGN AND PLANT LAYOUT

Solar Lab software was used for project design, PV array layout planning, and capacity assessment, with the following considerations:

(1) **PV Module selection:** A high-efficiency PV module, such as a monocrystalline PERC/TOPCon half-cut module, was selected from the software's database. The module's market availability was also considered during the selection process.

(2) Tilt Angle: Solar PV modules receive maximum annual average irradiation when tilted at an angle equal to the location's latitude. Based on the location's latitude angle, the tilt angle ideally should be close to 0°. However, the roof angle has been considered the tilt angle for PV arrays on slant roofs. For flat roofs and carport installation, a tilt of 10° facing south was considered to ease self-cleaning.

(3) Orientation (Azimuth): For locations in the Northern Hemisphere, Solar PV modules should be placed facing towards the South to receive maximum irradiation. The orientation of modules has been kept south-facing or aligned with the building orientation.

(4) Shadow Analysis and Inter-row spacing: Shadow analysis has been conducted for any object or construction part on the roof or near the building that can potentially cast a shadow on PV arrays, considering the longest shadow on 21st December (sun time 9:30 am and 3:30 pm). Based on this approach, inter-row spacing has been considered.

(5) Frame size: A module mounting structure can hold one or many PV modules. A group of modules attached to one such structure is called a Frame. A single module frame size (1 x 1) has been considered to keep the frame size flexible.

(6) Provision for maintenance: PV arrays have been arranged/placed so that there is adequate clearance for maintenance personnel to move without stepping on the modules for cleaning and other maintenance work.

(7) Module Spacing: A 25 mm spacing gap will be considered between adjacent modules for natural airflow and attachment of mid-clamps for fixing the module to stricture.

(8) Edge clearance for slant roof: Edge clearance has been considered to minimise wind impact on the structure.

The following pages present a summary of the site survey findings, plant design and 3-D layout, project capacity, estimated energy generation, and estimated greenhouse gas reduction.

SITE 1: SUPREMO TRIBUNAL DE JUSTIÇA

Building No.	Building No. 1	Building No. 2
District	Agua Grande district	Agua Grande district
Geo. co-ordinates	0.339346, 6.735500	0.339779, 6.733508
No. of buildings	1 (three parts attached)	1 (three parts attached)
Type of roof	Slant (15° tilt) (small part is flat)	Slant (15° tilt)
Roof materials	Tiles (wood structure)	Tiles (wood structure)
Roof orientation (Azimuth)	291°, 20°,110°,213°, 30°	167°, 347° (Refer design document)
Age of the roof	>15 years	>15 years (roof is new)
Usable roof area	491 m^2	715 m^2
Physical condition	Good	Good
Grid connection	Load: 20 kVA (3-phase)	Load: 25 kVA (3-phase)
Peak demand	20 kVA	25 kVA
Critical load	5 kVA (Office appliances, internet)	5 kVA (Office appliances, internet)
Estimated energy demand	49 MWh/year	65 MWh/year
Power outage	50- 60 hours per month	50- 60 hours per month
Backup power	No	25 kVA
PV capacity	42 kW_p	65 kW_p
Estimated generation	55 MWh/year (1st year)	84 MWh/year (1st year)
PV electricity consumed	35 MWh/year	47 MWh/year
PV electricity fed to grid	20 MWh/year	37 MWh/year
CO_2 emission reduction	815 tons (lifetime)	1253 tons (lifetime)
Additional requirement	50 kVA LT panel to be installed	75 kVA LT panel to be installed

Figure 12: Supremo Tribunal de Justiça (Building 1)

3-D image of PV Installation (View from South)

Figure 13: Supremo Tribunal de Justiça (Building 2)

3-D PV plant layout (View from South)

Figure 14: Site survey photos of Supremo Tribunal de Justiça (Building 2)

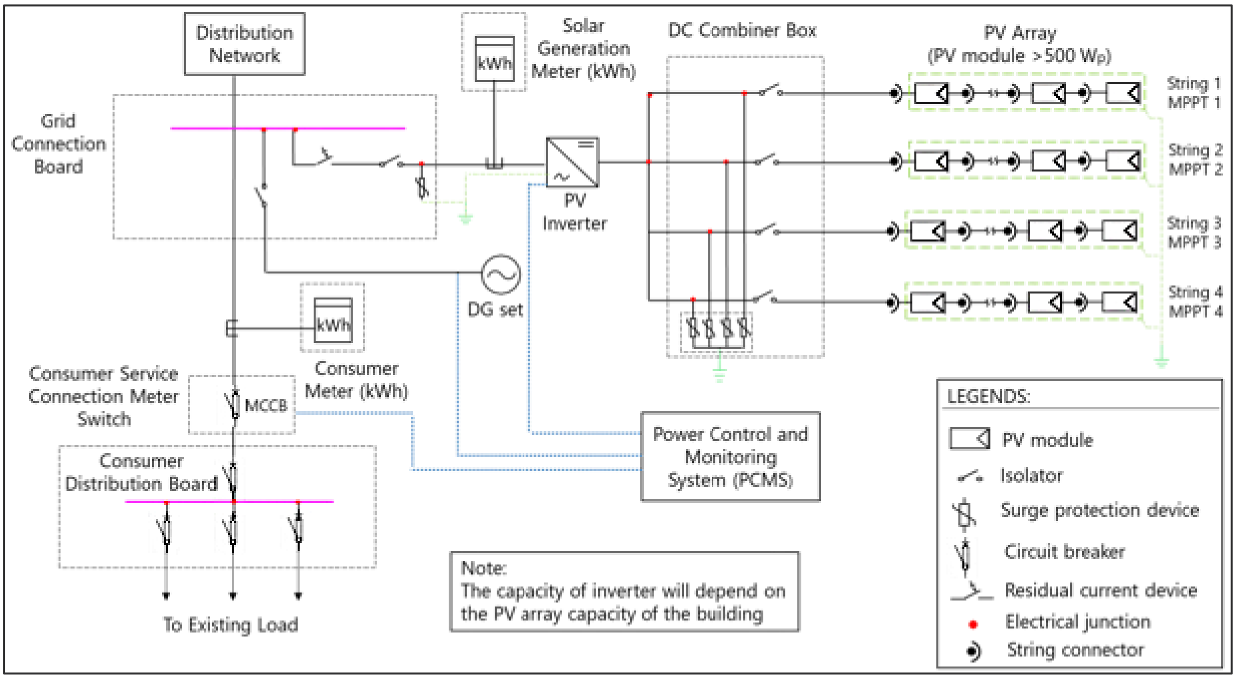


Figure 15: Single line diagram of rooftop PV system for Supremo Tribunal de Justiça (Building 2)

The single line diagram for the buildings of Supremo Tribunal de Justiça (Building 1) will be similar to Figure 15, only the diesel generator will not be present.

SITE 2: DIREÇÃO DO ENSINO PRIMÁRIO

District	Agua Grande district
Geo. co-ordinates	0.340270, 6.734672
No. of buildings	1
Type of roof	Flat
Roof materials	Concrete
Roof orientation (Azimuth)	152° (Refer design document)
Age of the roof	>30 years
Usable roof area	352 m^2
Physical condition	Good
Grid connection	Load ≈ 20 kVA (3-phase)
Peak demand	20 kVA
Estimated energy demand	52 MWh/year
Critical load	3 kVA (Office appliances, internet)
Power outage	50 - 60 hours per month
Backup power	25 kVA
PV capacity	32 kWp
Estimated generation	42 MWh/year (1st year)
PV electricity consumed	29 MWh/year
PV electricity fed to grid	13 MWh/year
CO_2 emission reduction	622 tons (lifetime)
Additional requirement	40 kVA LT panel to be installed for grid connection

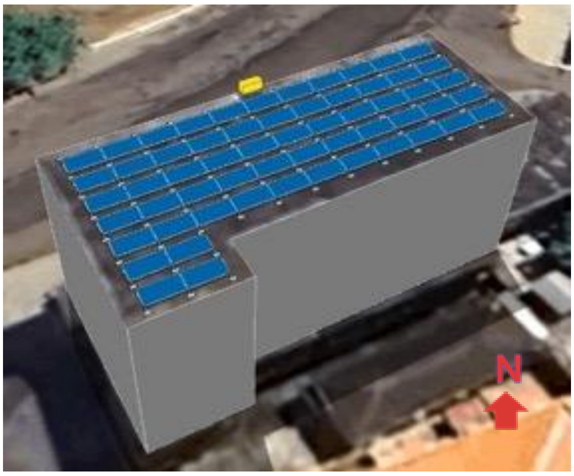


Figure 16: Direção do Ensino Primário

3-D PV plant layout (View from South)

Figure 17: Site survey photos of Direção do Ensino Primário

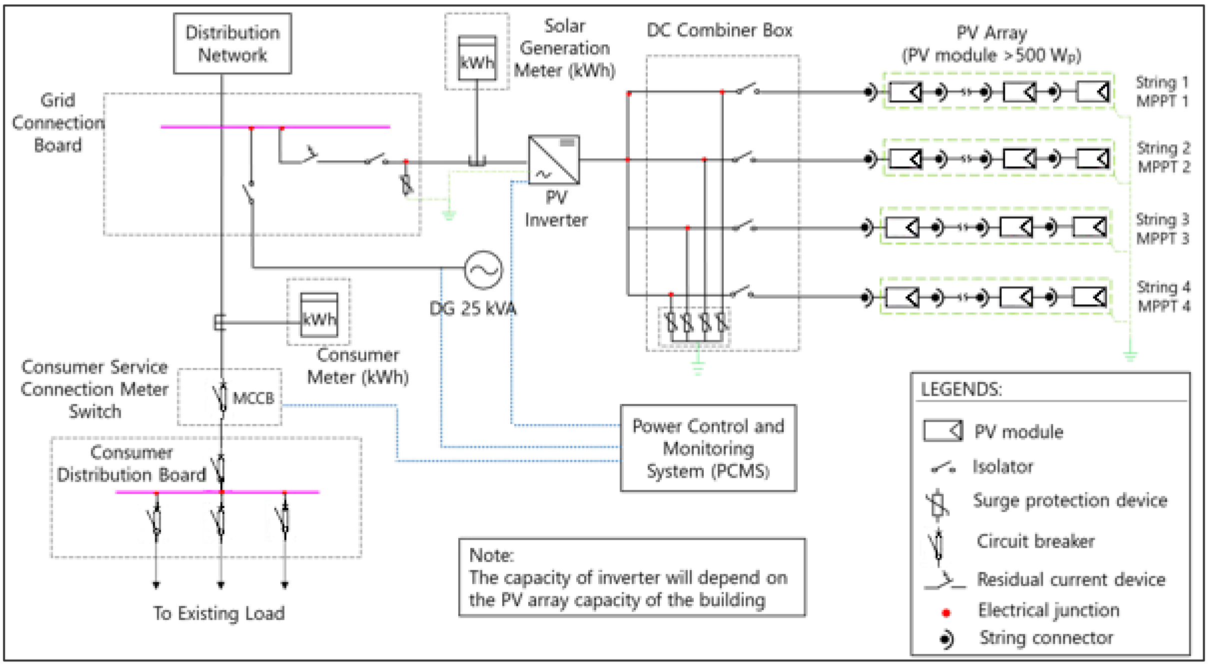


Figure 18: Single line diagram of rooftop PV system for Direção do Ensino Primário

SITE 3: PROCURADOR/MINISTÉRIO PUBLICO

District	Agua Grande
Geo. co-ordinates	0.340045, 6.734872
No. of buildings	2 (attached)
Type of roof	Slant (15 °)
Roof materials	Asbestos cement
Roof orientation (Azimuth)	159°, 339° (Refer design document)
Age of the roof	>15 years
Usable roof area	185 m^2
Physical condition	Good
Grid connection	15 kVA, 3-phase
Peak demand	15 kVA
Estimated energy demand	39 MWh/year
Critical load	3 kVA (office appliances, internet)
Power outage	50 - 60 hours per month
Backup power	Yes (20 kVA)
PV capacity	14 kWp
Estimated generation	19 MWh/year (1st year)
PV electricity consumed	14 MWh/year
PV electricity fed to grid	5 MWh/year
CO_2 emission reduction	275 tons (lifetime)
Additional requirement	None

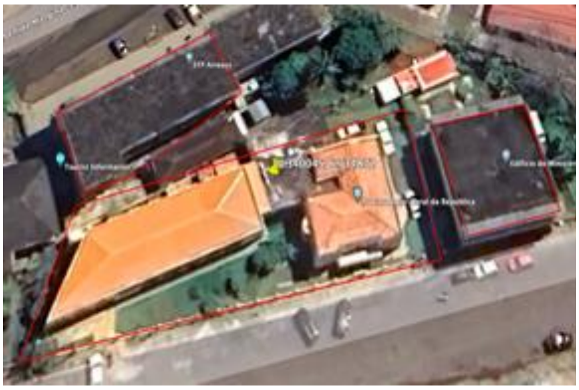
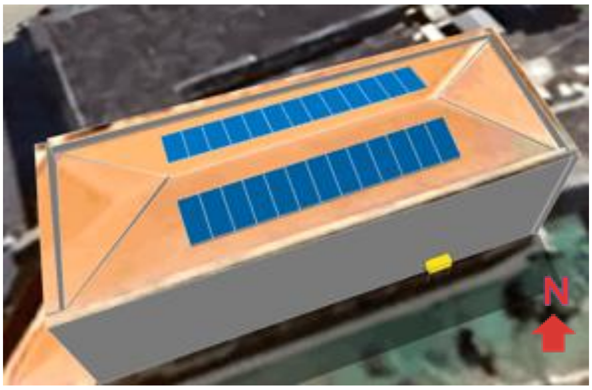


Figure 19: Procurador/Ministério Publico



3-D PV plant layout (View from South)

Figure 20: Site survey photos of Procurador/Ministério Publico

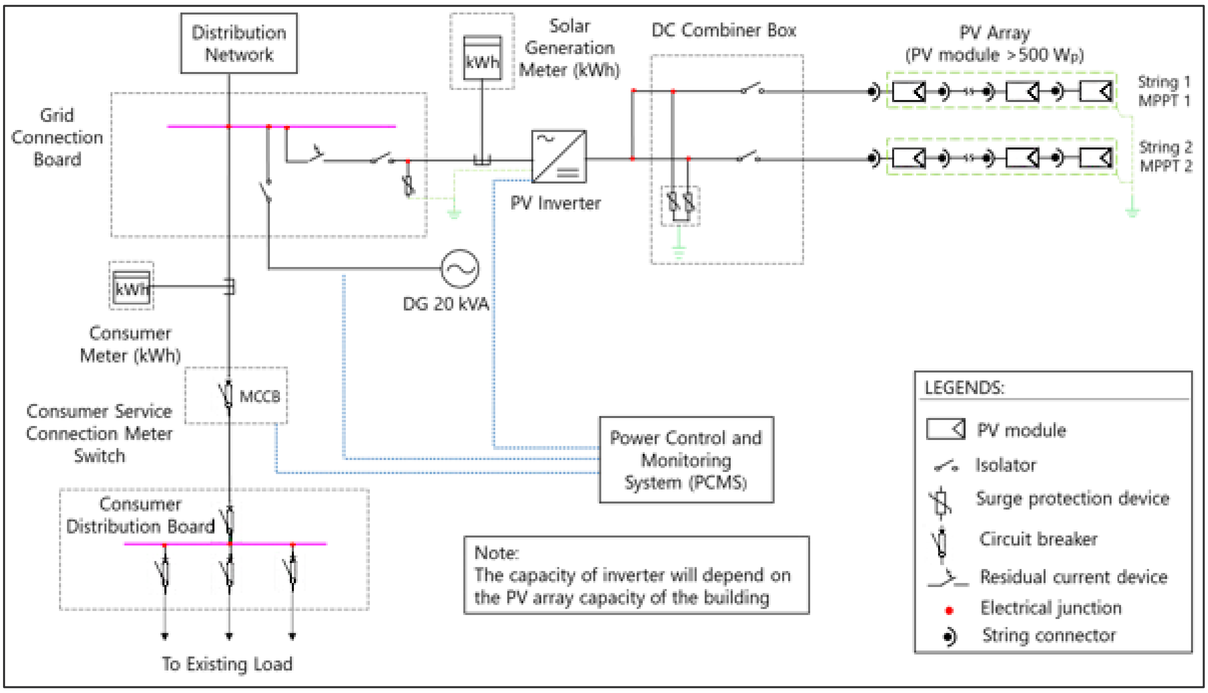


Figure 21: Single line diagram of rooftop PV system for Procurador/Ministério Publico

SITE 4: MINISTÉRIO DA DEFESA

District	Agua Grande
Geo. co-ordinates	0.344186, 6.736427
No. of buildings	6
Type of roof	1 building – flat 4 buildings – slant (15° tilt) 1 building - curved (12° curve)
Roof materials	RCC – 1 building Asbestos – 4 building CI sheet – 1 building
Roof orientation (Azimuth)	132°, 221° (Refer design document)
Age of the roof	>30 years
Usable roof area	1024 m^2
Physical condition	Not good
Grid connection	25 kVA, 3-phase
Peak demand	25 kVA
Estimated energy demand	65 MWh/year
Critical load	10 kVA (office appliances, communication system, internet)
Power outage	50- 60 hours per month
Backup power	Yes
PV capacity	86 kW_p
Estimated generation	111 MWh/year (1st year)
PV electricity consumed	49 MWh/year
PV electricity fed to grid	62 MWh/year
CO_2 emission reduction	1651 tons (lifetime)
Additional requirement	100 kVA LT panel to be installed for grid connection

Figure 22: Ministério Da Defesa

3-D PV plant layout (View from South)

Figure 23: Site survey photos of Ministério Da Defesa

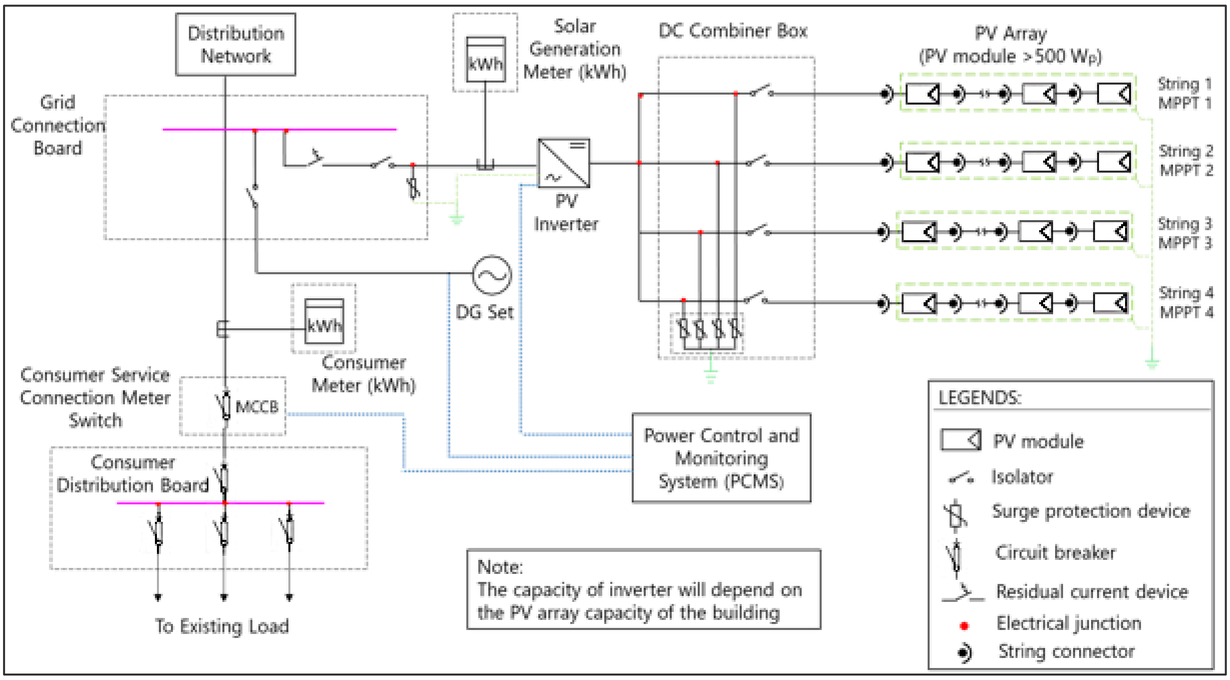


Figure 24: Single line diagram of rooftop PV system for Ministério Da Defesa

SITE 5: AUTORIDADE GERAL DE REGULACA (AGER)

District	Agua Grande
Geo. co-ordinates	0.343106, 6.736071
No. of buildings	1
Type of roof	Flat
Roof materials	RCC
Roof orientation (Azimuth)	204°, 205° (Refer design document)
Age of the roof	7-8 years
Usable roof area	200 m^2
Physical condition	Good
Grid connection	15 kVA, 3-phase
Peak demand	15 kVA
Estimated energy demand	39 MWh/year
Critical load	5 kVA (Office appliances, internet)
Power outage	50- 60 hours per month
Backup power	16 kVA
PV capacity	13 kWp
Estimated generation	17 MWh/year (1st year)
PV electricity consumed	12 MWh/year
PV electricity fed to grid	5 MWh/year
CO_2 emission reduction	257 tons (lifetime)
Additional requirement	None

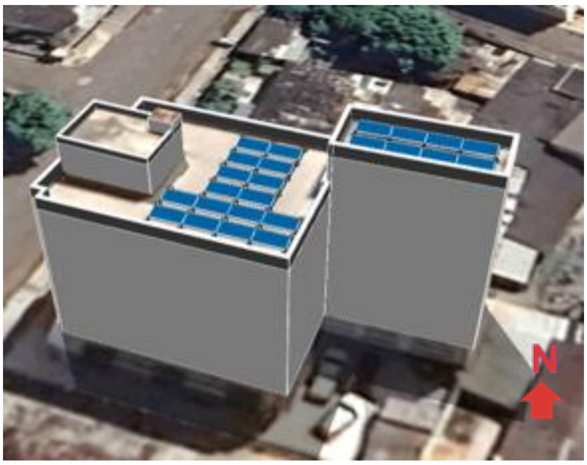


Figure 25: Autoridade Geral De Regulaca (AGER) 3-D PV plant layout (View from South)

Figure 26: Site survey photos of Autoridade Geral De Regulaca (AGER)

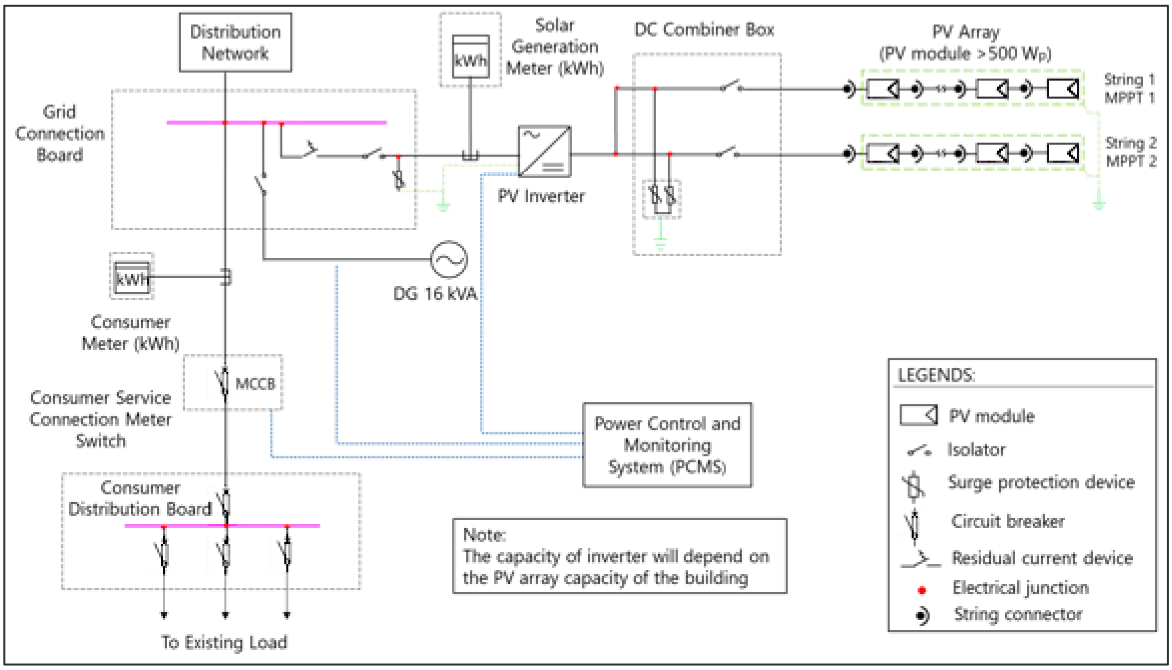


Figure 27: Single line diagram of rooftop PV system for Autoridade Geral De Regulaca (AGER)

SITE 6: HOSPITAL DR. AIRES DE MENEZES

District	Agua Grande
Geo. co-ordinates	0.356086, 6.722450
No. of buildings	18
Type of roof	Slant (16 buildings) and flat (2 building)
Roof materials	Asbestos (12 buildings) (12° tilt) Tiles (4 buildings) (12° tilt) RCC flat (2 building)
Roof orientation (Azimuth)	199°, 193° , 198°, 20°, 289°, 15° , 197° , 109° (Refer design document)
Age of the roof	10 to 40 years
Usable roof area	1898 m^2
Physical condition	Good
Grid connection	300 kVA
Peak demand	300 kVA
Estimated energy demand	1529 MWh/year
Critical load	100 kVA (Critical care equipment, refrigeration, communication)
Power outage	50- 60 hours per month
Backup power	500 kVA, 40 kVA
PV capacity	211 kW_p
Estimated generation	299 MWh/year (1st year)
PV electricity consumed	299 MWh/year
PV electricity fed to grid	0 MWh/year
CO_2 emission reduction	4440 tons (lifetime)
Additional requirement	None
Comments	• Most of the building roofs are made of asbestos and are more than 20 years old. • Two RCC buildings with flat roof and two newly constructed building with asbestos roof are considered for PV system installation.

Figure 28: Hospital Dr. Aires De Menezes   3-D PV plant layout (View from South)

Figure 29: Site survey photos of Hospital Dr. Aires De Menezes

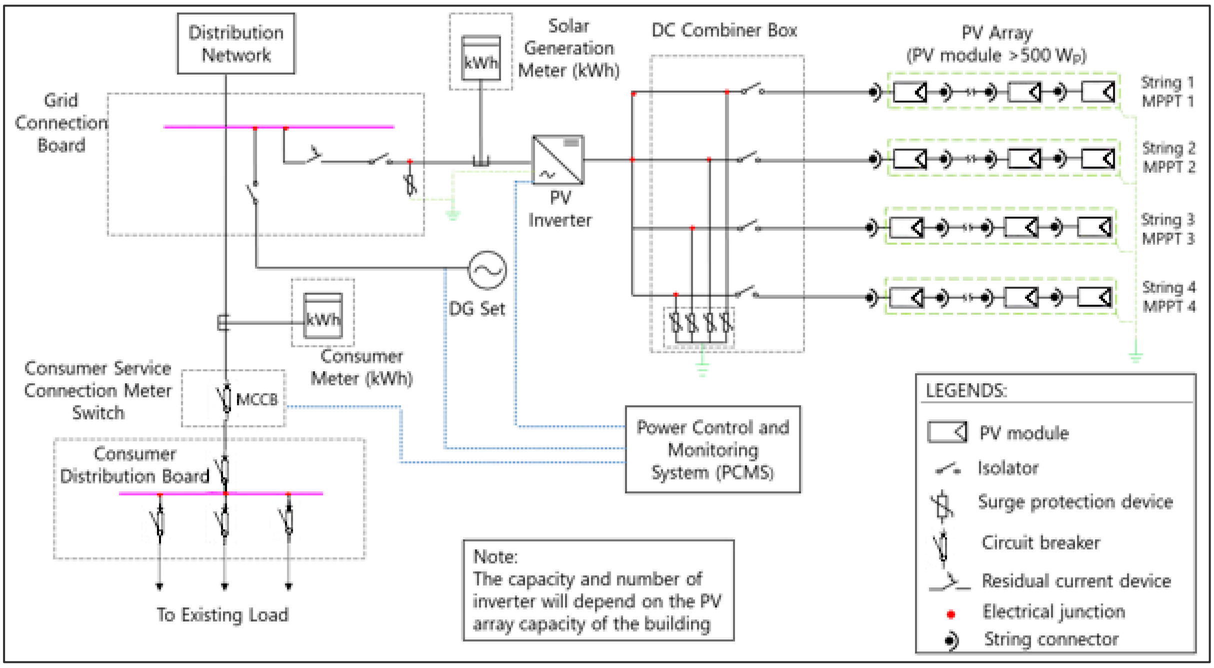
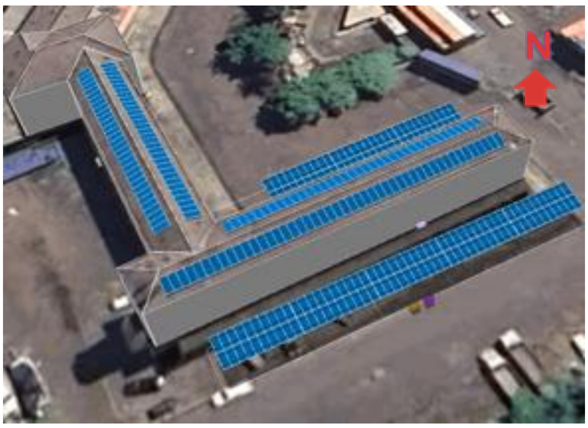


Figure 30: Single line diagram of rooftop PV system for Hospital Dr. Aires De Menezes

SITE 7: MINISTÉRIO DAS FINANÇAS E ECONOMIA AZUL

District	Agua Grande district
Geo. Co-ordinates	0.345784, 6.736942
No. of buildings	1
Type of roof	Slant (15° tilt)
Roof materials	Asbestos
Roof orientation (Azimuth)	160°, 70° ,251°, 340°,162° (Refer design document)
Age of the roof	>20 years
Usable roof area	1466 m^2
Physical condition	Good
Grid connection	Load: ≈ 50 kVA (3-phase)
Peak demand	50 kVA
Estimated energy demand	131 MWh/year
Critical load	10 kVA
Power outage	50- 60 hours per month
Backup power	2 x 50 kVA
PV capacity	169 kW_p
Estimated generation	218 MWh/year (1st year)
PV electricity consumed	97 kWh/year
PV electricity fed to grid	121 kWh/year
CO_2 emission reduction	3238 tons (lifetime)
Additional requirement	200 kVA LT panel to be installed for grid connection
Comments	• The main building roofs are made of asbestos and are more than 20 years old. • Carport PV can be installed on the south and north sides of the building.

Figure 31: Ministério Das Finanças E Economia Azul



3-D PV plant layout (View from South)

Figure 32: Site survey photos of Ministério Das Finanças E Economia Azul

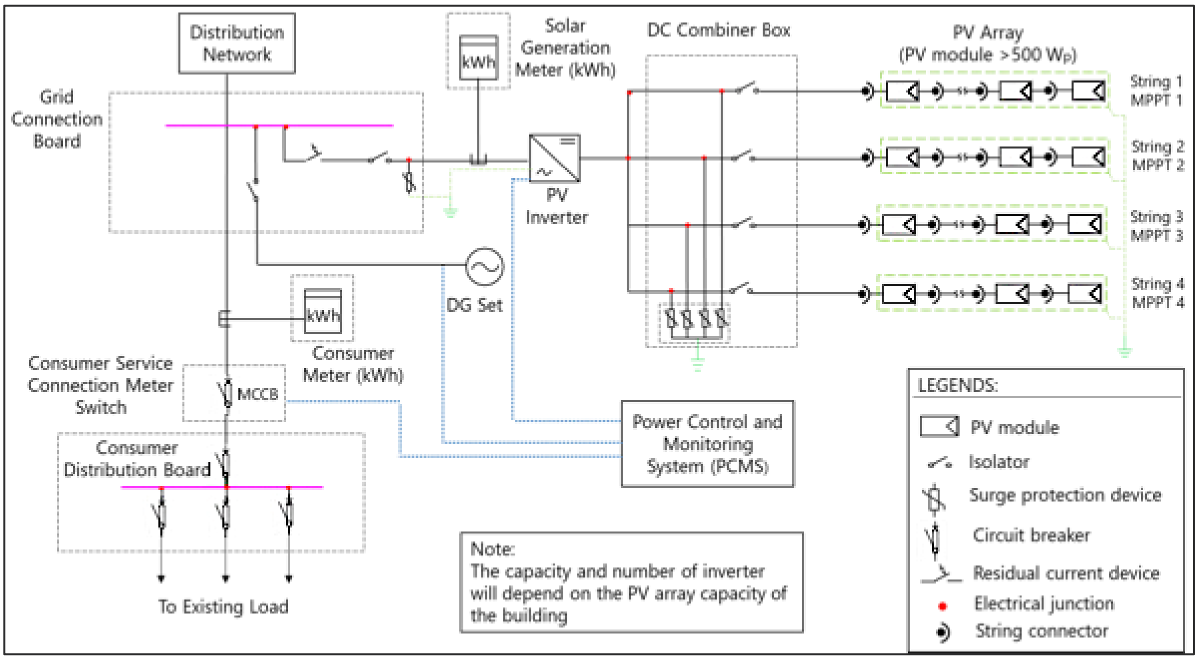


Figure 33: Single line diagram of rooftop PV system for Ministério Das Finanças E Economia Azul

SITE 8: LICEU NACIONAL

District	Agua Grande
Geo. Co-ordinates	0.339048, 6.739914
No. of buildings	Three buildings connected to each other
Type of roof	Flat
Roof materials	RCC
Roof orientation (Azimuth)	183°, 182° (Refer design document)
Age of the roof	About 15 years
Usable roof area	2918 m^2
Physical condition	Good
Grid connection	25 kVA, 3-phase
Peak demand	25 kVA
Estimated energy demand	523 MWh/year
Critical load	3 kVA (Computers, printers)
Power outage	50- 60 hours per month
Backup power	Yes (40 kVA)
PV capacity	272 kW_p
Estimated generation	358 MWh/year (1st year)
PV electricity consumed	46 MWh/year
PV electricity fed to grid	312 MWh/year
CO_2 emission reduction	5315 tons (lifetime)
Additional requirement	340 kVA LT panel to be installed for grid connection
Comments	• The buildings have the flat RCC roofs. • Grid-connection to be upgraded to install full PV capacity

Figure 34: Liceu Nacional

3-D PV plant layout (View from South)

Figure 35: Site survey photos of Liceu Nacional

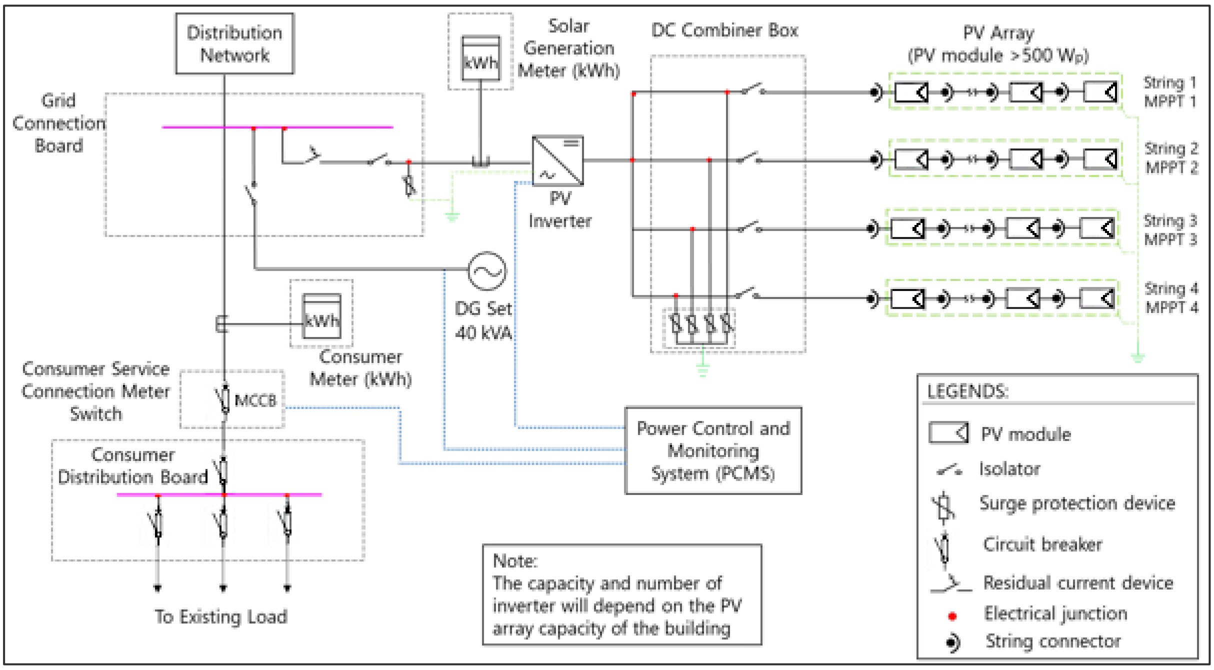


Figure 36: Single line diagram of rooftop PV system for Liceu Nacional

SITE 9: MINISTÉRIO DA EDUCAÇÃO

District	Agua Grande
Geo. co-ordinates	0.340066, 6.735176
No. of buildings	1
Type of roof	Flat
Roof materials	RCC
Roof orientation (Azimuth)	166° (Refer design document)
Age of the roof	>15 years
Usable roof area	247 m^2
Physical condition	Good
Grid connection	25 kVA, 3-phase
Peak demand	25 kVA
Estimated energy demand	65 MWh/year
Critical load	3 kVA (office appliances, internet)
Power outage	50- 60 hours per month
Backup power	40 kVA
PV capacity	23 kW_p
Estimated generation	30 MWh/year (1st year)
PV electricity consumed	21 MWh/year
PV electricity fed to grid	9 MWh/year
CO_2 emission reduction	445 tons (lifetime)
Additional requirement	None
Comments	Ballast type mounting structure is recommended.

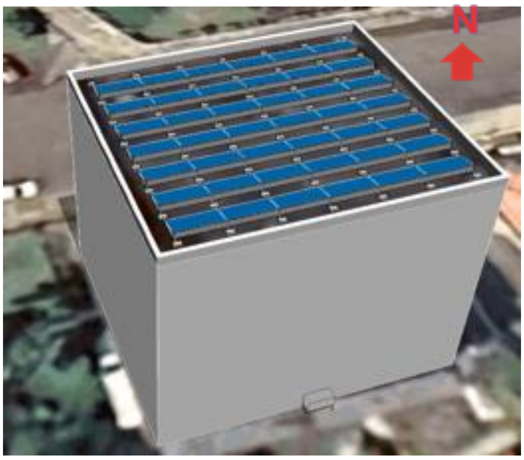


Figure 37: Ministério Da Educação 3-D PV plant layout (View from South)

Figure 38: Site survey photos of Ministério Da Educação

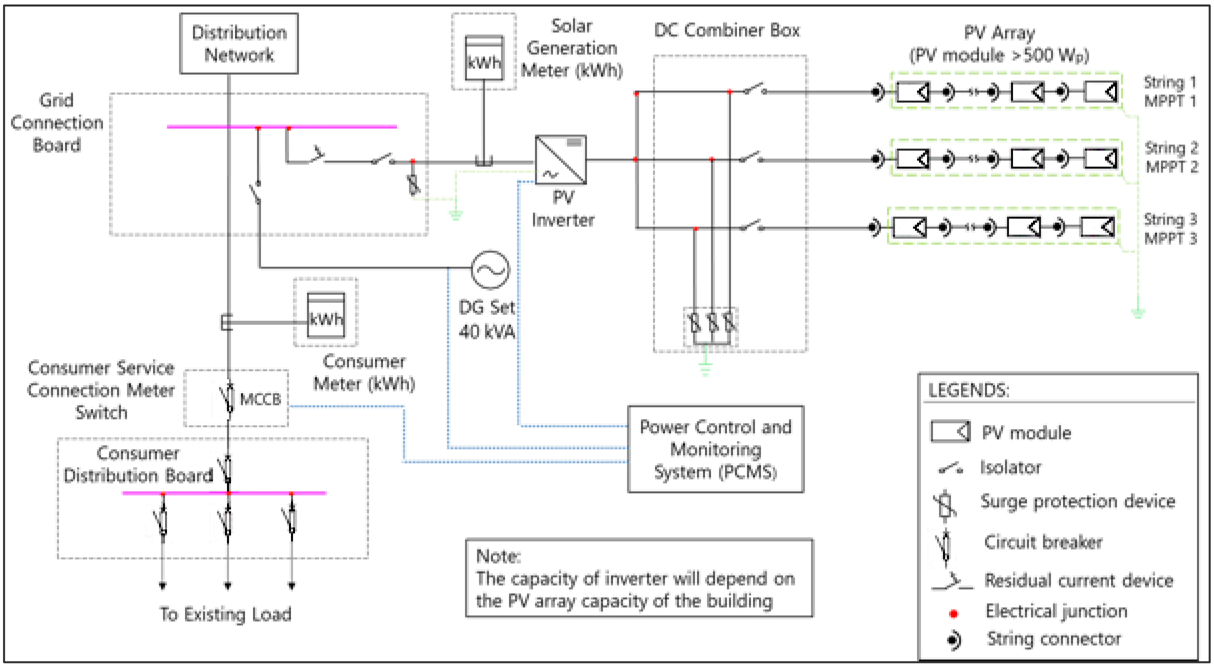


Figure 39: Single line diagram of rooftop PV system for Ministério Da Educação

SITE 10: TRIBUNAL DE CONTAS

District	Agua Grande
Geo. co-ordinates	0.340502, 6.735445
No. of buildings	1
Type of roof	Flat
Roof materials	RCC
Roof orientation (Azimuth)	198° (Refer design document)
Age of the roof	6 years (2018)
Usable roof area	500 m^2
Physical condition	Good
Grid connection	50 kVA
Peak demand	50 kVA
Estimated energy demand	131 MWh/year
Critical load	10 kVA (Office appliances, internet)
Power outage	50- 60 hours per month
Backup power	100 kVA
PV capacity	34 kW$_p$
BESS capacity	100 kWh
Estimated generation	44 MWh/year (1st year)
PV electricity consumed	44 MWh/year
PV electricity fed to grid	0 MWh/year
CO_2 emission reduction	656 tons (lifetime)
Additional requirement	None
Comments	Extended columns on the roof are to be considered to avoid shadow. Ballast mounting system is recommended.

Figure 40: Tribunal De Contas

3-D PV plant layout (View from South)

Figure 41: Site survey photos of Tribunal De Contas (with the existing PV system on the site)

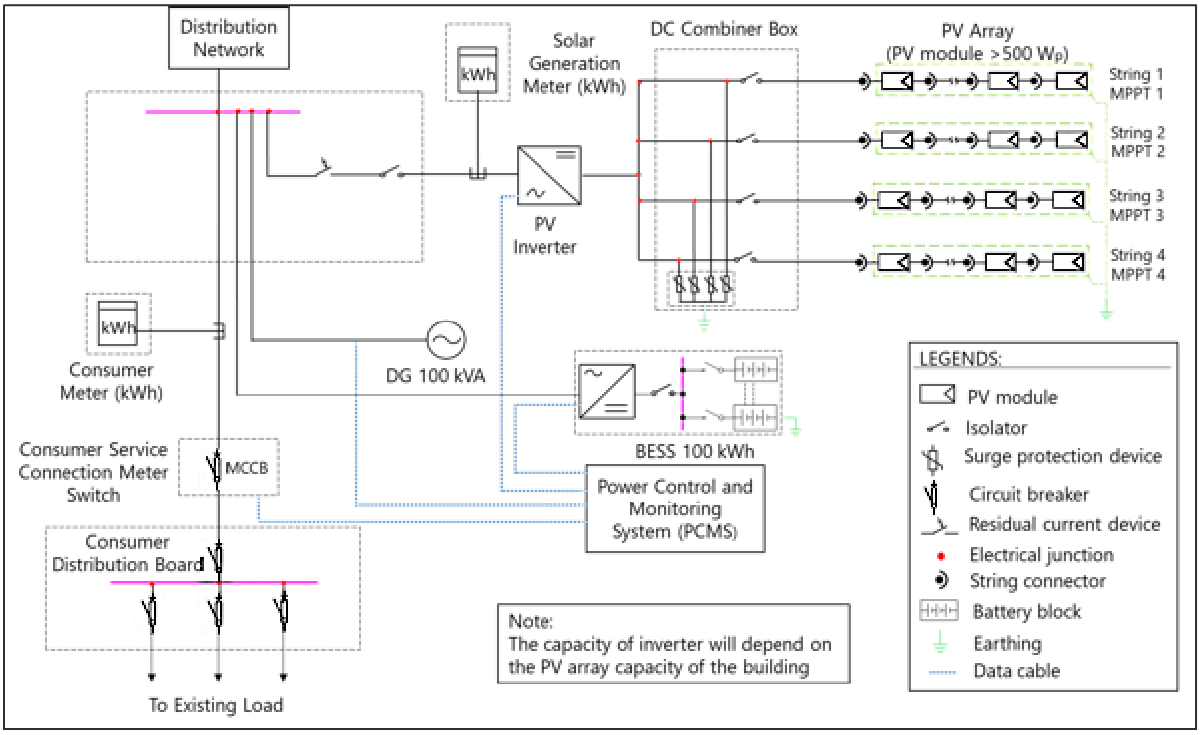


Figure 42: Single line diagram of rooftop PV system for Tribunal De Contas

SITE 11: LICEU NACIONAL DE SANTANA

District	Cantagalo
Geo. co-ordinates	0.263781, 6.743511
No. of buildings	1 (L shaped)
Type of roof	Flat
Roof materials	RCC
Roof orientation (Azimuth)	130°, 129° (Refer design document)
Age of the roof	35 years
Usable roof area	903 m^2
Physical condition	Poor
Grid connection	25 kVA
Peak demand	25 kVA
Estimated energy demand	52 MWh/year
Critical load	3 kVA (Computers, printers)
Power outage	50- 60 hours per month
Backup power	No
PV capacity	93 kW_p
Estimated generation	117 MWh/year (1st year)
PV electricity consumed	46 MWh/year
PV electricity fed to grid	71 MWh/year
CO_2 emission reduction	1739 tons (lifetime)
Additional requirement	110 kVA LT panel to be installed for grid connection
Comments	• Roof penetration to be avoided • Ballast mounting system is recommended.

Figure 43: Liceu Nacional De Santana

3-D PV plant layout (View from South)

Figure 44: Site survey photos of Liceu Nacional De Santana

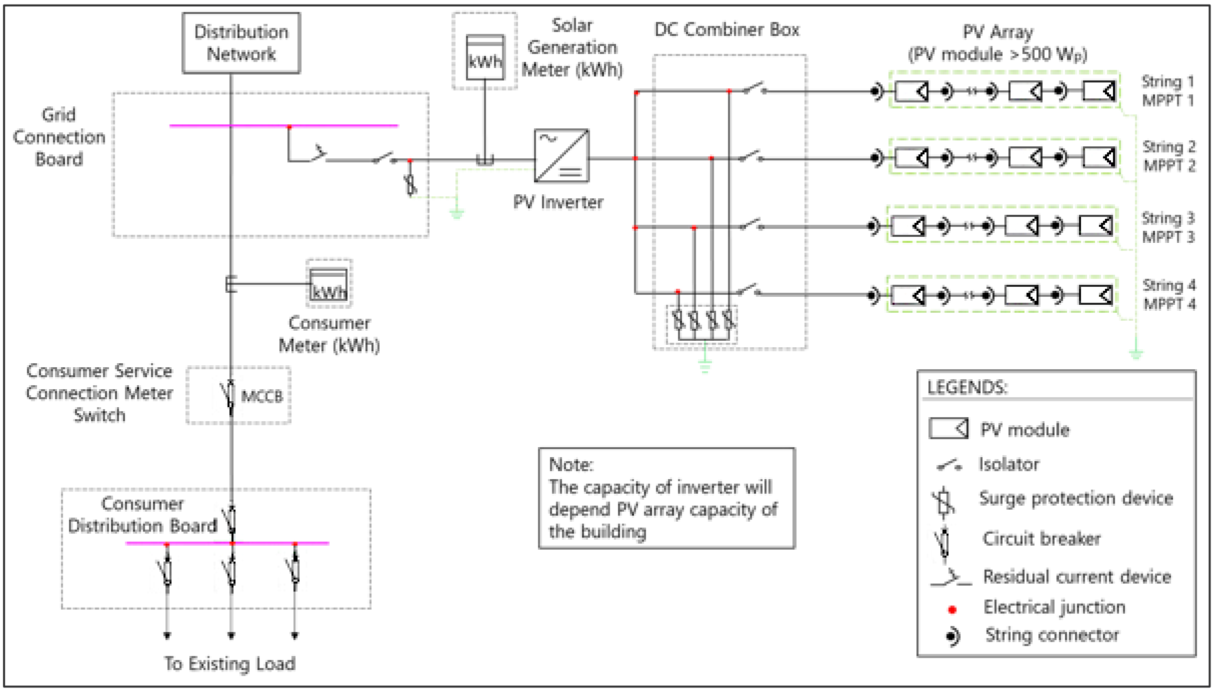


Figure 45: Single line diagram of rooftop PV system for Liceu Nacional De Santana

SITE 12: CENTRO POLIVALENTE DE CAUÉ

District	Caué district
Geo. co-ordinates	0.133876, 6.648637
No. of buildings	3
Type of roof	Building 1 & 2: Slant (20°) Building 3: flat
Roof materials	Building 1: Tiles Building 2: Lysaght trapezoidal sheets Building 3: RCC
Roof orientation (Azimuth)	360°, 87° ,267°, 178°,177° (Refer design document)
Age of the roof	Building 1: >20 years Building 2: about 10 years Building 3: >15 years
Usable roof area	746 m^2
Physical condition	The roof of building 1 is old. Not recommended for installation
Grid connection	Building 1: 3 kVA, 3 phase Building 2: 3 kVA, 3 phase Building 3: 25 kVA, 3 phase
Peak demand	Building 1: 3 kVA, building 2: 3 kVA, Building 3: 25 kVA
Estimated energy demand	81 MWh/year
Critical load	Building 3: 5 kVA (Computers, printers)
Backup power	None
PV capacity	73 kW_p
Estimated generation	104 MWh/year (1st year)
PV electricity consumed	58 MWh/year
PV electricity fed to grid	46 MWh/year
CO_2 emission reduction	1543 tons (lifetime)
Additional requirement	100 kVA LT panel to be installed for grid connection
Comments	Building 1: Old building with tile roof considered not suitable for PV installation

Figure 46: Centro Polivalente De Caué

3-D PV plant layout (View from South)

Figure 47: Site survey photos of Centro Polivalente De Caué

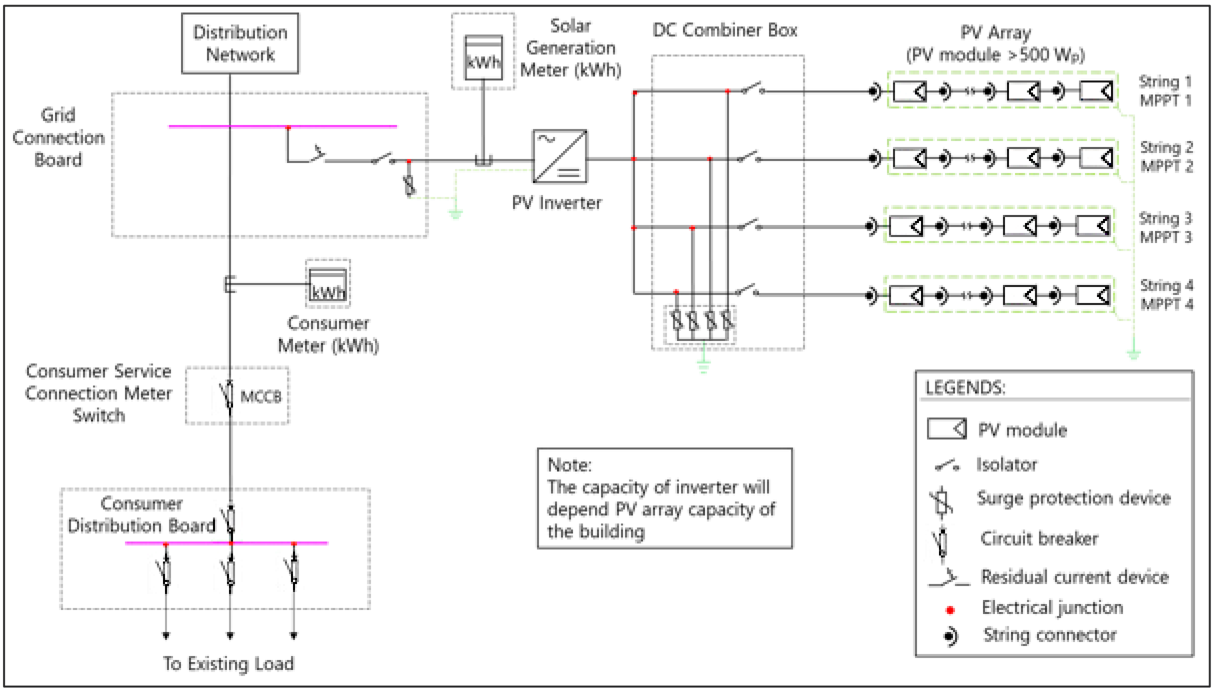
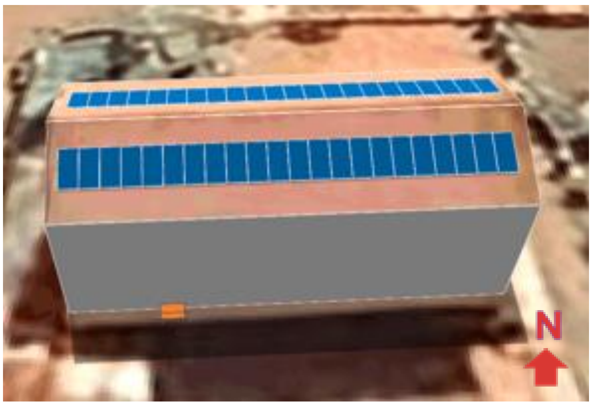


Figure 48: Single line diagram of rooftop PV system for Centro Polivalente De Caué

SITE 13: ESCOLA SECUNDARIA DE SÃO JOÃO DOS ANGOLARES

District	Caué
Geo. co-ordinates	0.133062, 6.648472
No. of buildings	1
Type of roof	Slant (20º)
Roof materials	Tiles
Roof orientation (Azimuth)	175º, 355º (Refer design document)
Age of the roof	Built in 1962
Usable roof area	314 m^2
Physical condition	Condition of tiles are not good, condition of the structure is good
Grid connection	5 kVA, three phase
Peak demand	5 kVA
Estimated energy demand	10 MWh/year
Critical load	1 kVA (Computers, printers)
Power outage	50- 60 hours per month
Backup power	No
PV capacity	24 kW_p
Estimated generation	31 MWh/year (1st year)
PV electricity consumed	9 MWh/year
PV electricity fed to grid	22 MWh/year
CO_2 emission reduction	455 tons (lifetime)
Additional requirement	30 kVA LT panel to be installed for grid connection
Comments	Some tiles may be required to be replaced for PV installation.

Figure 49: Escola Secundaria De São João Dos Angolares



3-D PV plant layout (View from South)

Figure 50: Site survey photo of Escola Secundaria De São João Dos Angolares

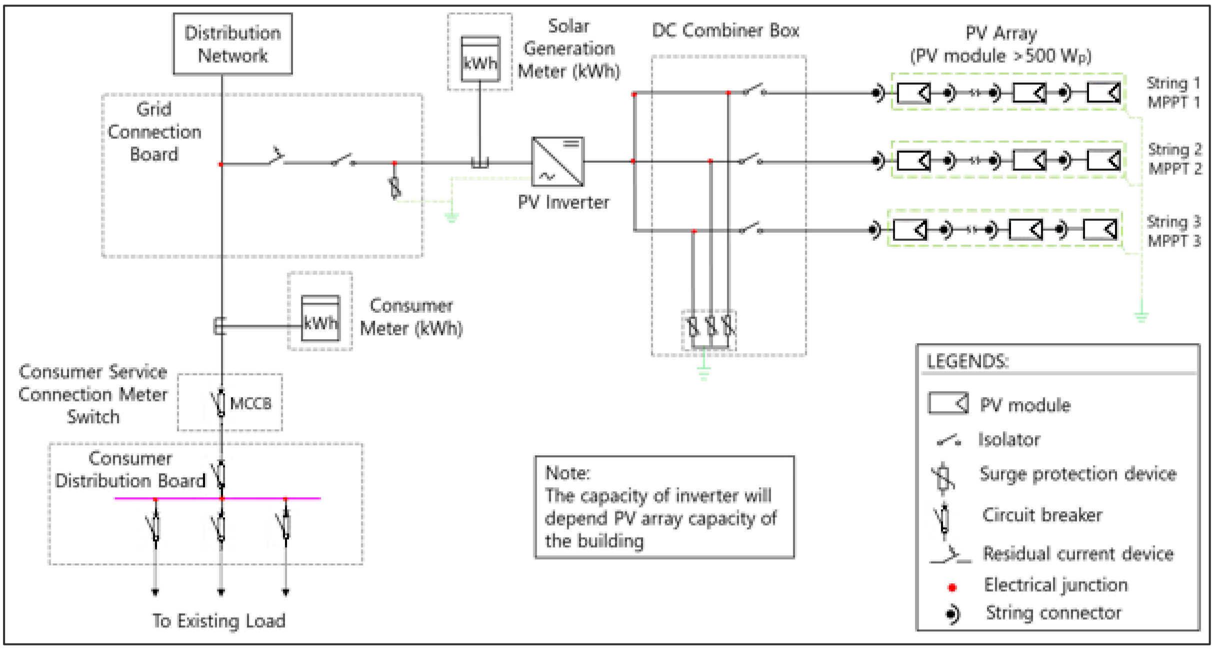
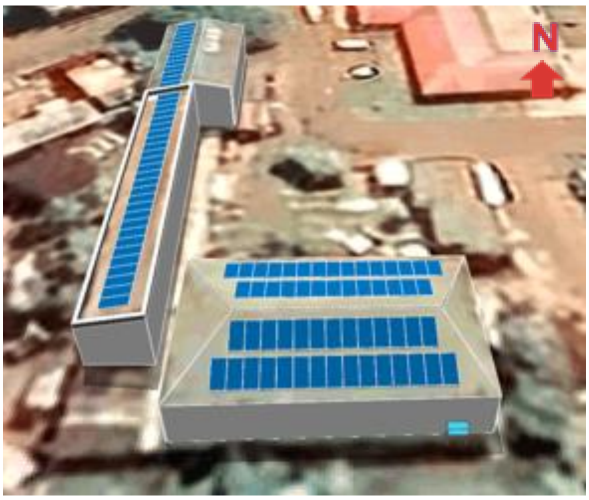


Figure 51: Single line diagram of rooftop PV system for Escola Secundaria De São João Dos Angolares

SITE 14: POSTO DE SAÚDE

District	Caué
Geo. co-ordinates	0.133114, 6.648135
No. of buildings	3
Type of roof	slant (14°)
Roof materials	Metal (Lysaght trapezoidal sheets)
Roof orientation (Azimuth)	178°, 359°, 269° (Refer design document)
Age of the roof	>30 years
Usable roof area	516 m^2
Physical condition	Not Good
Grid connection	15 kVA
Peak demand	15 kVA
Estimated energy demand	76 MWh/year
Critical load	3 kVA (Critical care equipment, refrigeration, lights)
Power outage	50- 60 hours per month
Backup power	20 kVA
PV capacity	53 kW_p
Estimated generation	74 MWh/year (1st year)
PV electricity consumed	45 MWh/year
PV electricity fed to grid	29 MWh/year
CO_2 emission reduction	1097 tons (lifetime)
Additional requirement	65 kVA LT panel to be installed for grid connection

Figure 52: Posto De Saúde



3-D PV plant layout (View from South)

Figure 53: Site survey photo of Posto De Saúde

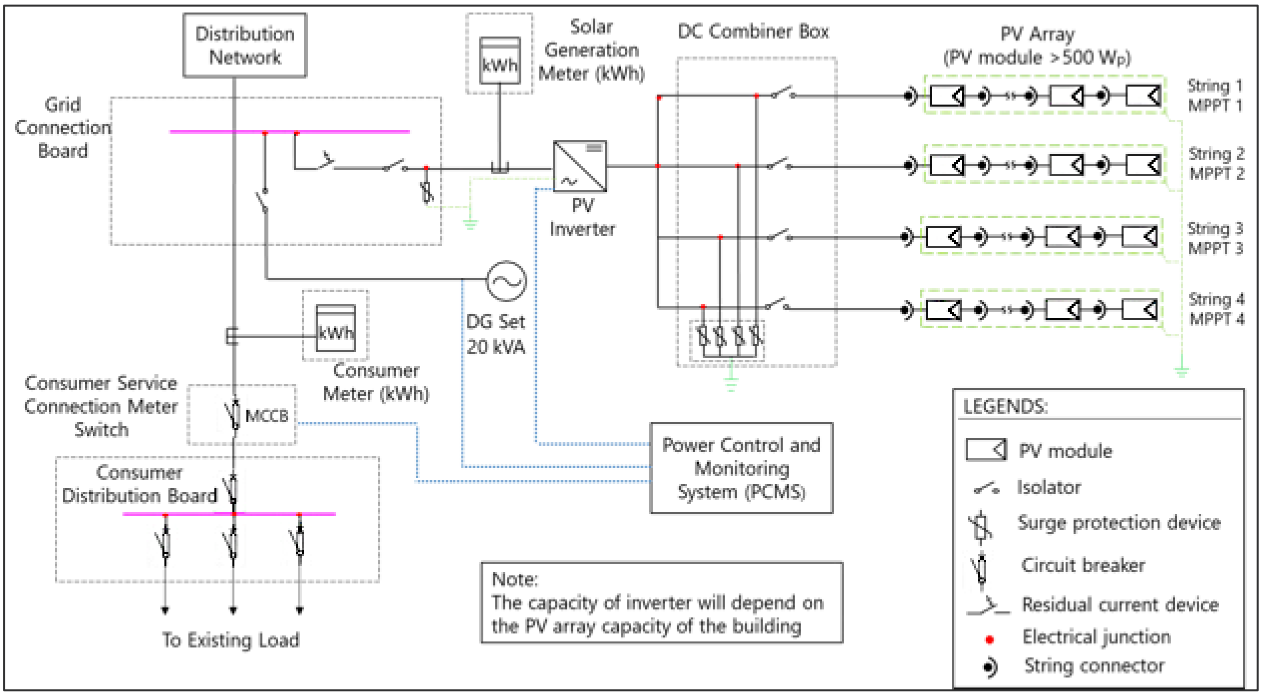


Figure 54: Single line diagram of rooftop PV system Posto De Saúde

SITE 15: MERCADO DE BOBO FORO

District	Mé Zochi
Geo. Co-ordinates	0.324577, 6.705579
No. of buildings	8
Type of roof	Slant (10°)
Roof materials	Lysaght trapezoidal sheets
Roof orientation (Azimuth)	113°, 112° ,292° (Refer design document)
Age of the roof	6-7 years
Usable roof area	10252 m^2
Physical condition	Good
Grid connection	100 kVA
Peak demand	100 kVA
Estimated energy demand	375 MWh/year
Critical load	10 kVA (water pump, refrigeration)
Power outage	50- 60 hours per month
Backup power	No
PV capacity	937 kW_p
Estimated generation	1318 MWh/year (1st year)
PV electricity consumed	310 MWh/year
PV electricity fed to grid	1008 MWh/year
CO_2 emission reduction	19547 metric tons
Additional requirement	Power can be evacuated at 6 kV nearest substation using a 1 MVA, 0.4/6 kV transformer and LT panel with switchyard at site and drawing transmission line to the substation
Comments	• The roof of the East side main building is affected by shadows from trees which can be trimmed. • Complete PV capacity cannot be connected to grid at site

Figure 55: Mercado De Bobo Foro

3-D PV plant layout (View from South)

Figure 56: Site survey photos of Mercado De Bobo Foro

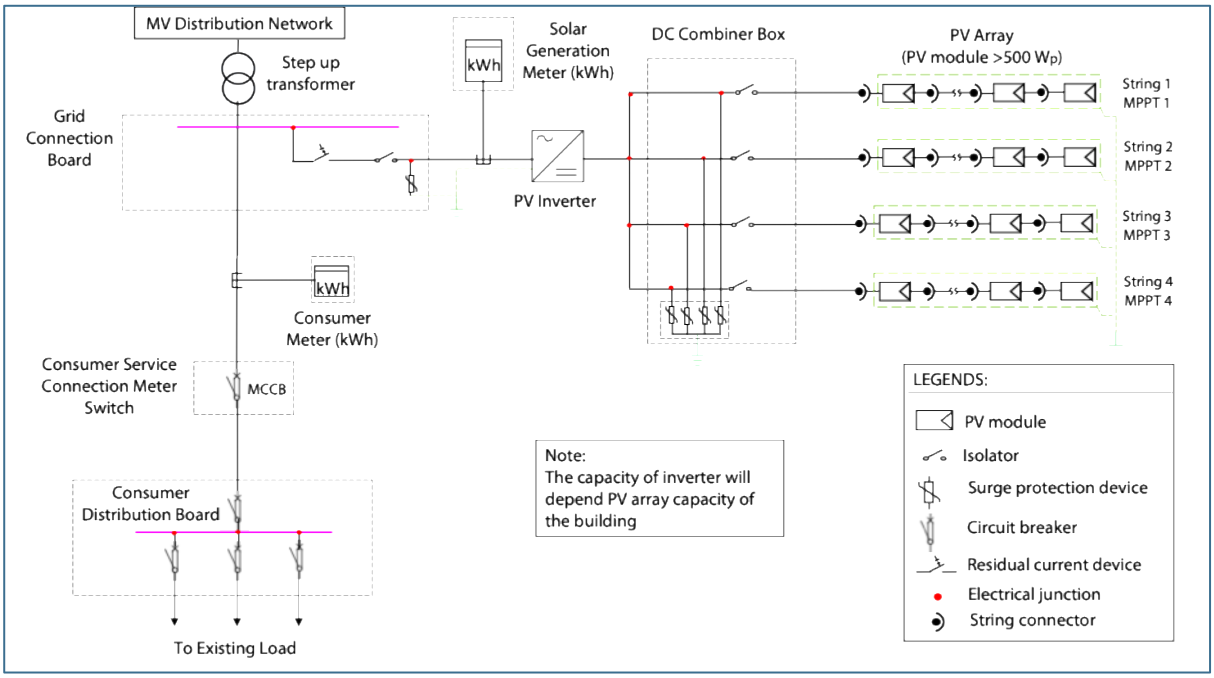


Figure 57: Single line diagram of rooftop PV system for Mercado De Bobo Foro

SITE 16: ESCOLA SECUNDARIA MARIA MANUELA MARGARIDO (MMM)

District	Mé Zochi district
Geo. co-ordinates	0.295383, 6.668566
No. of buildings	3 buildings
Type of roof	Slant (7°)
Roof materials	Lysaght trapezoidal sheets (Metal)
Roof orientation (Azimuth)	185°, 5°, 184°, 4° (Refer design document)
Age of the roof	12 years
Usable roof area	2044 m^2
Physical condition	Good
Grid connection	Load: 150 kVA (3-phase)
Peak demand	150 kVA
Estimated energy demand	314 MWh/year
Critical load	5 kVA (Computers, printers, internet)
Power outage	50- 60 hours per month
Backup power	DG set: 150 kVA
PV capacity	208 kW_p
Estimated generation	270 MWh/year (1st year)
PV electricity consumed	184 MWh/year
PV electricity fed to grid	86 MWh/year
CO_2 emission reduction	4005 tons (lifetime)
Additional requirement	250 kVA LT panel to be installed for grid connection

Figure 58: Escola Secundaria Maria Manuela Margarido

3-D PV plant layout (View from South)

Figure 59: Site survey photos of Escola Secundaria Maria Manuela Margarido

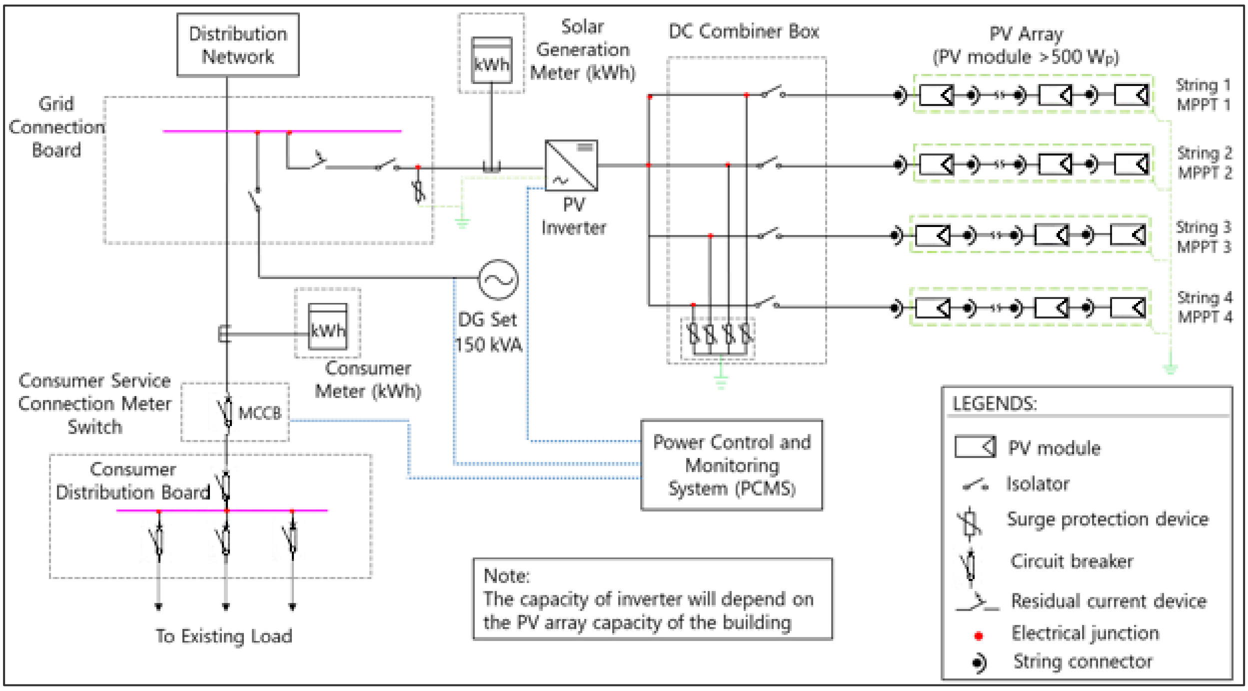


Figure 60: Single line diagram of rooftop PV system for Escola Secundaria Maria Manuela Margarido

SITE 17: ESCOLA PRIMÁRIA DE TRINDADE

District	Mé Zochi
Geo. co-ordinates	0.296825, 6.680038
No. of buildings	2 major buildings, 2 smaller buildings
Type of roof	Slant (15°)
Roof materials	Tiles and metal
Roof orientation (Azimuth)	12°, 191°, 192°, 281°, 99°, 280° (Refer design document)
Age of the roof	>15 years
Usable roof area	1215 m^2
Physical condition	Good
Grid connection	25 kVA
Peak demand	25 kVA
Estimated energy demand	52 MWh/year
Critical load	3 kVA (Computers, printers)
Power outage	50- 60 hours per month
Backup power	No
PV capacity	132 kW_p
Estimated generation	172 MWh/year (1st year)
PV electricity consumed	46 MWh/year
PV electricity fed to grid	126 MWh/year
CO_2 emission reduction	2558 tons (lifetime)
Additional requirement	150 kVA LT panel to be installed for grid connection

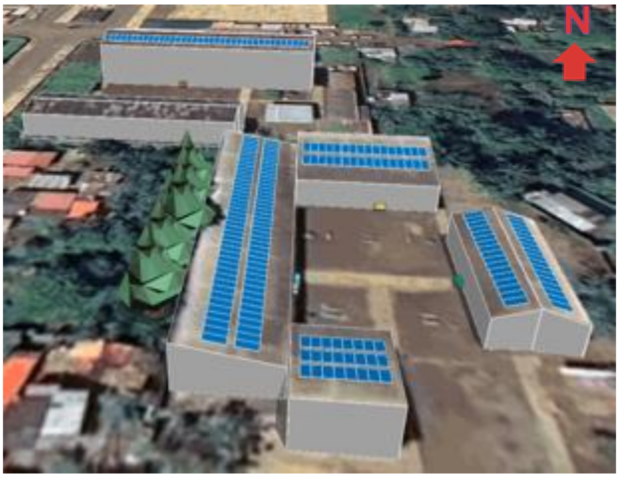


Figure 61: Escola Primária De Trindade 3-D PV plant layout (View from South)

Figure 62: Site survey photos of Escola Primária De Trindade

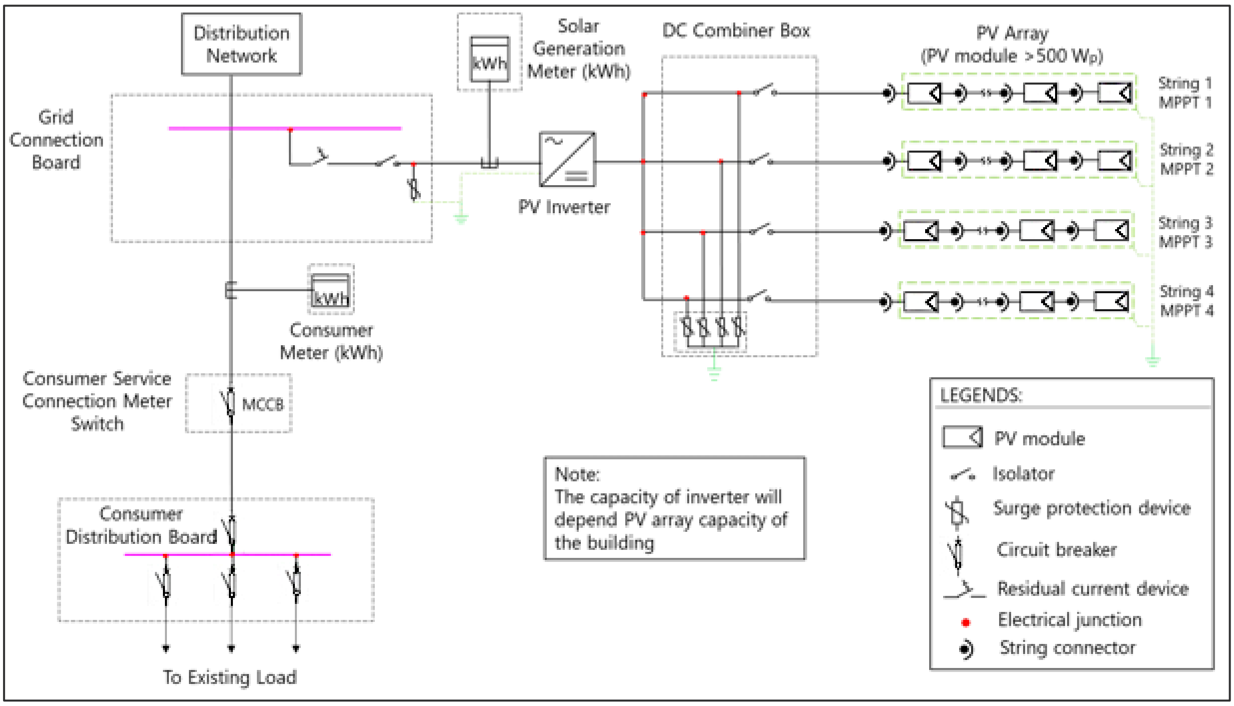
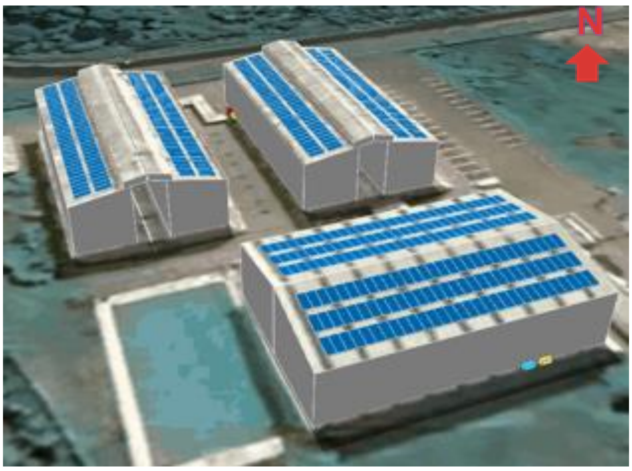


Figure 63: Single line diagram of rooftop PV system for Escola Primária De Trindade

SITE 18: LICEU MÉ CHINHÔ (SCHOOL)

District	Lobata
Geo. co-ordinates	0.375658, 6.650231
No. of buildings	3
Type of roof	Slant (10°)
Roof materials	Metal
Roof orientation (Azimuth)	252°, 72° ,161°, 341° (Refer design document)
Age of the roof	4-5 years
Usable roof area	2094 m^2
Physical condition	Good
Grid connection	Load: 150 kVA (3-phase)
Peak demand	150 kVA
Estimated energy demand	314 MWh/year
Critical load	10 kVA (Computers, printers, internet)
Power outage	50- 60 hours per month
Backup power	DG set: 150 kVA
PV capacity	249 kW_p
Estimated generation	321 MWh/year (1st year)
PV electricity consumed	216 MWh/year
PV electricity fed to grid	105 MWh/year
CO_2 emission reduction	4763 tons (lifetime)
Additional requirement	300 kVA LT panel to be installed for grid connection

Figure 64: Liceu Mé Chinhô (School)



3-D PV plant layout (View from South)

Figure 65: Site survey photos of Liceu Mé Chinhô

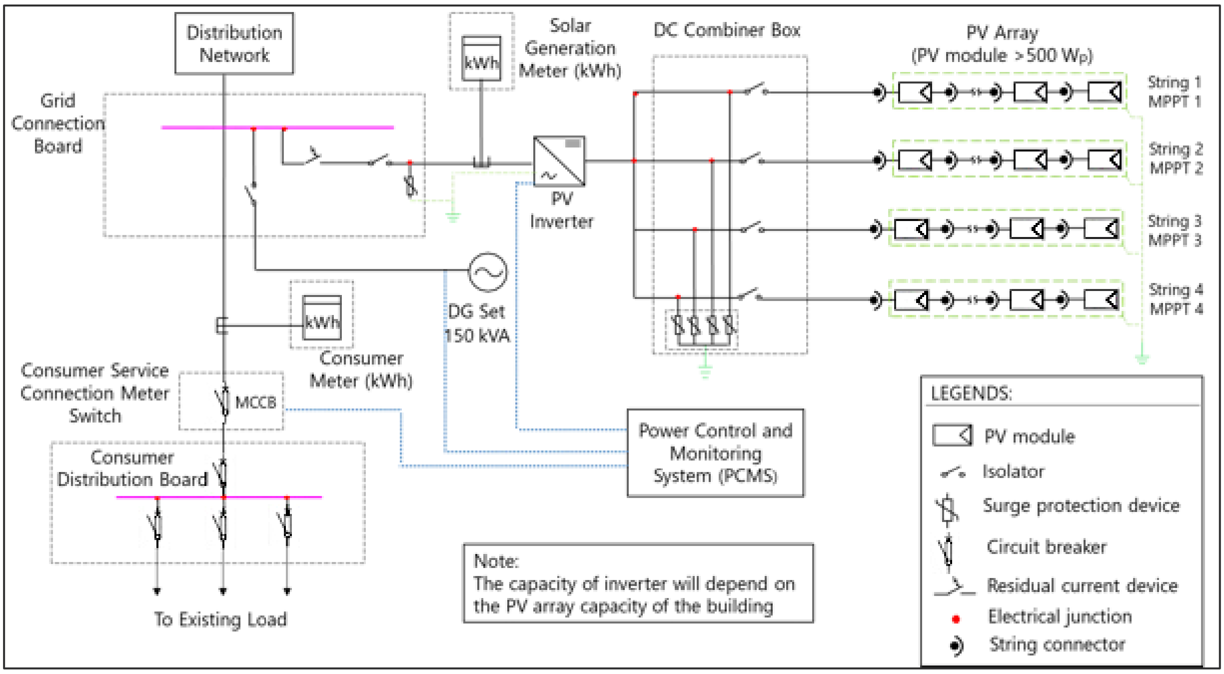


Figure 66: Single line diagram of rooftop PV system for Liceu Mé Chinhô

SITE 19: CENTRO HOSPITALAR DE LOBATA

District	Lobata
Geo. co-ordinates	0.378000, 6.636840
No. of buildings	One building in four different part
Type of roof	Three parts slant (10^{o})/ one small part flat
Roof materials	Three major parts – Asbestos; flat part RCC
Roof orientation (Azimuth)	166^{o} (Refer design document)
Age of the roof	>40 years
Usable roof area	77 m^2
Physical condition	Asbestos roofs are not in good condition
Grid connection	10 kVA
Peak demand	10 kVA
Estimated energy demand	51 MWh/year
Critical load	5 kVA (Critical care equipment, refrigerators)
Power outage	50- 60 hours per month
Backup power	15 kVA
PV capacity	8 kW_p
Estimated generation	11 MWh/year (1st year)
PV electricity consumed	11 MWh/year
PV electricity fed to grid	0 MWh/year
CO_2 emission reduction	162 tons (lifetime)
Additional requirement	None
Comments	• The building roofs are made of asbestos and old. It is not considered suitable for installation of PV modules. • The flat roof of the front building can be used to instal limited number of PV modules.

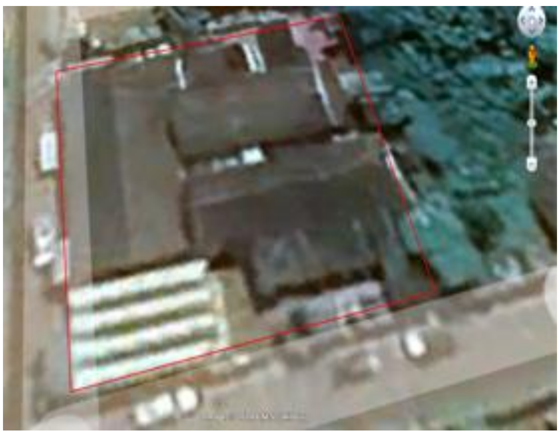
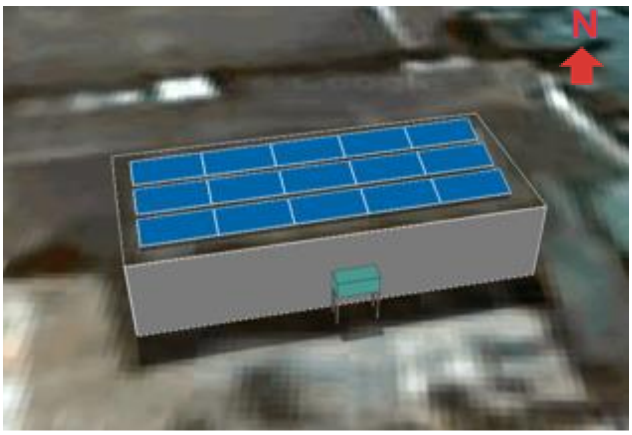


Figure 67: Centro Hospitalar De Lobata



3-D PV plant layout (View from South)

Figure 68: Site survey photos of Centro Hospitalar De Lobata

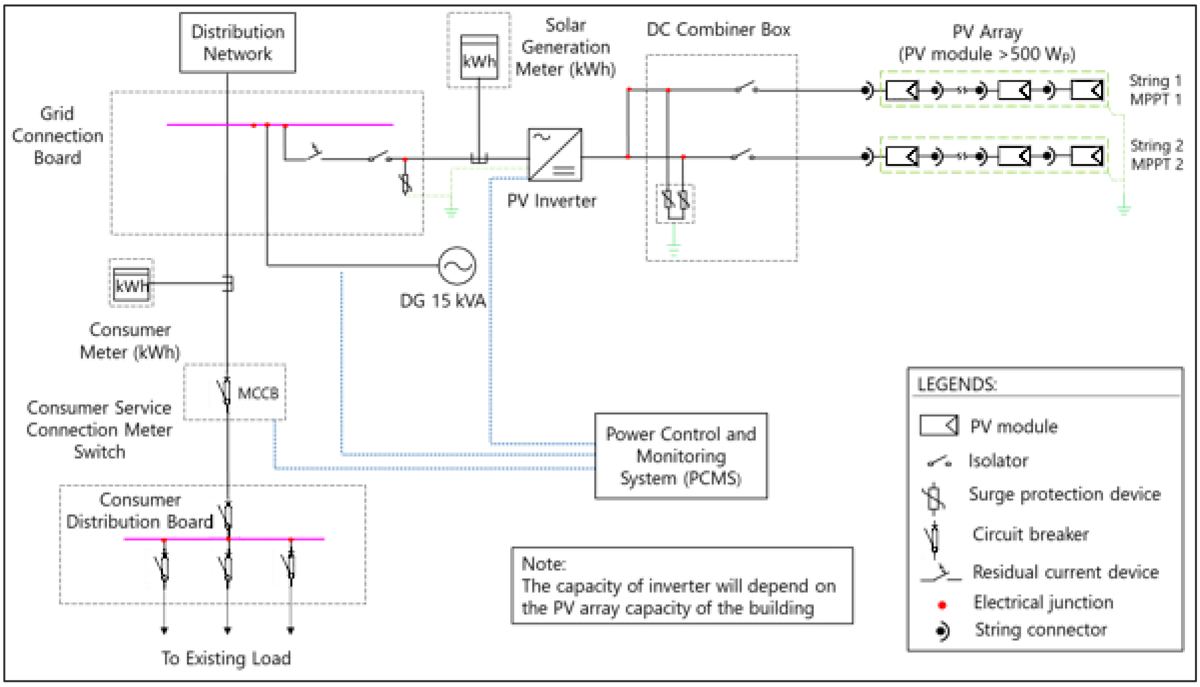
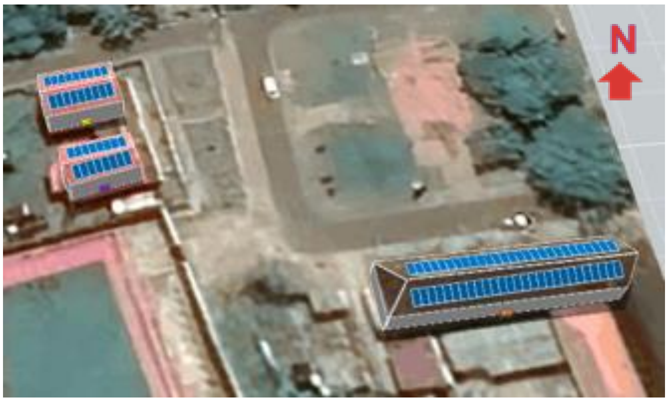


Figure 69: Single line diagram of rooftop PV system for Centro Hospitalar De Lobata

SITE 20: CAMARA DISTRITAL DE LOBATA

District	Lobata
Geo. co-ordinates	0.379155, 6.637134
No. of buildings	3 buildings
Type of roof	Slant (15° and 20°)
Roof materials	Building 1: Lysaght trapezoidal sheets (20° tilt) Building 2: Asbestos (15° tilt) Building 3: Tiles (15° tilt)
Roof orientation (Azimuth)	352°, 170° ,176°, 358°,167°, 350° (Refer design document)
Age of the roof	Building 1: 10-15 years Building 2: > 15 years Building 3: < 10 years
Usable roof area	466 m^2
Physical condition	Good
Grid connection	Building 1: 3 kVA, three phase Building 2: 3 kVA, three phase Building 3: 5 kVA, three phase
Peak demand	Building 1: 3 kVA, building 2: 3 kVA, building 3: 5 kVA
Estimated energy demand	29 MWh/year
Critical load	Building 1: 1 kVA (Office appliances, internet)
Power outage	50- 60 hours per month
Backup power	40 kVA
PV capacity	48 kW_p
Estimated generation	62 MWh/year (1st year)
PV electricity consumed	22 MWh/year
PV electricity fed to grid	40 MWh/year
CO_2 emission reduction	922 tons (lifetime)
Additional requirement	60 kVA LT panel to be installed for grid connection
Comments	• One building is not suitable for installation of PV system. • PV systems can be installed on the district office and in the market building. • Diesel generator is in the market complex and power is supplied to office buildings during power outages.

Figure 70: Camara Distrital De Lobata



3-D PV plant layout (View from South)

Figure 71: Site survey photos of Camara Distrital De Lobata

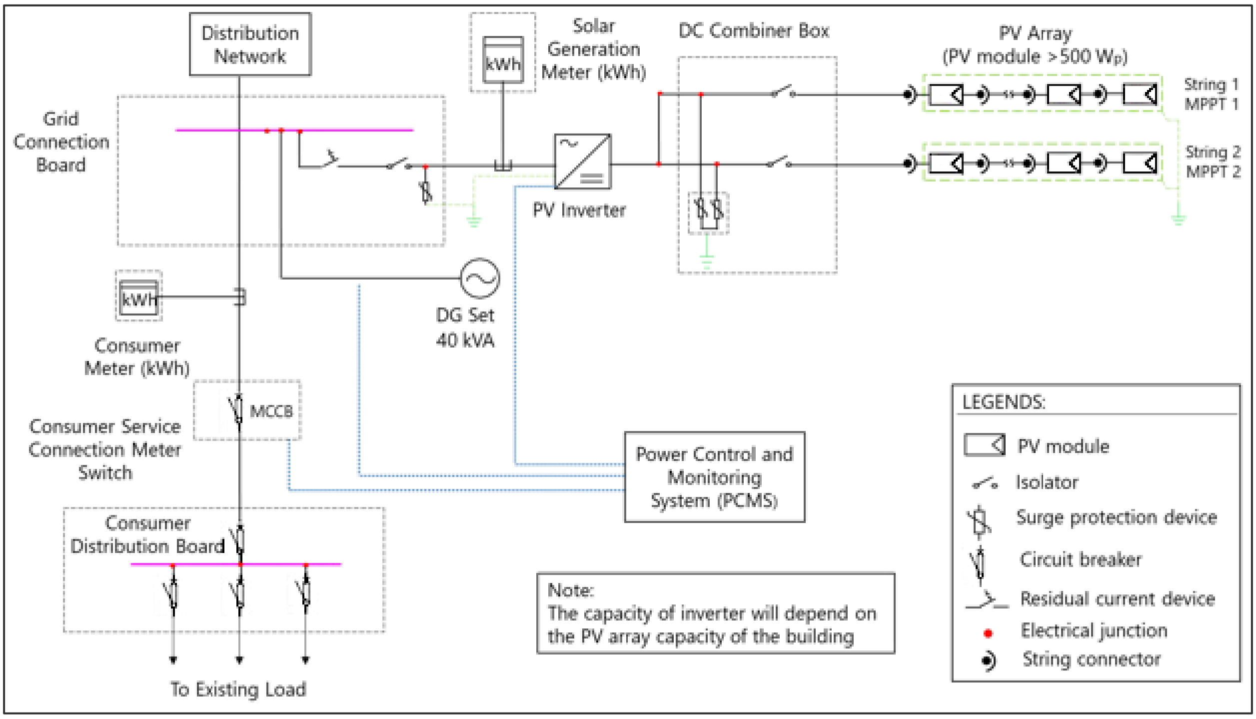
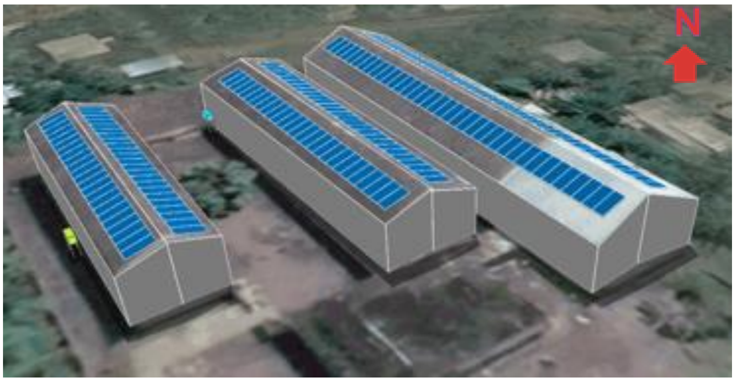


Figure 72: Single line diagram of rooftop PV system for Camara Distrital De Lobata

SITE 21: ESCOLA SECUNDÁRIA DE NEVES

District	Lembá
Geo. co-ordinates	0.357505, 6.545040
No. of buildings	4
Type of roof	3 slant (15°), 1 flat
Roof materials	Asbestos, Metal and RCC
Roof orientation (Azimuth)	234°, 53° ,233°, 52°,232° (Refer design document)
Age of the roof	27 years
Usable roof area	1008 m^2
Physical condition	Yes (Roof of the RCC building is damaged) One asbestos roof broken
Grid connection	10 kVA
Peak demand	10 kVA
Estimated energy demand	21 MWh/year
Critical load	1 kVA (Computers)
Power outage	50- 60 hours per month
Backup power	No
PV capacity	96 kW_p
Estimated generation	133 MWh/year (1st year)
PV electricity consumed	18 MWh/year
PV electricity fed to grid	115 MWh/year
CO_2 emission reduction	1968 tons (lifetime)
Additional requirement	120 kVA LT panel to be installed for grid connection

Figure 73: Escola Secundária De Neves



3-D PV plant layout (View from South)

Figure 74: Site survey photos of Escola Secundária De Neves

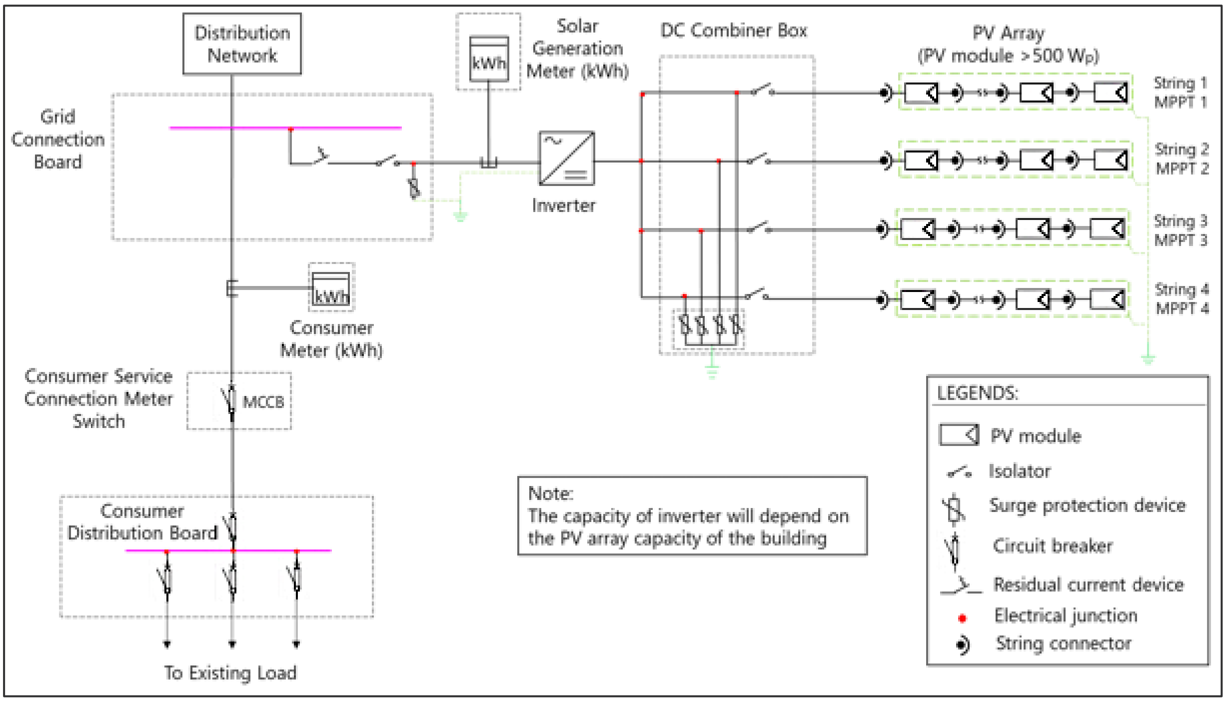
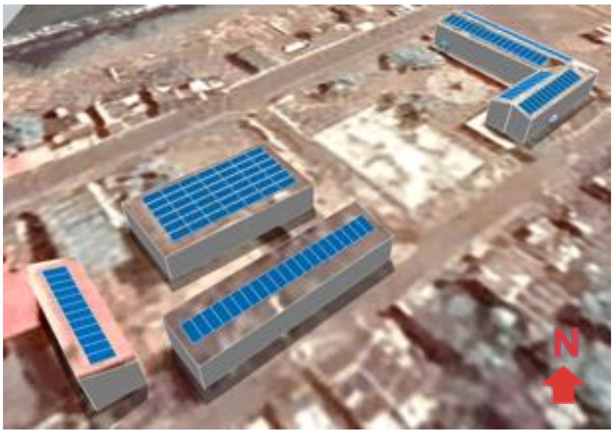


Figure 75: Single line diagram of rooftop PV system for Escola Secundária De Neves

SITE 22: ESCOLA SECUNDÁRIA DE SANTA CATARINA

District	Lembá
Geo. co-ordinates	0.270007, 6.472640
No. of buildings	4
Type of roof	Building 1: slant (15°), building 2: flat, building 3: slant (15°), Building 4: slant (15°)
Roof materials	Building 1: Asbestos, building 2: RCC, building 3: Metal, Building 4: Lysaght
Roof orientation (Azimuth)	231°, 51° ,319°, 137°, 53°, 141°,144° (Refer design document)
Age of the roof	>20 years
Usable roof area	378 m^2
Physical condition	Good
Grid connection	10 kVA
Peak demand	10 kVA (Computers)
Estimated energy demand	21 MWh/year
Power outage	50- 60 hours per month
Critical load	1 kVA
Backup power	No
PV capacity	75 kW_p
Estimated generation	106 MWh/year (1st year)
PV electricity consumed	18 MWh/year
PV electricity fed to grid	88 MWh/year
CO_2 emission reduction	1567 tons (lifetime)
Additional requirement	90 kVA LT panel to be installed for grid connection

Figure 76: Escola Secundária De Santa Catarina



3-D PV plant layout (View from South)

Figure 77: Site survey photos of Escola Secundária De Santa Catarina

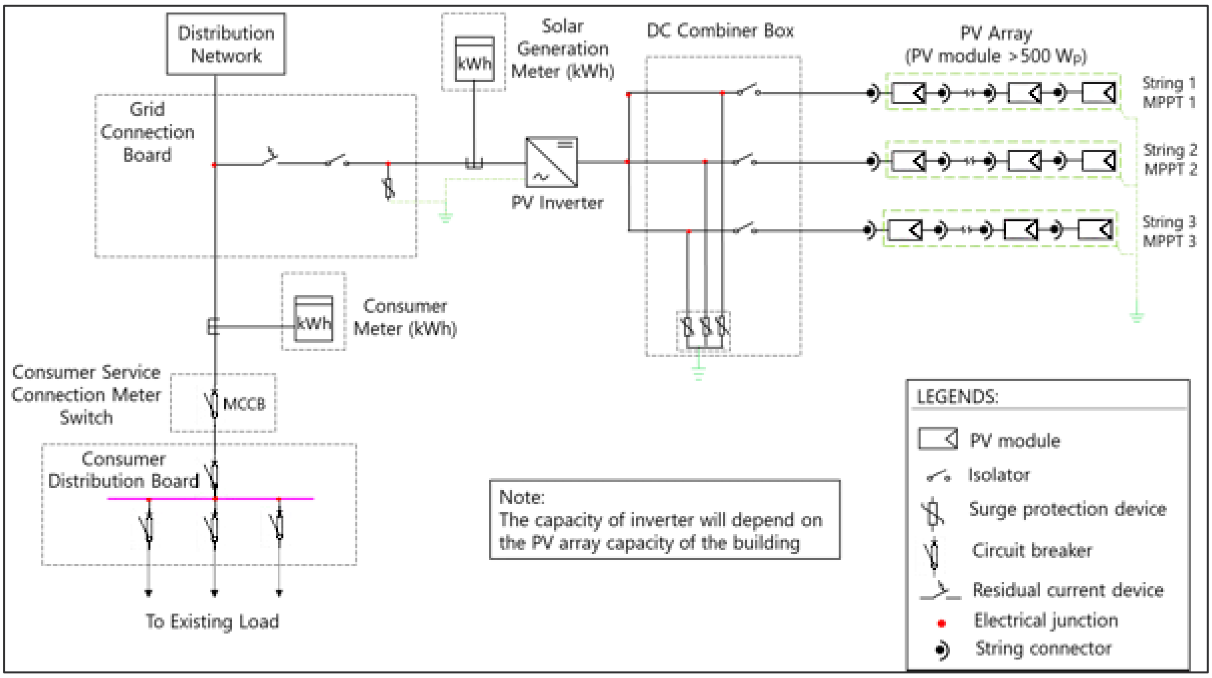
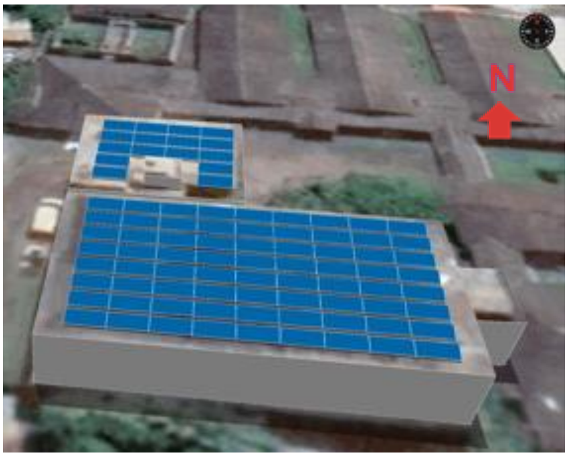


Figure 78: Single line diagram of rooftop PV system for Escola Secundária De Santa Catarina

SITE 23: POSTO DE SAUDE DE LEMBÁ

District	Lembá
Geo. co-ordinates	0.357927, 6.553228
No. of buildings	9
Type of roof	2 buildings with flat roof 7 building with slant roof
Roof materials	Flat buildings: RCC Slant buildings: Asbestos and metal
Roof orientation (Azimuth)	188° (Refer design document)
Age of the roof	>30 years
Usable roof area	391 m^2
Physical condition	Asbestos roof condition is not good. RCC roofs are suitable.
Grid connection	20 kVA
Peak demand	20 kVA
Estimated energy demand	102 MWh/year
Critical load	7 kVA (Critical care equipment, refrigerators)
Power outage	50- 60 hours per month
Backup power	No
PV capacity	48 kW_p
Estimated generation	70 MWh/year (1st year)
PV electricity consumed	57 MWh/year
PV electricity fed to grid	13 MWh/year
CO_2 emission reduction	1036 tons (lifetime)
Additional requirement	60 kVA LT panel to be installed for grid connection
Comments	• Buildings with asbestos roof are not considered for PV systems installation. • Two RCC buildings with flat roof are considered for PV system installation.

Figure 79: Posto De Saude De Lembá



3-D PV plant layout (View from South)

Figure 80: Site survey photos of Posto De Saude De Lembá

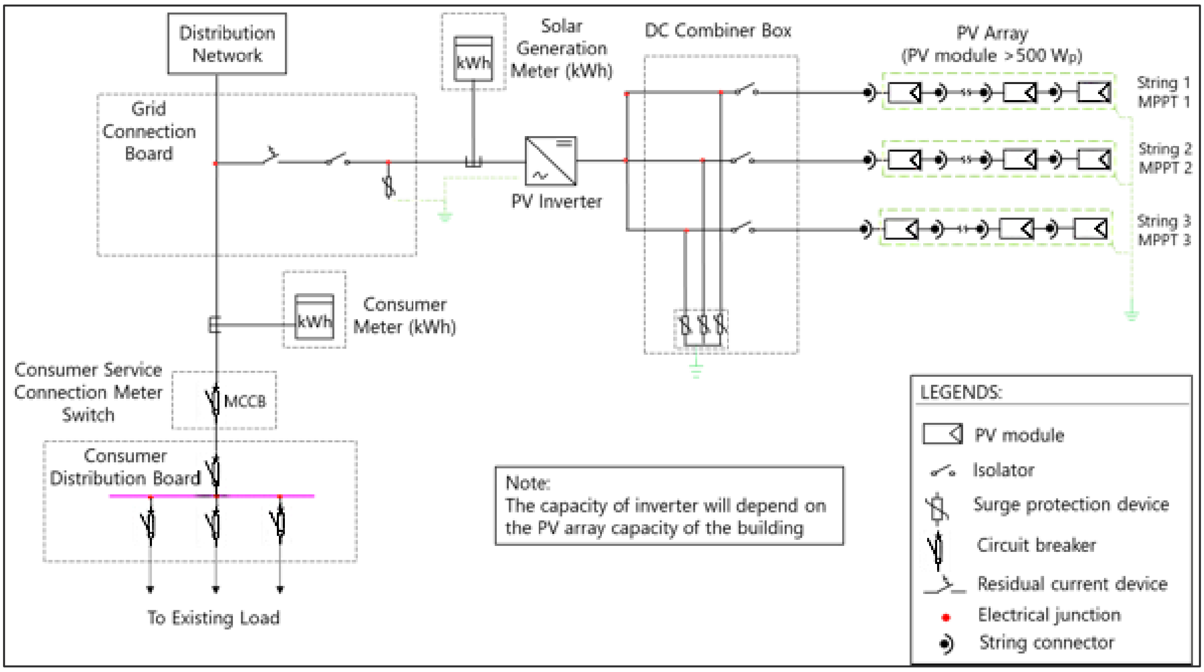


Figure 81: Single line diagram of rooftop PV system for_Posto De Saude De Lembá

SITE 24: CAMARA DISTRITAL DE LEMBÁ

Building No.	Building No. 1	Building No. 2
District	Lembá	Lembá
Geo. co-ordinates	0.358654, 6.544597	0.358654, 6.544597
No. of buildings	1	1
Type of roof	Slant (20°)	Slant (12°)
Roof materials	Tiles & asbestos	Metal (Lysaght sheets)
Roof orientation (Azimuth) (Refer design document)	135°, 226°, 317°, 45°	178°, 358° , 356°, 179°, 360°
Age of the roof	40 years	5-6 years
Usable roof area	210 m^2	247 m^2
Physical condition	Fine	Good
Grid connection	3 kVA, three phase	5 kVA, three phase (freezer load)
Peak demand	3 kVA	5 kVA
Estimated energy demand	8 MWh/year	13 MWh/year
Critical load	1 kVA (office appliances)	5 kVA (Refrigeration)
Power outage	50- 60 hours per month	50- 60 hours per month
Backup power	No	No
PV capacity	22 kW_p	25 kW_p
Estimated generation	30 MWh/year (1st year)	36 MWh/year (1st year)
PV electricity consumed	6 MWh/year	10 MWh/year
PV electricity fed to grid	24 MWh/year	26 MWh/year
CO_2 emission reduction	448 tons (lifetime)	527 tons (lifetime)
Additional requirement	30 kVA LT panel to be installed for grid connection in both building	

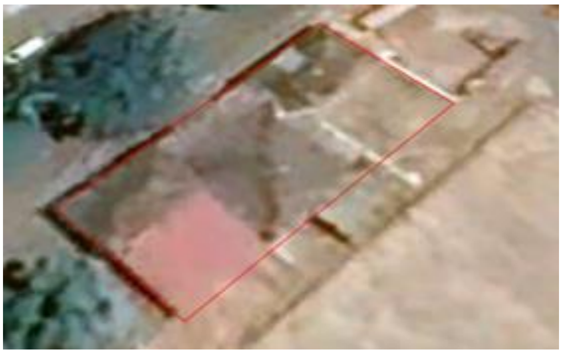
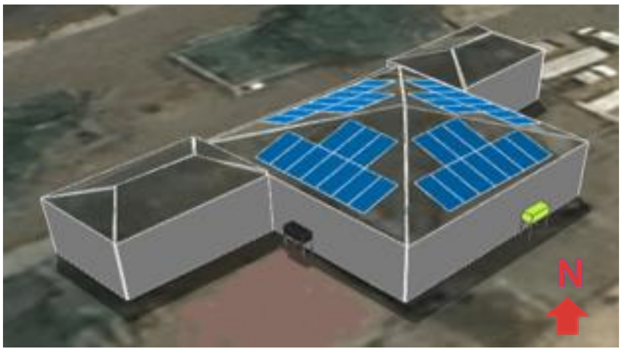
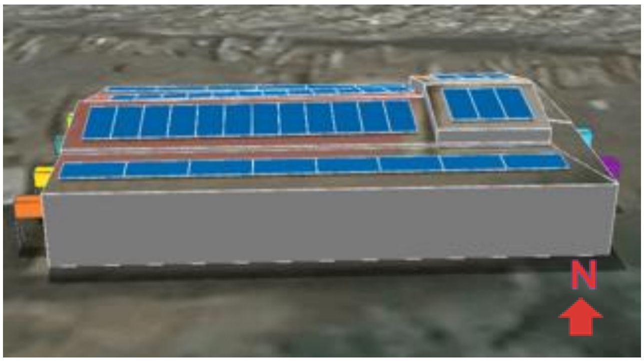


Figure 82: Camara Distrital De Lembá (Building No.1)



3-D PV plant layout (View from South)

Figure 83: Camara Distrital De Lembá (Building No.2)



3-D PV plant layout (View from South)

Figure 84: Site survey photos of Camara Distrital De Lembá (Building No.1)

Figure 85: Site survey photos of Camara Distrital De Lembá (Building No.2)

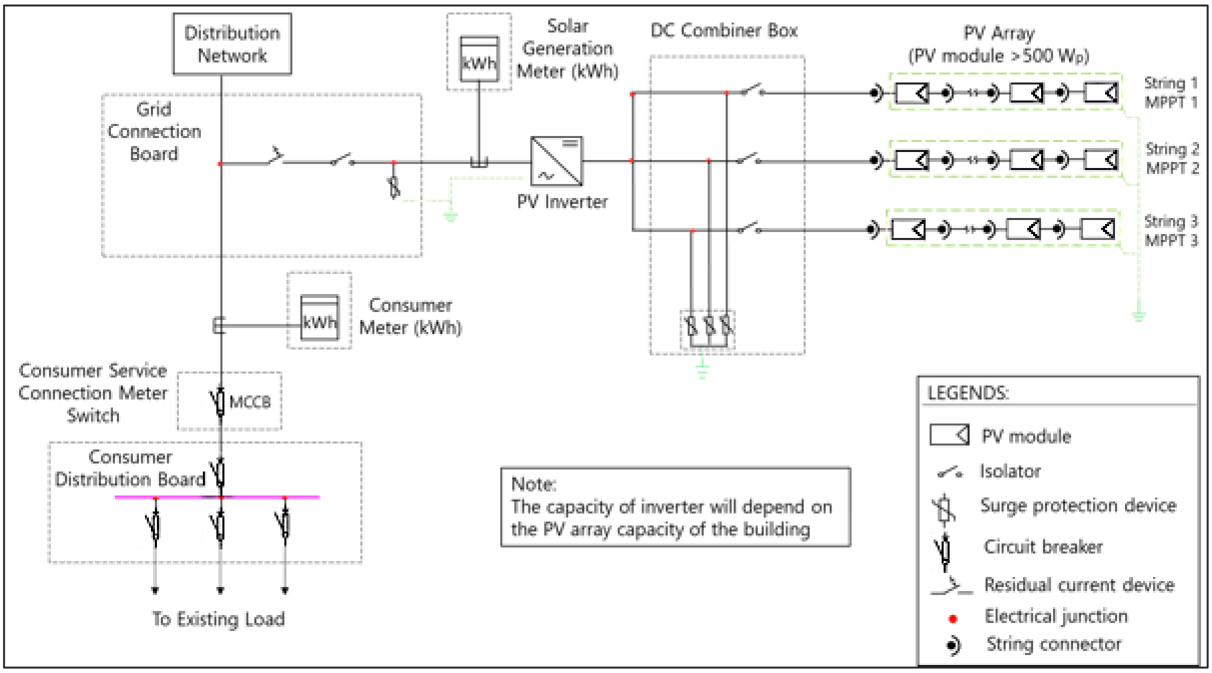


Figure 86: Single line diagram of rooftop PV system for Camara Distrital De Lembá

SITE 25: FABRICA DE CHOCOLATE

District	Lembá
Geo. co-ordinates	0.389749, 6.629590
No. of buildings	2
Type of roof	Slant (15°)
Roof materials	Metal (Lysaght trapezoidal sheets)
Roof orientation (Azimuth)	82°, 262° ,287°, 106°,285°, 96° (Refer design document)
Age of the roof	2-3 years
Usable roof area	1385 m^2
Physical condition	Good
Grid connection	50 kVA, three phase
Peak demand	50 kVA
Estimated energy demand	131 MWh/year
Critical load	15 kVA (Process equipment, refrigeration)
Power outage	50- 60 hours per month
Backup power	3 x 20 kVA; 1 x 25 kVA
PV capacity	121 kW_p
Estimated generation	171 MWh/year (1st year)
BESS capacity	150 kWh
PV electricity consumed	149 MWh/year
PV electricity fed to grid	22 MWh/year
CO2 emission reduction	2535 tons (lifetime)
Additional requirement	150 kVA LT panel to be installed for grid connection

Figure 87: Fabrica De Chocolate   3-D PV plant layout (View from South)

Figure 88: Site survey photos of Fabrica De Chocolate

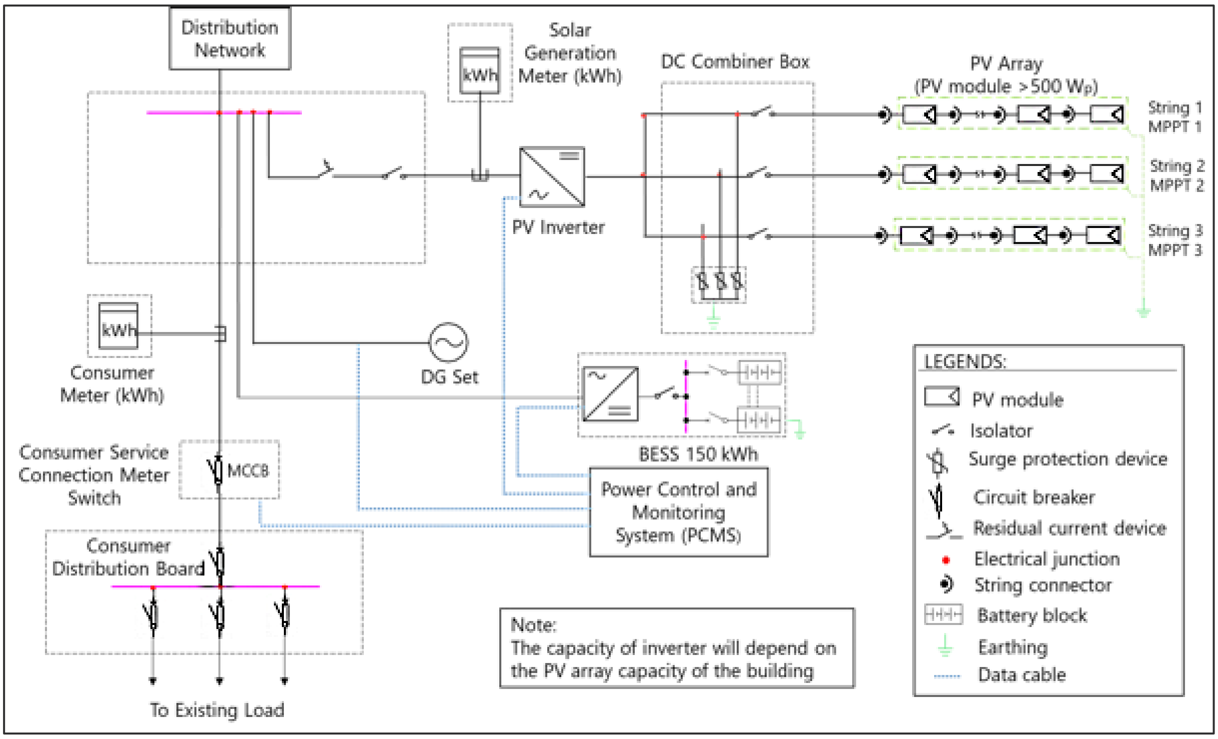
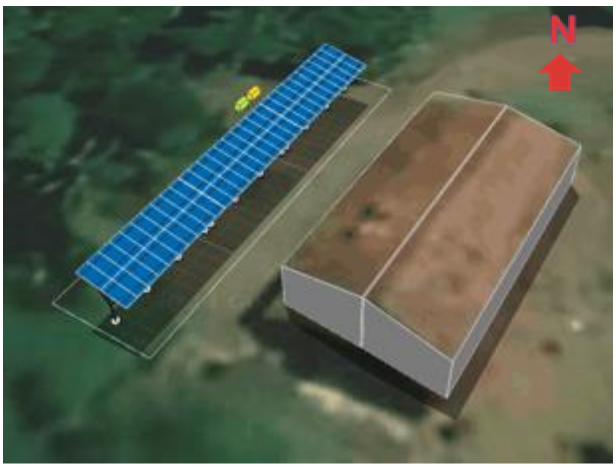


Figure 89: Single line diagram of rooftop PV system for_Fabrica De Chocolate

SITE 26: DIREÇÃO REGIONAL DE AMBIENTE E COSERVAÇÃO DA NATUREZA PRÍNCIPE

District	Região Autónoma do Príncipe (RAP)
Geo. co-ordinates	1.622401, 7.402924
No. of buildings	1
Type of roof	Slant (15°)
Roof materials	Tiles
Roof orientation (Azimuth)	121° (Refer design document)
Age of the roof	6-7 years
Usable roof area	246 m^2
Physical condition	Not Good
Grid connection	5 kVA, three phase
Peak demand	5 kVA
Estimated energy demand	13 MWh/year
Critical load	1 kVA (Office appliances, internet)
Power outage	180 – 200 hours per month (midnight to morning)
Backup power	No (Daily power cut for 6 -8 hours, weekend no power 1-2 days)
PV capacity	33 kW_p
Estimated generation	48 MWh/year (1st year)
PV electricity consumed	10 MWh/year
PV electricity fed to grid	38 MWh/year
CO_2 emission reduction	708 tons (lifetime)
Additional requirement	40 kVA LT panel to be installed for grid connection
Comments	Car port installation is suggested.

Figure 90: Direção Regional De Ambiente E Conservação da Natureza Príncipe



3-D PV plant layout (View from South)

Figure 91: Site survey photos of Direção Regional De Ambiente E Conservação da Natureza Príncipe

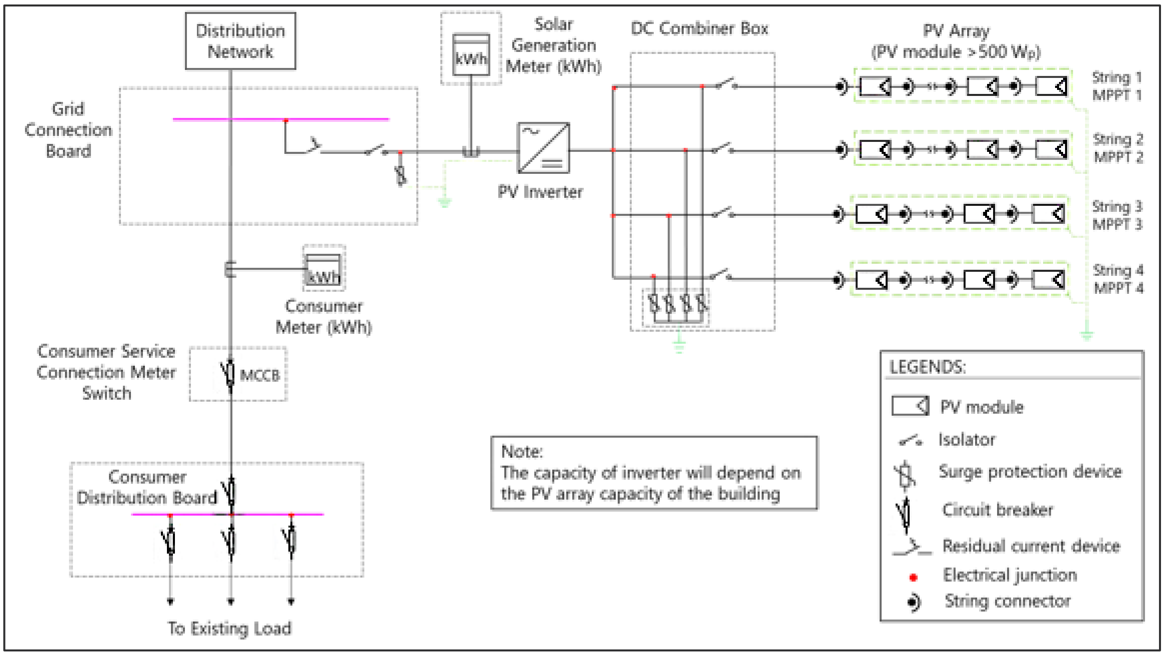
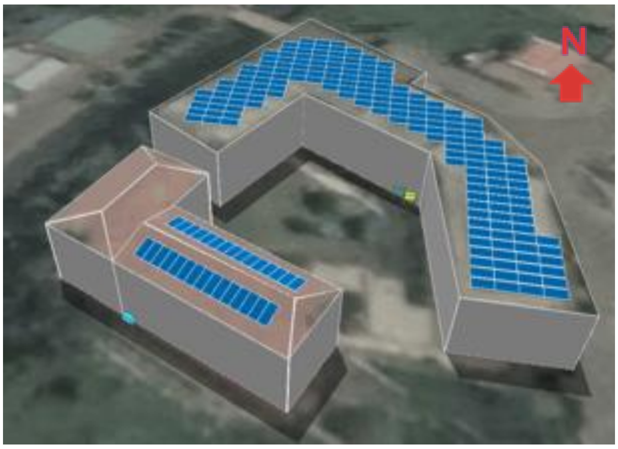


Figure 92: Single line diagram of PV system for_Direção Regional De Ambiente E Conservação da Natureza Príncipe

SITE 27: ESCOLA DE PADRÃO

District	Região Autónoma do Príncipe (RAP)
Geo. co-ordinates	1.641298, 7.419496
No. of buildings	2
Type of roof	New Building: slant (15°) Old building: RCC flat
Roof materials	New Building: Lysaght trapezoidal sheets Old building: RCC
Roof orientation (Azimuth)	34°, 214° ,190° (Refer design document)
Age of the roof	New Building: 3 years Old building: 30 years
Usable roof area	873 m^2
Physical condition	Good
Grid connection	10 kVA, three phase
Peak demand	10 kVA
Estimated energy demand	21 MWh/year
Critical load	1 kVA (computers)
Power outage	180 – 200 hours per month (midnight to morning)
Backup power	No
PV capacity	114 kW_p
Estimated generation	164 MWh/year (1st year)
PV electricity consumed	19 MWh/year
PV electricity fed to grid	145 MWh/year
CO2 emission reduction	2436 tons (lifetime)
Additional requirement	140 kVA LT panel to be installed for grid connection

Figure 93: Escola De Padrão



3-D PV plant layout (View from South)

Figure 94: Site survey photos of Escola De Padrão

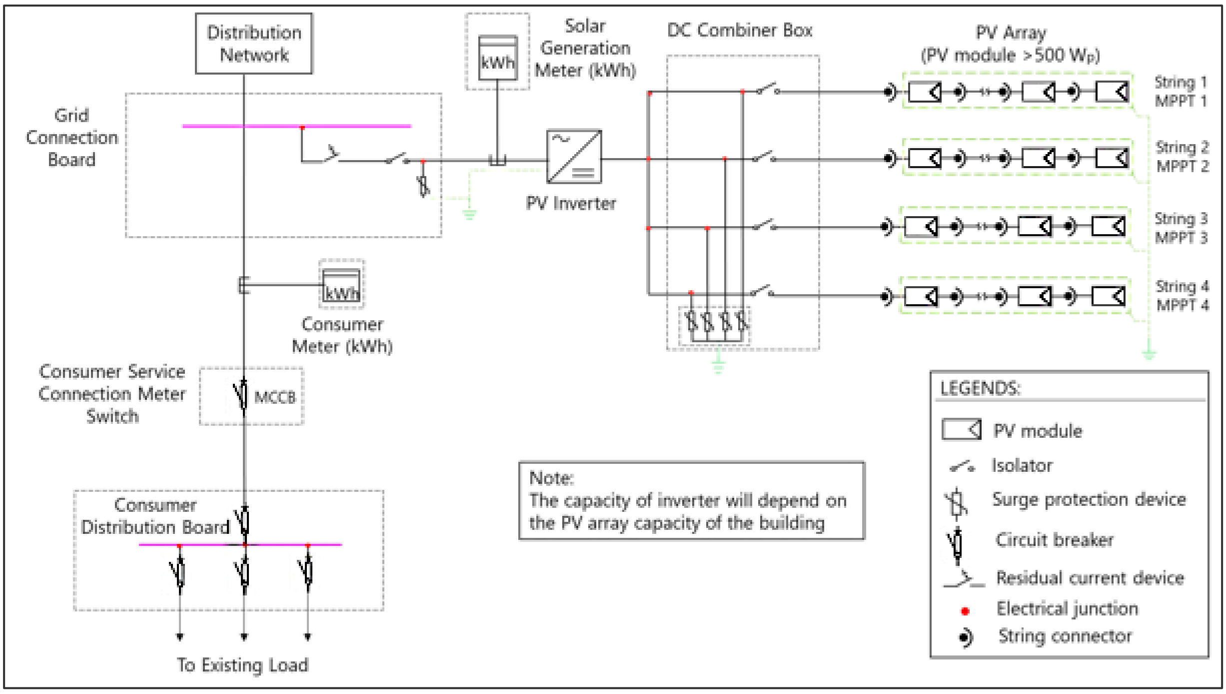
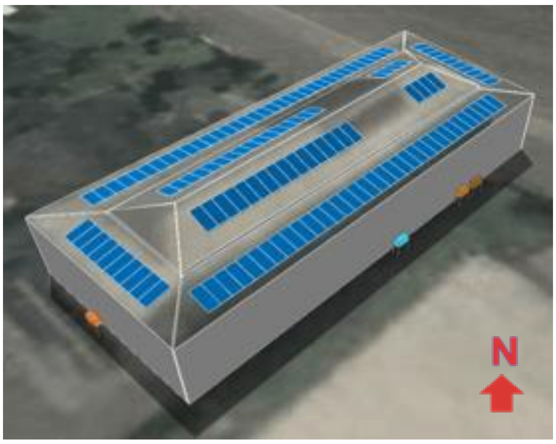


Figure 95: Single line diagram of rooftop PV system for_Escola De Padrão

SITE 28: BANCO INTERNACIONAL DE SÃO TOMÉ E PRÍNCIPE (BISTP)

District	Região Autónoma do Príncipe (RAP)
Geo. co-ordinates	1.641280, 7.421113
No. of buildings	1
Type of roof	Slant (20°)
Roof materials	Metal (Lysaght trapezoidal sheets)
Roof orientation (Azimuth)	315°, 135°, 223°, 134°, 48°, 316° (Refer design document)
Age of the roof	9 years
Usable roof area	731 m^2
Physical condition	Good
Grid connection	100 kVA, three phase
Peak demand	100 kVA
Estimated energy demand	262 MWh/year
Critical load	25 kVA (Office appliances, internet, lights)
Power outage	180 – 200 hours per month (midnight to morning)
Backup power	2 x 150 kVA
PV capacity	70 kW_p
Estimated generation	98 MWh/year (1st year)
BESS capacity	300 kWh
PV electricity consumed	98 MWh/year
PV electricity fed to grid	0 MWh/year
CO_2 emission reduction	1461 tons (lifetime)
Additional requirement	None
Comments	Skylights area is present which is to be avoided for installation of PV modules.

Figure 96: Banco Internacional De São Tomé E Príncipe (Bistp)



3-D PV plant layout (View from South)

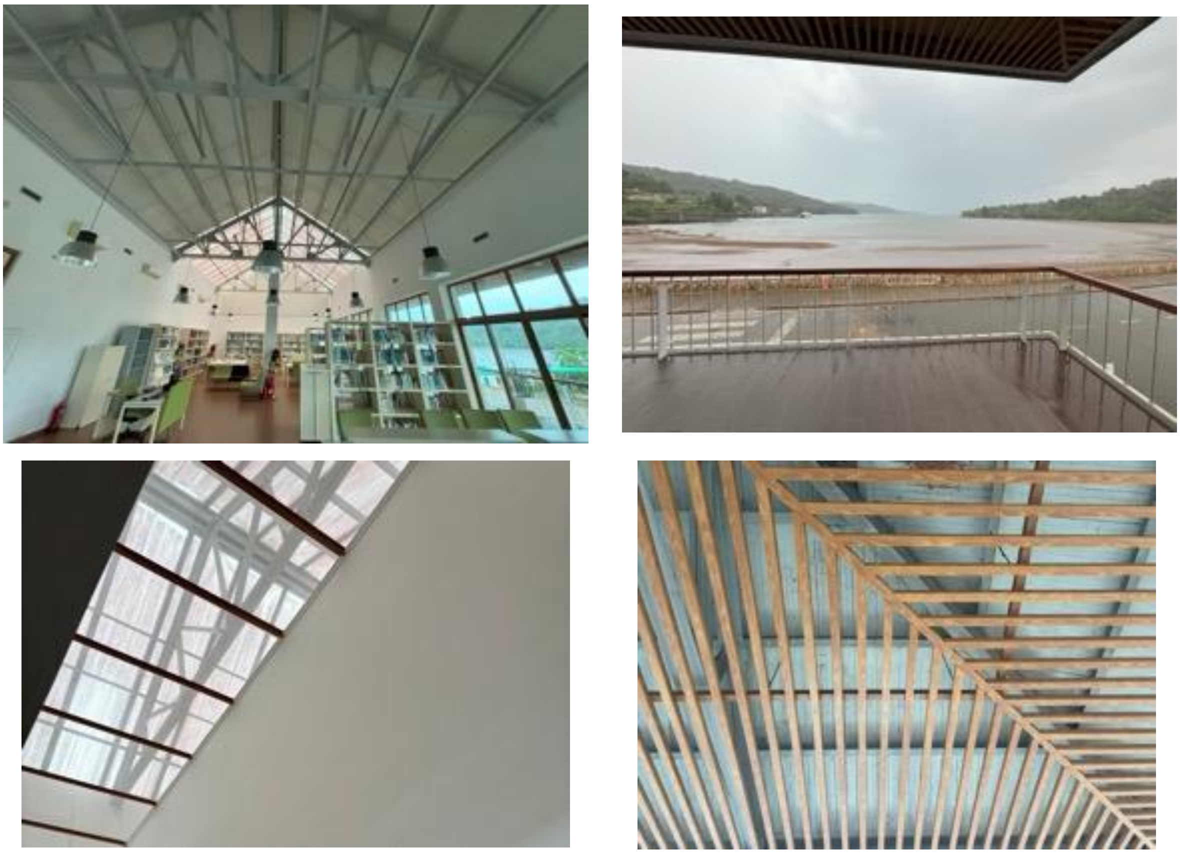


Figure 97: Site survey photos of Banco Internacional De São Tomé E Príncipe (Bistp)

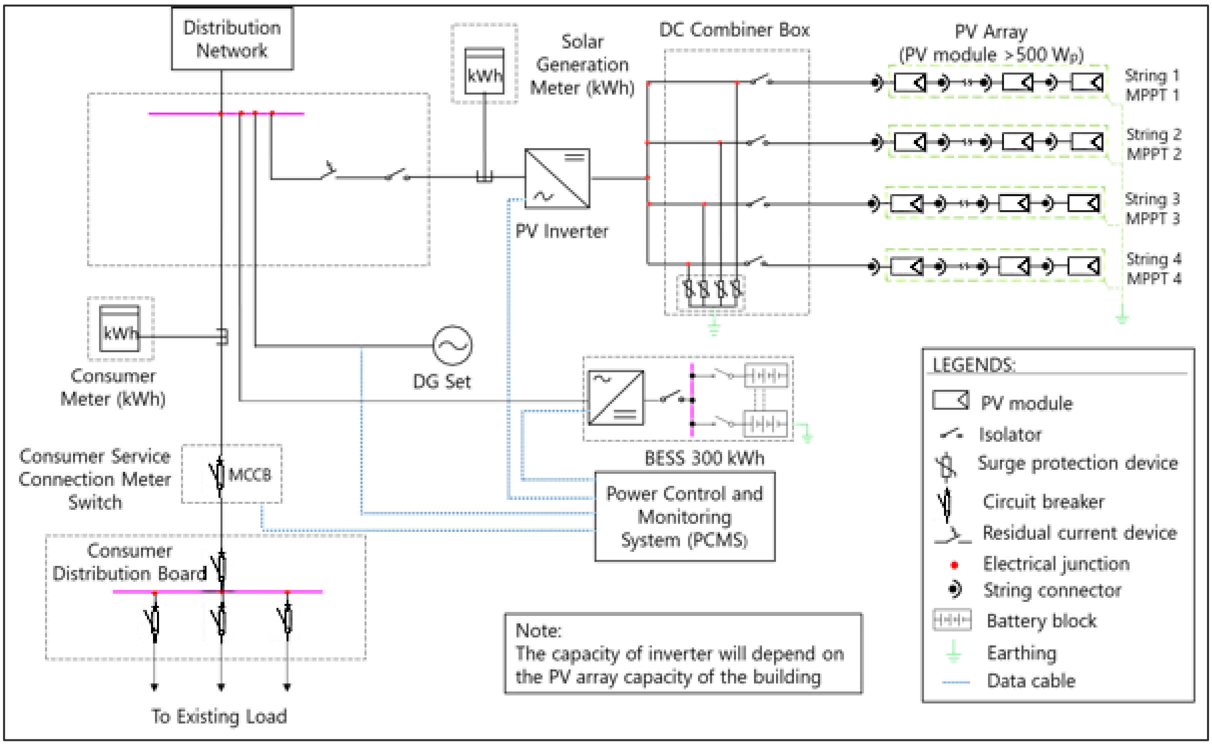
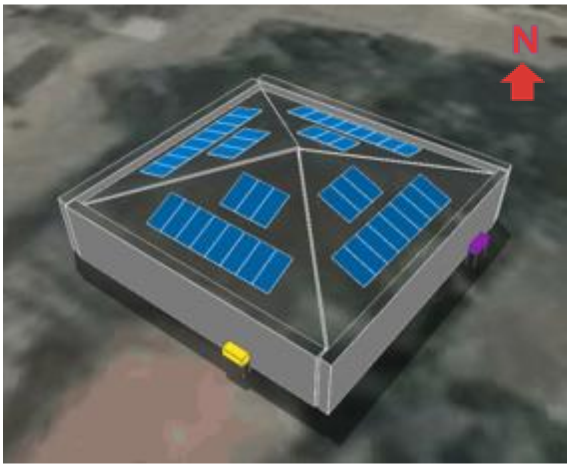


Figure 98: Single line diagram of rooftop PV system for Banco Internacional De São Tomé & Príncipe

SITE 29: CASA DA CULTURA

District	Região Autónoma do Príncipe (RAP)
Geo. co-ordinates	1.637300, 7.418969
No. of buildings	1
Type of roof	Slant (20°)
Roof materials	Tiles
Roof orientation (Azimuth)	217°, 311° , 130°, 32° (Refer design document)
Age of the roof	14 years
Usable roof area	225 m^2
Physical condition	Good
Grid connection	10 kVA, three phase
Peak demand	10 kVA
Estimated energy demand	26 MWh/year
Critical load	1 kVA (Computers, lights)
Power outage	180 – 200 hours per month (midnight to morning)
Backup power	Yes (Not functioning)
PV capacity	24 kW_p
Estimated generation	31 MWh/year (1st year)
PV electricity consumed	18 MWh/year
PV electricity fed to grid	13 MWh/year
CO_2 emission reduction	461 tons (lifetime)
Additional requirement	30 kVA LT panel to be installed for grid connection
Comments	Growing coconut trees may cast shadow on the lower part of the roof.

Figure 99: Casa Da Cultura



3-D PV plant layout (View from South)

Figure 100: Site survey photos of Casa Da Cultura

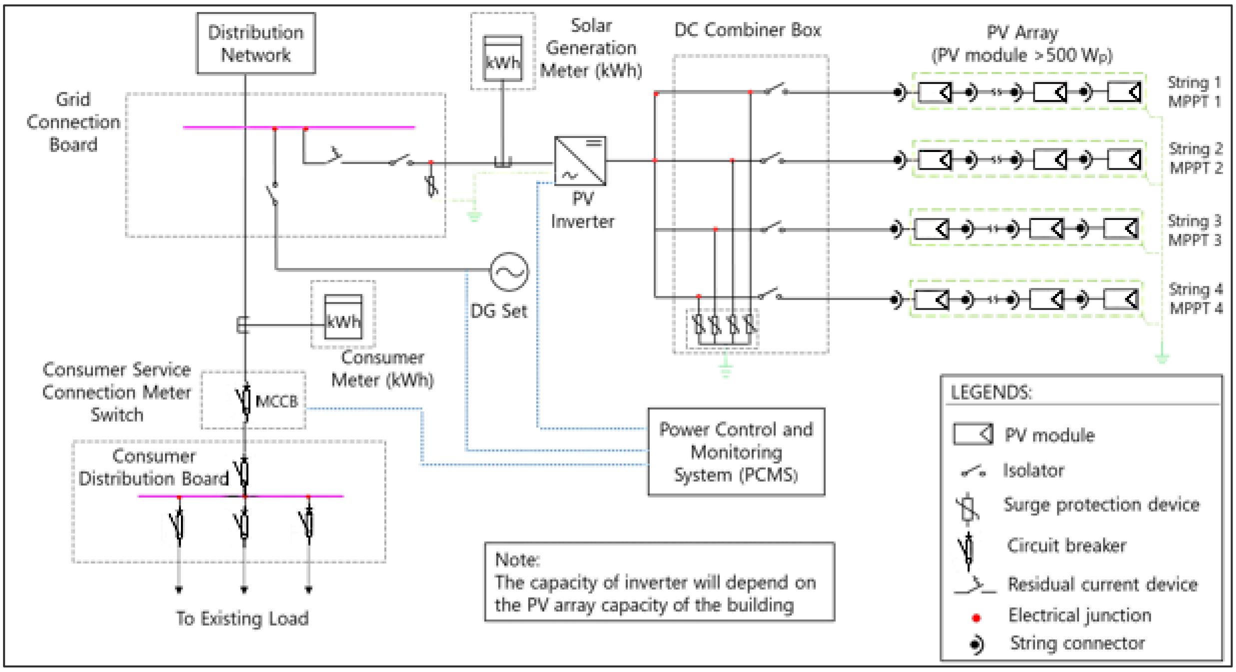


Figure 101: Single line diagram of rooftop PV system for Casa Da Cultura

SITE 30: ESCOLA DE SANTO ANTONIO

District	Região Autónoma do Príncipe (RAP)
Geo. co-ordinates	1.634786, 7.416313
No. of buildings	4
Type of roof	3 major building: slant (15°) 1 small building: flat
Roof materials	Two buildings: Asbestos One building Lysaght One building: RCC
Roof orientation (Azimuth)	200°, 20° ,197°, 18°, 14°,193° (Refer design document)
Age of the roof	>15 years
Usable roof area	780 m^2
Physical condition	Good
Grid connection	10 kVA, 3 phase
Peak demand	10 kVA
Estimated energy demand	21 MWh/year
Critical load	1 kVA (Computers)
Power outage	180 – 200 hours per month (midnight to morning)
Backup power	None
PV capacity	78 kW_p
Estimated generation	110 MWh/year (1st year)
PV electricity consumed	19 MWh/year
PV electricity fed to grid	91 MWh/year
CO_2 emission reduction	1632 tons (lifetime)
Additional requirement	100 kVA LT panel to be installed for grid connection
Comments	One small PV system installed in one building which is not functioning.

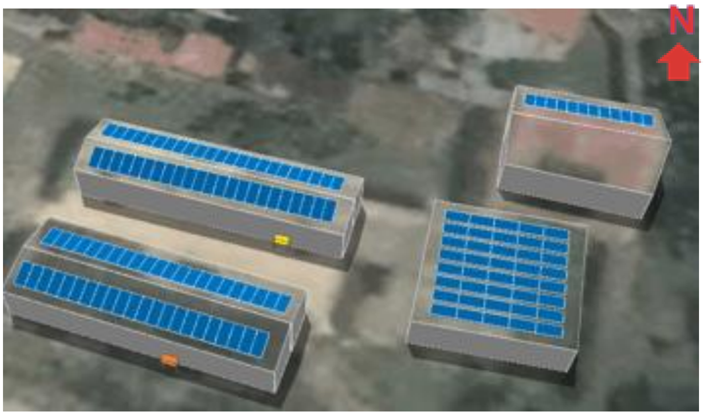


Figure 102: Escola De Santo Antonio 3-D PV plant layout (View from South)

Figure 103: Site survey photos of Escola De Santo Antonio

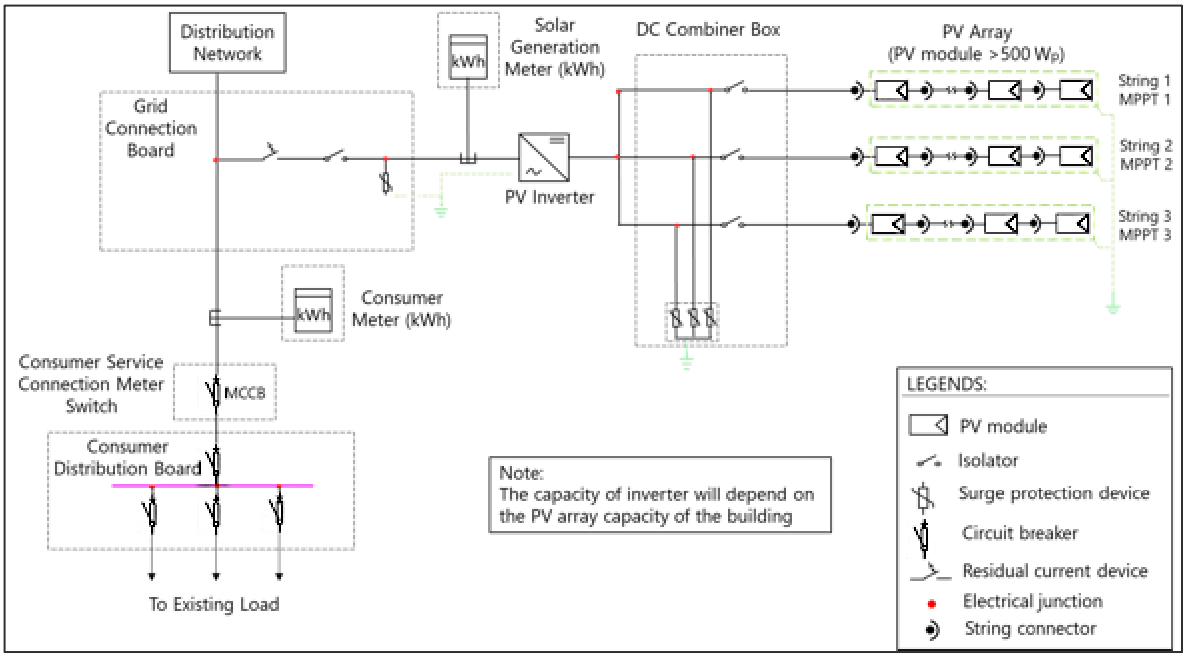


Figure 104: Single line diagram of rooftop PV system for Escola De Santo Antonio

SITE 31: HOSPITAL DR. MANUEL QUARESMA DIAS DA GRAÇA

District	Região Autónoma do Príncipe (RAP)
Geo. co-ordinates	1.645163, 7.421525
No. of buildings	2 attached buildings
Type of roof	Slant (4°)
Roof materials	Asbestos and metal (Lysaght)
Roof orientation (Azimuth)	246°, 64° (Refer design document)
Age of the roof	>20 years (Asbestos roof) >10 years (Metal roof)
Usable roof area	531 m^2
Physical condition	Good
Grid connection	25 kVA, three phase
Peak demand	25 kVA
Estimated energy demand	127 MWh/year
Critical load	15 kVA (Critical care equipment, refrigerators, lights)
Power outage	180 – 200 hours per month (midnight to morning)
Backup power	40 kVA diesel generator
PV capacity	75 kW_p
Estimated generation	99 MWh/year (1st year)
BESS capacity	150 kWh
PV electricity consumed	99 MWh/year
PV electricity fed to grid	0 MWh/year
CO_2 emission reduction	1474 tons (lifetime)
Additional requirement	100 kVA LT panel to be installed for grid connection
Comments	PV system integrated with BESS is recommended

Figure 105: Hospital Dr. Manuel Quaresma Dias da Graça

3-D PV plant layout (View from South)

Figure 106: Site survey photos of Hospital Dr. Manuel Quaresma Dias da Graça

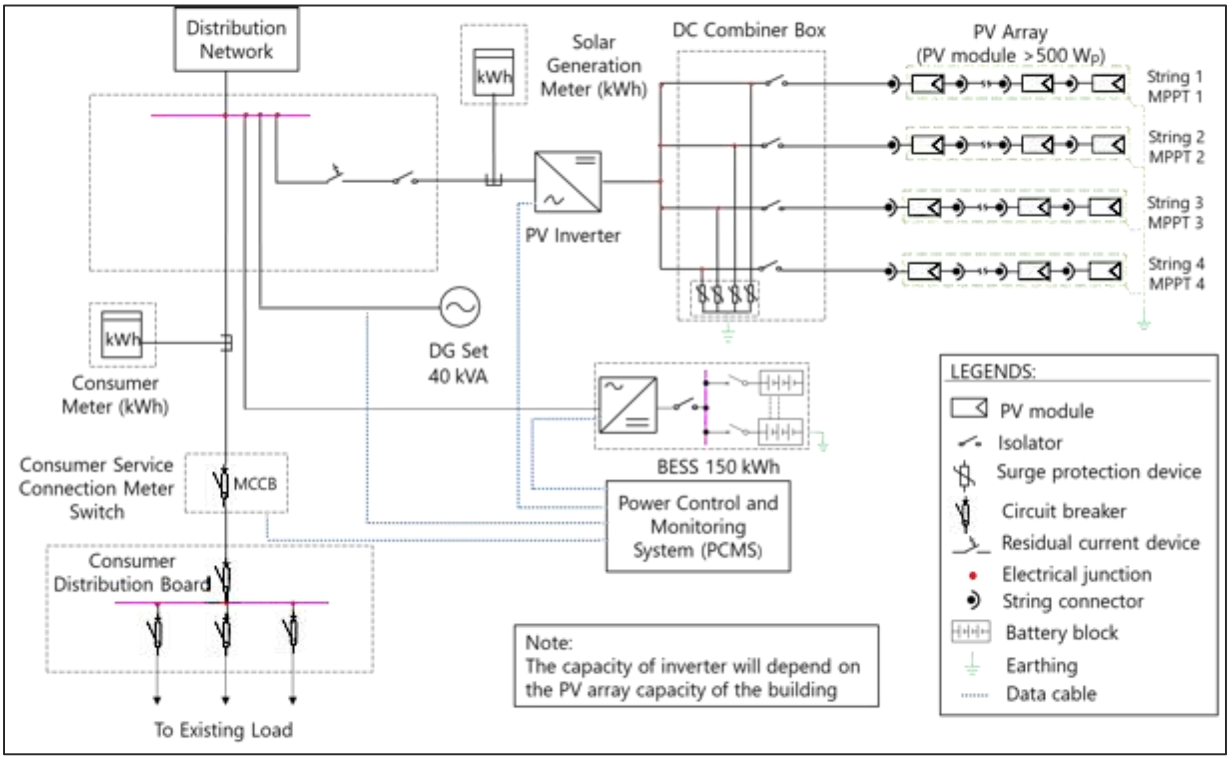


Figure 107: Single line diagram of rooftop PV system for Hospital Dr. Manuel Quaresma Dias da Graça

Table 11: Summary of PV plant capacity, energy yield and GHG reduction of all sites

Site No.	Site name	PV plant capacity (kW_p)	Estimated Energy generation (MWh/year)	GHG emission reduction metric tons (25 years)
	São Tomé Island			
1	Supremo Tribunal de Justiça	107	139	2068
2	Direção do Ensino Primário	32	42	622
3	Procurador/ Ministério publico	14	19	275
4	Ministério da Defesa	86	111	1652
5	Autoridade Geral De Regulaca (AGER)	13	17	257
6	Hospital Dr. Aires de Menezes	211	299	4440
7	Ministério das Finanças e Economia Azul	169	218	3238
8	Liceu Nacional	272	358	5315
9	Ministério da Educação	23	30	445
10	Tribunal de Contas	34	44	656
11	Liceu Nacional de Santana	93	117	1739
12	Centro Polivalente de Caué	73	104	1543
13	Escola Secundaria de São João dos Angolares	24	31	455
14	Posto de Saúde	53	74	1097
15	Mercado de Bobo Foro	937	1318	19547
16	Escola Secundaria Maria Manuela Margarido (MMM)	208	270	4005
17	Escola Primária de Trindade	132	172	2558
18	Liceu Mé Chinhô	249	321	4763
19	Centro Hospitalar de Lobata	8	11	162
20	Camara Distrital de Lobata	48	62	922
21	Escola Secundária de Neves	96	133	1968
22	Escola Secundária de Santa Catarina	75	106	1567
23	Posto de Saude de Lembá	48	70	1036
24	Camara Distrital de Lembá	47	66	975
25	Fabrica de Chocolate	121	171	2535

Site No.	Site name	PV plant capacity (kW_p)	Estimated Energy generation (MWh/year)	GHG emission reduction metric tons (25 years)
	Total for Saõ Tomé Island	3173	4303	63840
	Príncipe Island			
26	Direção Regional de Ambiente e Conservação da Natureza Príncipe	33	48	708
27	Escola de Padrão	114	164	2436
28	Banco Internacional de São Tomé e Príncipe (BISTP)	70	98	1461
29	Casa da Cultura	24	31	461
30	Escola de Santo Antonio	78	110	1632
31	Hospital DR. Manuel Quaresma Dias Da Graça	75	99	1474
	Total for Príncipe	394	550	8172
	Total for Saõ Tomé and Príncipe	**3567**	**4853**	**72012**

3.4 AGGREGATED PV POWER PLANT CAPACITY

The PV plant capacity was determined for each site after the plant layout design based on available shadow-free areas suitable for installing PV arrays. PV plant capacity for each site is presented in Table 11. The aggregated PV capacity that can be installed in 31 surveyed sites is 3567 kWp with 3173k Wp in Total for Saõ Tomé Island and 394 kWp in Príncipe Island. However, not all sites are readily suitable for installing full PV capacity due to the limitation of the present grid connection infrastructure. Based on the available grid connection infrastructure, 1265 kWp PV capacity can be installed without upgrading the grid connection facility at the site. Site-specific recommendations are made in section 3.3 above.

3.5 ENERGY GENERATION ESTIMATION

Energy generation estimation for each site has been simulated separately using Solar Lab software. Separate reports for each site have been generated and uploaded to the data room created in OneDrive. The estimated energy generation for each site is presented in Table 13. The total energy generation of all 31 sites is estimated to be 4853 MWh per year (first year). Energy generation from PV power plants will degrade, which is considered to be 0.5% per year.

3.6 GREENHOUSE GAS EMISSION REDUCTION

The fourth Inventory of Greenhouse Gas Emissions and Removals (IGEE) for São Tomé and Príncipe is compiled using the methodology outlined in the Intergovernmental Panel on Climate Change

(IPCC) guidelines from 2006, in contrast to previous inventories which were based on the IPCC 1996 guidelines. The gases accounted for in calculating greenhouse gas emissions include Carbon Dioxide (CO_2), Methane (CH_4), Nitrous Oxide (N_2O), and Hydrofluorocarbons (HFCs).

According to the National Action Plan for Adaptation to Climate Change, São Tomé and Príncipe emit 568,663.87 metric tons of CO_2 equivalent, while it absorbs 1,544,545.2 metric tons of CO_2 equivalent. The two largest sources of greenhouse gas emissions are the energy and transport sectors, primarily due to the use of fossil fuels and the burning of firewood [1].

The National Action Plan for Adaptation to Climate Change in São Tomé and Príncipe also proposes the following solutions for mitigating greenhouse gas emissions in the energy sector:

- Implement measures to curb forest degradation by adopting technologies that decrease the reliance on firewood for energy purposes, such as improved cookstoves.
- Establish water stations equipped with accessible technologies and knowledge on a national scale.
- Diversify renewable energy sources beyond hydroelectricity, including biomass, solar, wind, and others, to reduce dependence on fossil fuels. This entails conducting a thorough assessment of available energy resources.

Implementing the NREAP and NEEAP is intended to bring substantial environmental advantages by notably decreasing greenhouse gas (GHG) emissions within the power sector. The goal is to meet the target outlined in the Nationally Determined Contributions (NDC) for 2021, aiming for a 27% reduction in emissions by 2030.

According to the UNFCCC standardised baseline recommendation report, the emission factor for grid electricity systems applicable to solar and wind projects is 0.660 tCO_2/MWh for São Tomé and Príncipe. This is used to estimate the CO_2 emission reduction from proposed solar projects.

Table 13 shows each surveyed site's estimated greenhouse gas emission reduction (in equivalent metric tons of CO_2). The estimated solar energy generation from aggregated PV plant capacity of 3567 kW_p is 4853 MWh annually, contributing to a greenhouse gas emission reduction of 3203 tCO_2 equivalent. Considering the degradation of PV power generation @0.5% per year, the total estimated CO_2 emission reduction during the 25-year project life for all 31 sites is 72012 metric tons. This will contribute to a reduction of 0.51% of the present CO_2 equivalent emission per year.

3.7 GRID INTEGRATION ASSESSMENT

Section 3.3 gives the grid-connected load of each surveyed site. All surveyed sites have three-phase grid connections. PV power plants with equivalent capacity can be installed without any change in the grid connection infrastructure. For the sites where potential PV plant capacity is marginally higher than the connected load, grid infrastructure upgrades are required inside the premises. For the sites where the PV plant capacity is substantially higher than the connected load, connecting the entire PV plant capacity at the building premises will not be feasible. In such cases, grid infrastructure upgrades are required up to the level where PV systems are to be connected. Table

12 summarises the estimated PV plant capacity, grid-connection capacity with no major change or upgrade, and the installed capacity of the standby diesel generator at the surveyed sites.

Table 12: Summary of buildings with grid connection capacity

Site No.	Site name	PV plant capacity (kW_p)	Grid connection capacity (kVA)	Diesel Generator installed (kVA)
	São Tomé Island			
1	Supremo Tribunal de Justiça	107	45	25
2	Direção do Ensino Primário	32	20	25
3	Procurador/ Ministério publico	14	14	25
4	Ministério da Defesa	86	25	25
5	Autoridade Geral De Regulaca (AGER)	13	13	16
6	Hospital Dr. Aires de Menezes	211	211	540
7	Ministério das Finanças e Economia Azul	169	50	100
8	Liceu Nacional	272	25	40
9	Ministério da Educação	23	23	40
10	Tribunal de Contas	34	34	100
11	Liceu Nacional de Santana	93	25	0
12	Centro Polivalente de Caué	73	31	0
13	Escola Secundaria de São João dos Angolares	24	5	0
14	Posto de Saúde	53	15	20
15	Mercado de Bobo Foro	937	100	0
16	Escola Secundaria Maria Manuela Margarido (MMM)	208	150	150
17	Escola Primária de Trindade	132	25	0
18	Liceu Mé Chinhô	249	150	125
19	Centro Hospitalar de Lobata	8	8	25
20	Camara Distrital de Lobata	48	11	40
21	Escola Secundária de Neves	96	10	0
22	Escola Secundária de Santa Catarina	75	10	0
23	Posto de Saude de Lembá	48	20	40
24	Camara Distrital de Lembá	47	10	0

Site No.	Site name	PV plant capacity (kW_p)	Grid connection capacity (kVA)	Diesel Generator installed (kVA)
25	Fabrica de Chocolate	121	50	85
	Total for Saõ Tomé Island	3173	1080	1421
	Príncipe Island			
26	Direção Regional de Ambiente e Conservação da Natureza Príncipe	33	5	0
27	Escola de Padrão	114	10	0
28	Banco Internacional de São Tomé e Príncipe (BISTP)	70	100	300
29	Casa da Cultura	24	10	25
30	Escola de Santo Antonio	78	10	0
31	Hospital DR. Manuel Quaresma Dias Da Graça	75	50	40
	Total for Príncipe	394	185	365
	Total for São Tomé and Príncipe	**3567**	**1265**	**1786**

3.8 UPGRADATION OF GRID NETWORK

As per the National Energy Efficiency Action Plan (NEEAP) and National Renewable Energy Action (NREAP), the grid system in São Tomé and Príncipe has losses of around 33%, of which 11% are technical losses, and the remaining 22% are commercial losses (EMAE 2019). The NEEAP states that the STP government aims to reduce the total grid losses to 30% by 2030 and 8% by 2050, limiting technical losses to 5% and commercial losses to 3%. In summary, there is immense room for improving the country's grid infrastructure. The report also recommends introducing EE standards and related reductions in energy demand, which will positively impact RE penetration in the grid. The main reasons for technical losses are inadequate monitoring, inspection and maintenance of grid assets.

The following grid upgrade/maintenance will be required to integrate distributed rooftop PV systems into the distribution systems and centralised PV power plants to the MV-level transmission grid.

1) **Minor upgradation at consumer premises:** This includes installing an additional grid-connection box with a manual circuit breaker, residual current device (RCD), surge protection device (SPD), energy meter and zero export device in the absence of a net metering framework.
2) **Major upgradation at the point of interconnection (POI):** This is required when the PV system's capacity is larger than the current carrying capacity of the existing grid connection to the premises/ building. In this case, the PV plant has to be connected where adequate current

carrying capacity is available. Depending upon the capacity of the PV system, this point of interconnection (POI) may be at LV level but outside the building/premises or at a higher voltage level at the distribution transformer or substation. For example, if PV system capacity is such that it cannot be integrated at the building grid but can be integrated at the nearest distribution network, a separate connection line of adequate current-carrying capacity has to be drawn from the building premises to the distribution line. In the case of a large PV system, which is to be connected at the MV level, a separate step-up transformer and transmission line are to be laid from the PV system to the POI.

3) Upgradation/replacement of transformers: When the PV plant capacity is larger than the transformer capacity at the POI, but the transmission line can carry the power from the PV plant, the transformer is to be replaced with an adequate capacity or an additional transformer to be installed.

4) Regular maintenance of transmission and distribution network: An additional transmission line may be required for power evacuation to integrate a large central PV power plant. Since grid availability is a must for the reliable operation of grid-connected PV power plants, the availability of power at the transmission and distribution network is key to the success of solar power projects. Therefore, adequate monitoring, inspection, and regular maintenance must be ensured for the transmission and distribution network.

4 ECONOMIC AND COST-BENEFIT ANALYSIS

The upfront capital cost for rooftop PV projects is estimated based on established and ongoing projects in the country and the prevailing project development costs of rooftop PV systems in the West African region. The estimated upfront capital cost covers all costs associated with designing, supplying, installing, and commissioning the PV systems without battery energy storage facilities. A life cycle cost-benefit analysis was performed for all the systems proposed for each site, considering the existing grid-connection capacity. Savings from replacing grid electricity, diesel generation fuel consumption reduction, payback period and levelized cost of PV electricity have been calculated using a financial model. Table 13 gives the inputs and assumptions considered for financial analysis.

Table 13: Common inputs and assumptions for financial analysis

Sl. No.	Particulars	Unit	Value
1	Upfront capital cost for PV systems	US$/kW$_p$	1300
2	Annual power generation	kWh/kW$_p$/year	1365
3	Cost of battery energy storage systems	US$/kWh	500
4	Electricity tariff used for calculation of savings	US$/kWh	0.25
5	Retail price of diesel used for calculation of savings	US$/liter	1.50
6	Currency conversion ratio	USD : STN	1 : 23.41
7	Escalation of electricity price	% per year	1%
8	Annual reduction of generation due to degradation	%	0.75%
9	Operation and maintenance cost	% of project cost	1.20%
10	Escalation in O & M	%	3%
11	Interest rate for term loan [https://www.bistp.st/inicio/institucional/quem-somos/relatorio-contas/]	%	10%
12	Interest rate on working capital loans	%	10%
13	Viability Gap Funding from Govt/ Donor	% of project cost	0%
14	Plant life assumed for working of depreciation	Year	25
15	Residual Value	%	10%
16	Depreciation of plant (Straight line method)	Percent per year	3.60%
17	Equity	% of project cost	30%
18	Term loan	% of project cost	70%
19	Term loan period	Years	10.00
20	Discounting Factor	%	10.22%

Note: The project cost includes all taxes and duties. Currently, there is no import duty or value-added tax on renewable energy products in São Tomé and Príncipe. A 15% service tax is applicable for activities like installation, operation and maintenance of renewable energy systems. The interest rate for term loans is considered 10% per year which may vary between 8% to 12% depending upon loan tenure, loan amount and bank.

4.1 LEVELISED COST OF ELECTRICITY

The following formula has been used to determine the levelized cost of electricity (LCOE) for energy generation.

$$LCOE = \frac{NPV\ of\ total\ cost\ over\ 25\ years\ of\ project\ life}{NPV\ of\ electrical\ energy\ generated\ over\ 25\ years}$$

The NPV of total cost over the project life has been estimated considering operation and maintenance cost, escalation, interest on bank loan, and depreciation. The NPV of electrical energy generated over the project life is considered with generation degradation @0.75% per year. Table 14 presents LCOE for PV systems with and without battery energy storage systems (BESS).

Table 14: Levelized cost of electricity

Type of PV systems	US¢ per kWh	STN per kWh
LCOE without BESS	6.68	1.56
LCOE with BESS for 3 hours full load backup	17.20	4.02

4.2 FINANCIAL BENEFITS TO CONSUMERS

There are two direct benefits to electricity consumers who install rooftop PV systems in the CAPEX model.

1) Benefits from savings grid-electricity
2) Benefits from the reduction of diesel consumption when operated at lower loading

The benefits from reduced grid electricity consumption will be based on the customer category mentioned in Table 6. The benefits of reducing diesel consumption will be based on hours of power outages.

Since most consumers use diesel generators for backup power supply during power outages, the reduction in diesel consumption has been calculated after integrating the PV system into their grid network. The reduction in diesel consumption has been calculated based on average savings at lower loading of diesel generator sets and hours of operation during power outages. A cumulative 60 hours of running time per month is considered. The reduction of fuel consumption at different loadings of diesel generators is presented in Table 15.

Table 15: Diesel generator fuel consumption and savings at different loading

Generator Size (kW)	25% Load (l/hour)	50% Load (l/hour)	75% Load (l/hour)	100% Load (l/hour)	Savings at 75% load (l/hour)	Savings at 50% load (l/hour)	Savings at 25% load (l/hour)
20	2.27	3.41	4.92	6.06	1.14	2.65	3.79
30	4.92	6.81	9.08	10.98	1.89	4.16	6.06
40	6.06	8.71	12.11	15.14	3.03	6.44	9.08
60	6.81	10.98	14.38	18.17	3.79	7.19	11.36
75	9.08	12.87	17.41	23.09	5.68	10.22	14.01
100	9.84	15.52	21.96	28.01	6.06	12.49	18.17
125	11.73	18.93	26.88	34.45	7.57	15.52	22.71
135	12.49	20.44	28.77	37.10	8.33	16.66	24.61
150	13.63	22.33	31.80	41.26	9.46	18.93	27.63

Table 16 summarises the financial benefits for consumers from grid electricity savings, diesel consumption reductions, and payback periods for their investments in rooftop PV projects. It has been observed that, in São Tomé Island, the typical payback period is around five (5) years with savings from grid electricity and reduced diesel consumption. The sites with no diesel generator will have a payback period of around six (6) years as there is no additional saving from reduced diesel consumption. Similarly, in Príncipe Island, payback with a diesel generator is around three (3) years; without a diesel generator, the same is around four (4) years. This difference is due to the higher tariff for grid electricity in Príncipe Island.

Table 16: Summary of savings and simple payback period for identified sites

Site No.	Site name	PV capacity	Estimated PV Generation (MWh/year)	PV electricity directly consumed (MWh/year)	Electricity tariff (USD/kWh)	Savings from electricity with net metering (USD/year)	Savings from electricity without net metering (USD/year)	Savings from DG set under loading (USD/year)	Cost of PV system (USD)	Simple payback period with net metering (Years)	Simple payback period without net metering (Years)
	São Tomé Island										
1	Supremo Tribunal de Justiça	107	139	82	0.26	36140	21320	2621	139100	3.59	5.81
2	Direção do Ensino Primário	32	42	29	0.26	10920	7540	1742	41600	3.29	4.48
3	Procurador/ Ministério publico	14	19	14	0.26	4940	3640	1383	18200	2.88	3.62
4	Ministério da Defesa	86	111	49	0.26	28860	12740	1742	111800	3.65	7.72

Site No.	Site name	PV capacity	Estimated PV Generation (MWh/year)	PV electricity directly consumed (MWh/year)	Electricity tariff (USD/kWh)	Savings from electricity with net metering (USD/year)	Savings from electricity without net metering (USD/year)	Savings from DG set under loading (USD/year)	Cost of PV system (USD)	Simple payback period with net metering (Years)	Simple payback period without net metering (Years)
5	Autoridade Geral De Regulaca (AGER)	13	17	12	0.26	4420	3120	1383	16900	2.91	3.75
6	Hospital Dr. Aires de Menezes	211	299	299	0.26	77740	77740	15805	274300	2.93	2.93
7	Ministério das Finanças e Economia Azul	169	218	97	0.26	56680	25220	4149	219700	3.61	7.48
8	Liceu Nacional	272	358	46	0.26	93080	11960	1729	353600	3.73	25.83
9	Ministério da Educação	23	30	21	0.26	7800	5460	1729	29900	3.14	4.16
10	Tribunal de Contas (with BESS)	34	44	44	0.26	11440	11440	2074	84200	6.23	6.23
11	Liceu Nacional de Santana	93	117	46	0.26	30420	11960	0	120900	3.97	10.11
12	Centro Polivalente de Caué	73	104	58	0.26	27040	15080	0	94900	3.51	6.29
13	Escola Secundaria de São João dos Angolares	24	31	9	0.26	8060	2340	0	31200	3.87	13.33
14	Posto de Saúde	53	74	45	0.26	19240	11700	1383	68900	3.34	5.27
15	Mercado de Bobo Foro	937	1318	310	0.26	342680	80600	0	1218100	3.55	15.11
16	Escola Secundaria Maria Manuela Margarido (MMM)	208	270	184	0.26	70200	47840	12910	270400	3.25	4.45
17	Escola Primária de Trindade	132	172	46	0.26	44720	11960	0	171600	3.84	14.35
18	Liceu Mé Chinhô	249	321	216	0.26	83460	56160	12910	323700	3.36	4.69
19	Centro Hospitalar de Lobata	8	11	11	0.26	2860	2860	1037	10400	2.67	2.67
20	Camara Distrital de Lobata	48	62	22	0.26	16120	5720	864	62400	3.67	9.48
21	Escola Secundária de Neves	96	133	18	0.26	34580	4680	0	124800	3.61	26.67
22	Escola Secundária de Santa Catarina	75	106	18	0.26	27560	4680	0	97500	3.54	20.83
23	Posto de Saude de Lembá	48	70	57	0.26	18200	14820	1729	62400	3.13	3.77
24	Camara Distrital de Lembá	47	66	16	0.26	17160	4160	0	61100	3.56	14.69
25	Fabrica de Chocolate (with BESS)	121	171	149	0.26	44460	38740	5426	217300	4.36	4.92
	Príncipe Island										
26	Direção Regional de Ambiente e Conservação da Natureza Príncipe	33	48	10	0.26	12480	2600	0	42900	3.44	16.50
27	Escola de Padrão	114	164	19	0.26	42640	4940	0	148200	3.48	30.00

Site No.	Site name	PV capacity	Estimated PV Generation (MWh/year)	PV electricity directly consumed (MWh/year)	Electricity tariff (USD/kWh)	Savings from electricity with net metering (USD/year)	Savings from electricity without net metering (USD/year)	Savings from DG set under loading (USD/year)	Cost of PV system (USD)	Simple payback period with net metering (Years)	Simple payback period without net metering (Years)
28	Banco Internacional de São Tomé E Príncipe (BISTP) (with BESS)	70	98	98	0.42	41160	41160	9404	211000	4.17	4.17
29	Casa da Cultura	24	31	18	0.26	8060	4680	691	31200	3.57	5.81
30	Escola de Santo Antonio	78	110	19	0.26	28600	4940	0	101400	3.55	20.53
31	Hospital DR. Manuel Quaresma Dias Da Graça (with BESS)	75	99	99	0.42	41580	41580	2634	157500	3.56	3.56

Additional diesel savings will be achieved for the PV systems with BESS, as BESS will replace the diesel generator for a specified time based on the BESS capacity and duration of power outages. However, the payback period will be longer due to the additional cost of BESS. These sites were selected based on discussions with the respective customers.

4.3 FINANCIAL BENEFITS TO UTILITY COMPANY EMAE

Benefits from reduced consumption of diesel:

The available diesel generator capacity in São Tomé Island is 16.93 MW and 1.1 MW in Príncipe Island as presented in Table 17.

Table 17: Available central diesel generation capacity in São Tomé and Príncipe in 2022 [7]

Plants	Available capacity (MW)
Sao Tomé thermoelectric plants	1.40
Santo Amaro I	5.10
Santo Amaro II	3.30
Santo Amaro III	6.40
Bobo Forro II	0.728
Príncipe	1.10

The fuel consumption in a diesel power generator varies when it operates at different loading or capacity. Fuel consumption decreases when a diesel generator operates at a lower load. However, specific fuel consumption, i.e. diesel consumption per kWh of electricity generation, increases at lower loading. For example, when operated continuously, a Caterpillar Cat 3516 diesel generator consumes 326.3 litres per hour at 100% loading and 181.5 litres per hour at 50% loading (Figure 108). Therefore, at 50% loading, the generator consumes 44.38% less fuel. However, the specific fuel consumption of the generator will be 0.255 litre/kWh at 100% loading and 0.284 litres/kWh at 50% loading, which is an increase of 11.37%. Therefore, if this generator operates for 24 hours at 100% loading, it will consume 7831.2 litres of diesel and generate 30720 kWh of electricity. When the generator operates at 50% loading, it will consume 4356 litres of diesel, generating 15360 kWh of electricity.

Performance	Standby		Mission Critical		Prime		Continuous	
Frequency	50 Hz		50 Hz		50 Hz		50 Hz	
Gen set power rating with fan	1600 ekW		1600 ekW		1460 ekW		1280 ekW	
Gen set power rating with fan @ 0.8 power factor	2000 kVA		2000 kVA		1825 kVA		1600 kVA	
Emissions	Low Fuel		Low Fuel		Low Fuel		Low Fuel	
Performance number	DM7961-03		EM0609-01		DM7962-03		DM7963-02	
Fuel Consumption								
100% load with fan – L/hr (gal/hr)	405.7	(107.2)	405.7	(107.2)	370.6	(97.9)	326.3	(86.2)
75% load with fan – L/hr (gal/hr)	305.7	(80.8)	305.7	(80.8)	282.8	(74.7)	252.3	(66.6)
50% load with fan – L/hr (gal/hr)	217.3	(57.4)	217.3	(57.4)	203.1	(53.7)	181.5	(48.0)
25% load with fan – L/hr (gal/hr)	126.4	(33.4)	126.4	(33.4)	119.5	(31.6)	109.0	(28.8)

Figure 108: Fuel consumption of Caterpillar Cat 3516 diesel generator set (Source-Caterpillar)

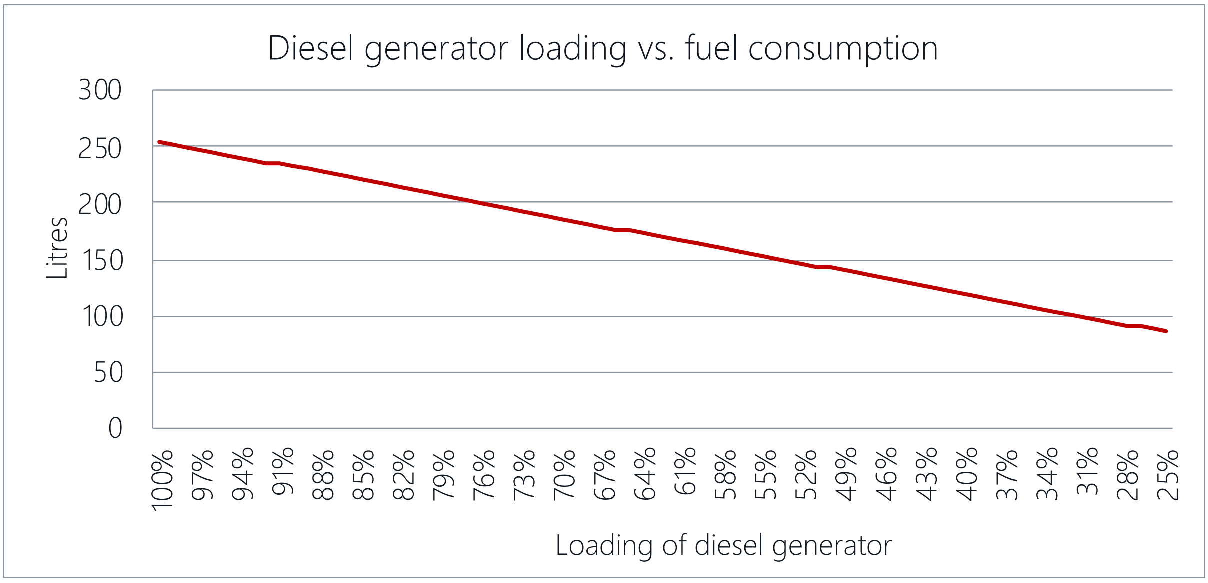


Figure 109: Diesel generator fuel consumption vs loading (1 MW plant) (Source: Caterpillar)

Diesel savings are calculated considering installing 1080 kW_p rooftop PV systems in São Tomé Island and 160 kW_p rooftop PV in Príncipe Island. Diesel generator loading is estimated based on load profile and solar power available in a 15-minute time block. For São Tomé Island, it is estimated that 1080 kW_p rooftop solar power plants will generate 1.47 GWh of electricity annually and save 329,000 litres of diesel annually. Considering the retail price of diesel as STN 35 (($US 1.5) per litre, the total amount saved by EMAE from reduced diesel consumption will be about US$ 500,000 per year. However, EMAE will also lose revenue from lesser electricity consumption, @STN 6.03/kWh, and the total revenue loss will be about US$ 385700. Therefore, the net financial benefit to EMAE will be US$ 114,300 per year.

Similarly, for Príncipe Island, 185 kW_p rooftop solar power plants will generate 0.27 GWh of electricity annually and save 61,180 litres of diesel annually. Considering the retail price of diesel as STN 35 per litre, the total amount saved by EMAE from reduced diesel consumption will be about US$ 93,100 per year, and revenue loss from 270,000 kWh of solar electricity @ STN 9.87 per kWh will be about US$ 115,865 per year. Therefore, the net financial loss to EMAE will be US$ 22,765 per year.

Table 18 presents monthly electricity demand, solar energy generation and diesel fuel savings in São Tomé Island. Table 19 presents monthly electricity demand, solar energy generation and diesel fuel savings in Príncipe Island.

Table 18: Summary of diesel fuel savings in São Tomé Island

Months	Electricity demand in São Tomé (GWh)	Solar energy generation from 1.08 MW_p (GWh)	Estimated fuel consumption without solar [A] (kilo liter)	Estimated fuel consumption at reduced load with solar [B] (kilo liter)	Fuel savings [A]-[B] (kilo liter)
January	8.42	0.13	2145	2116	28
February	7.61	0.11	1937	1913	24
March	8.42	0.13	2145	2117	28
April	8.15	0.12	2076	2048	27
May	8.42	0.12	2145	2118	27
June	8.15	0.11	2076	2051	24
July	8.42	0.12	2145	2119	26
August	8.42	0.12	2145	2117	28
September	8.15	0.13	2076	2046	30
October	8.42	0.14	2145	2113	32
November	8.15	0.13	2076	2047	28
December	8.42	0.12	2145	2118	27
Total	99.15	1.47	25252	24923	329

Table 19: Summary of diesel fuel savings in Príncipe Island

Months	Electricity demand in Principe (GWh)	Solar energy generation from 185 kW_p (GWh)	Estimated fuel consumption without solar [A] (kilo liter)	Estimated fuel consumption at reduced load with solar [B] (kilo liter)	Fuel savings [A]-[B] (kilo liter)
January	0.94	0.02	238	233	5.33
February	0.85	0.02	215	211	4.55
March	0.94	0.02	238	233	5.31
April	0.91	0.02	231	226	5.09
May	0.94	0.02	238	233	4.95
June	0.91	0.02	231	226	4.46
July	0.94	0.02	238	234	4.74
August	0.94	0.02	238	233	5.12
September	0.91	0.02	231	225	5.44
October	0.94	0.03	238	232	5.94
November	0.91	0.02	231	225	5.30
December	0.94	0.02	238	233	4.95
Total	11.02	0.27	2806	2745	61.18

Benefit from avoided generation:

When solar power is available during the day, the load on the diesel generators will be reduced, reducing fuel consumption, as explained in the previous section. When multiple generators operate in parallel, switching off certain generators is possible based on the power demand and solar power available during the daytime, as shown in Figure 110. However, to ensure stability in the power supply, solar power generation must be stable and firm, which is different in real-life situations.

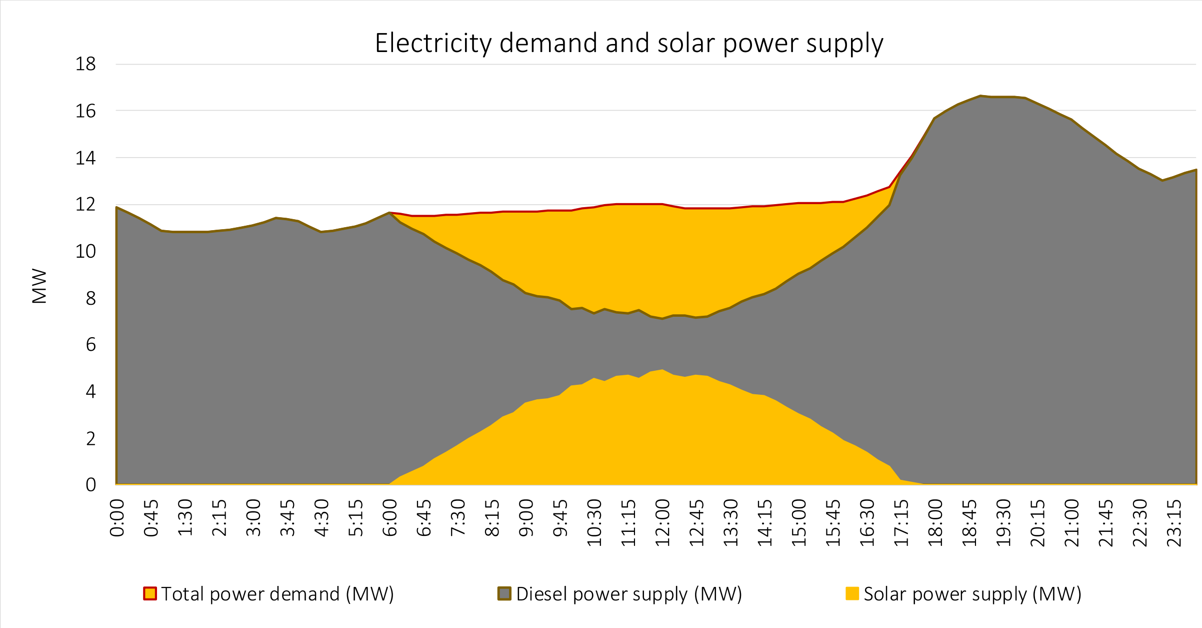


Figure 110: Typical day load profile and average solar power contribution

A battery energy storage system (BESS) is a feasible option for stabilising this variation of solar energy generation and ensuring a smooth solar power generation profile. The capacity of battery energy storage for stabilising solar power is determined based on diurnal cloud coverage in the sky, which is discussed in the next section.

Benefit from deferred grid upgradation:

São Tomé and Príncipe's power distribution system requires renovation and major upgrades to integrate large-scale renewable power generators. Installation of distributed renewable energy systems, such as rooftop PV systems, will take the load off the distribution system, as they generate and consume power locally. This will reduce ohmic loss, improve the distribution system's decongestion, and stabilise the network components. Therefore, installing distributed rooftop PV systems with or without BESS will defer the investment required for network upgrades.

4.4 ENERGY STORAGE REQUIREMENT

Figure 111 below shows the average solar generation profile derived using daily average solar irradiance values. However, the availability of solar irradiance is variable due to cloud presence in the atmosphere. Therefore, the output of solar power plants will also be variable. A typical daily solar power generation profile is superimposed on the average generation profile in Figure 111.

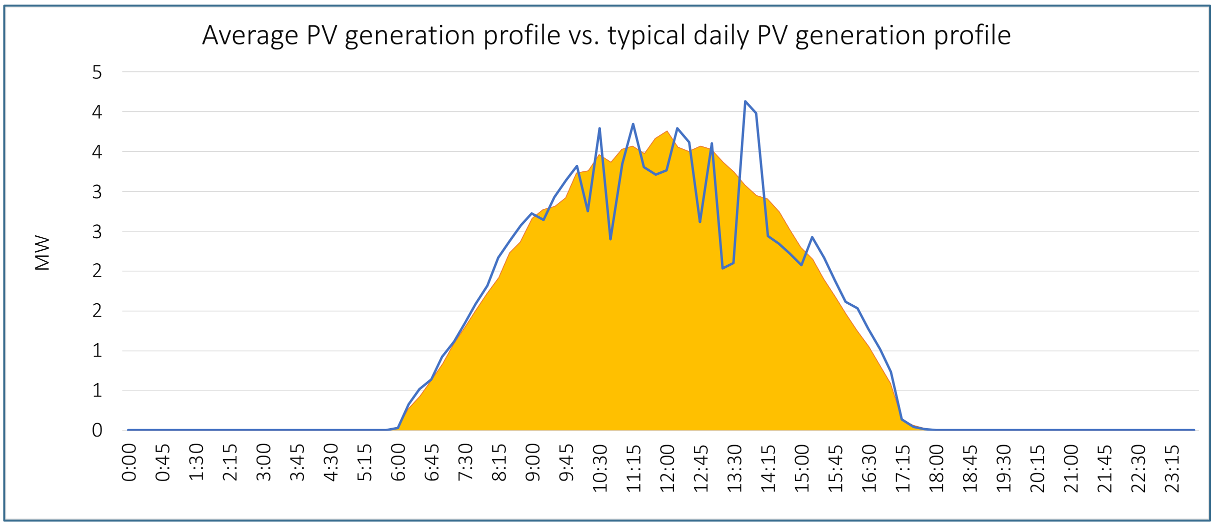


Figure 111: Solar power generation profile – average and actual on a typical day

The amount of variation or change in power generation at a certain moment will be driven by the cloud presence in the sky. Figure 112 presents the diurnal cloud coverage of São Tomé and Príncipe; the maximum coverage between 8 a.m. and 4 p.m. is 78%.

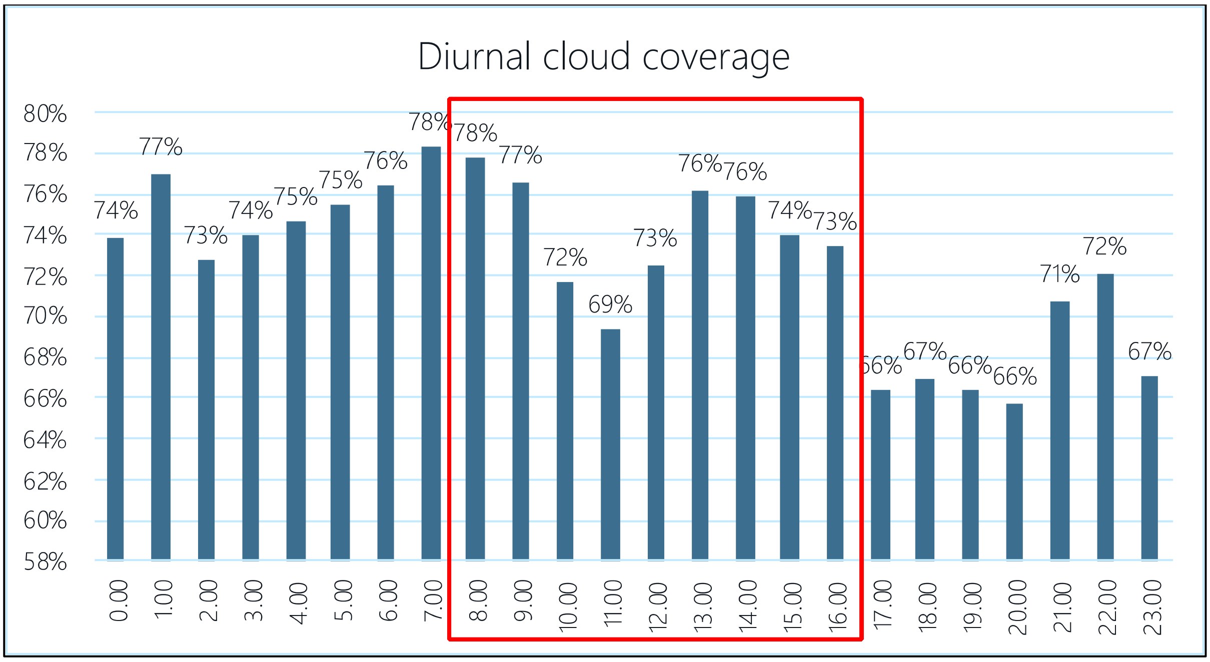


Figure 112: Diurnal cloud coverage of São Tomé and Príncipe (Source: NASA)

To overcome the variation in power generation, a battery energy storage system (BESS) can be used to smoothen the generation profile. Therefore, using BESS at a central location or the consumers' end is necessary to deliver firm power from the solar power plants in a predicted generation profile. Operation of diesel generator sets can be scheduled with a firm and schedulable solar power generation.

Figure 113 presents surplus and deficit solar power generation to the average estimated power generation from a 1 MW_p solar power plant.

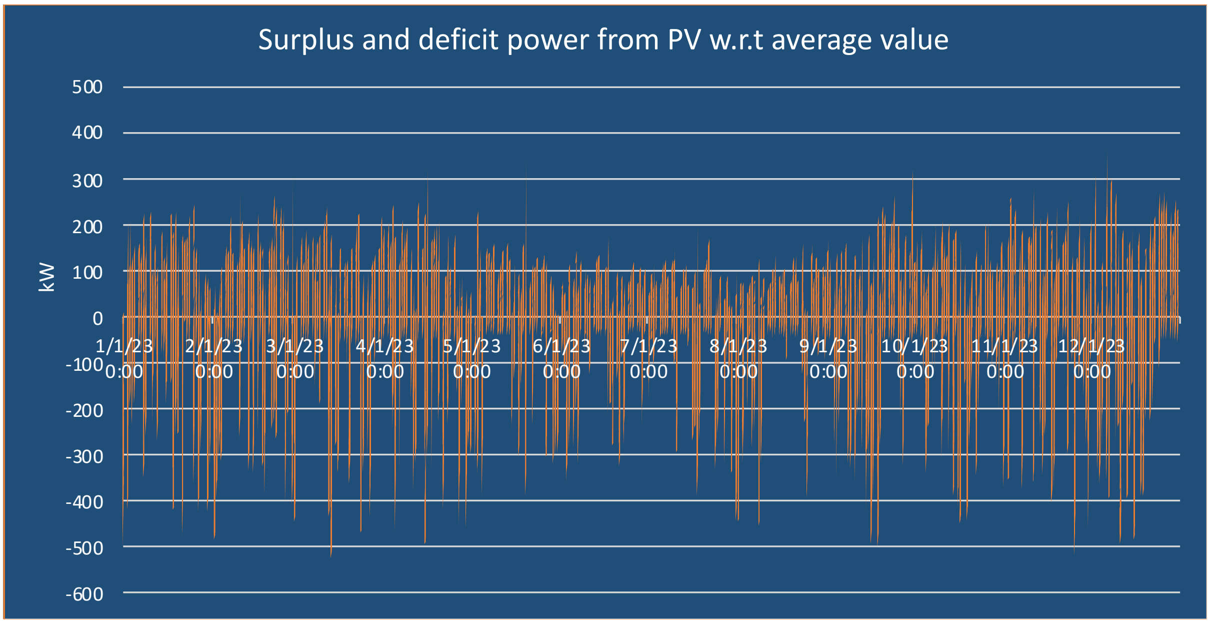


Figure 113: Surplus and deficit power from 1 MW_p PV power plant w.r.t average value

The maximum deficit power with respect to the average value is 526 kW for a 15-minute interval of solar data. However, occasions of deficit power occur at 500 kW, or more only 3 times in a year. Figure 114 shows the number of occasions of deficit power at different levels. The project owners/ operators may decide at what level of power deficit they want to run the solar power plant with predetermined firm power based on the cost of the battery system and/or based on regulatory requirements.

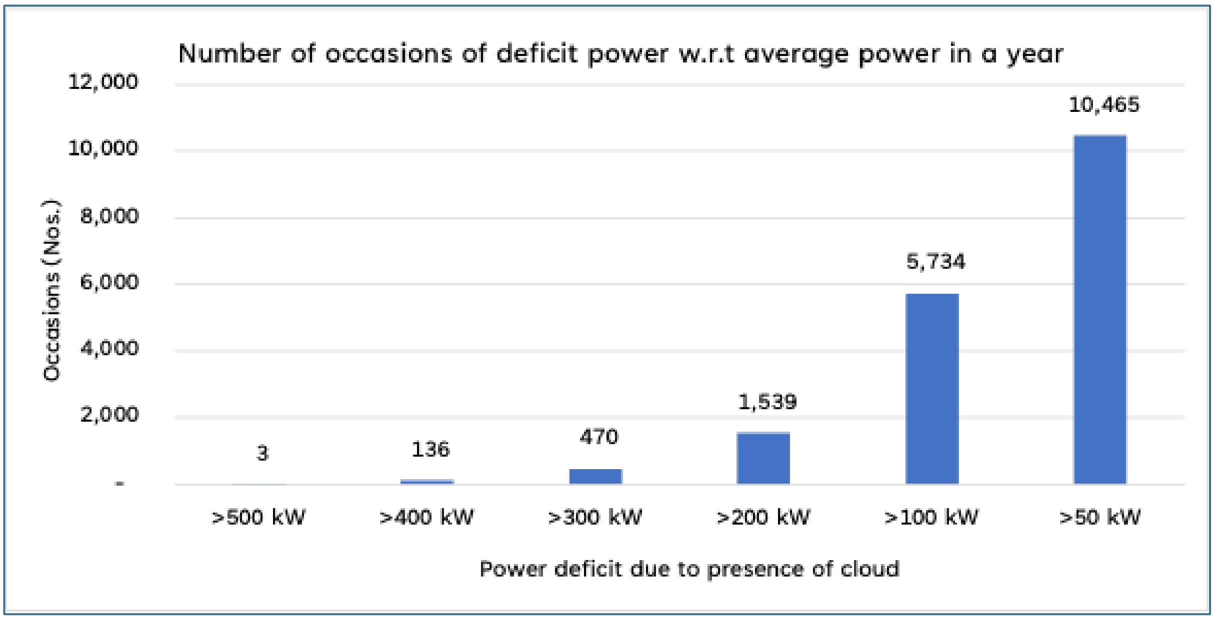


Figure 114: Number of occasions of deficit power w.r.t average value at different levels

On the other hand, the required battery energy capacity will be based on the duration of the deficit power with respect to the average firm power intended to be supplied. For this purpose, battery energy capacity is designed for a typical day, considering the worst day (having a higher power deficit with larger occasions of power deficit) in a year. This exercise was carried out using the GSES in-house battery sizing tool for a utility-scale solar power plant for 365 days of a typical year with a 15-minute time-block. Based on the analysis, the maximum battery storage capacity required per MW_p PV plant installed in STP is estimated to be 3200 kWh with maximum cloud coverage, and the average battery capacity required per MW_p solar power installed capacity is 800 kWh. In this case, the project owners/operators may also decide at what level of average power they want to run the solar power plant with the certainty of firm power based on the cost of the battery system, diesel saving plan and/or the regulatory requirements.

4.5 STRATEGY TO MINIMISE DIESEL IMPORT

More than 95% of electricity in São Tomé and Príncipe is generated from diesel generators. The country imports about 35,000 kilo-litres (~30,000 tonnes) per year. Figure 115 presents the projection of diesel imports until 2050 as per NREAP.

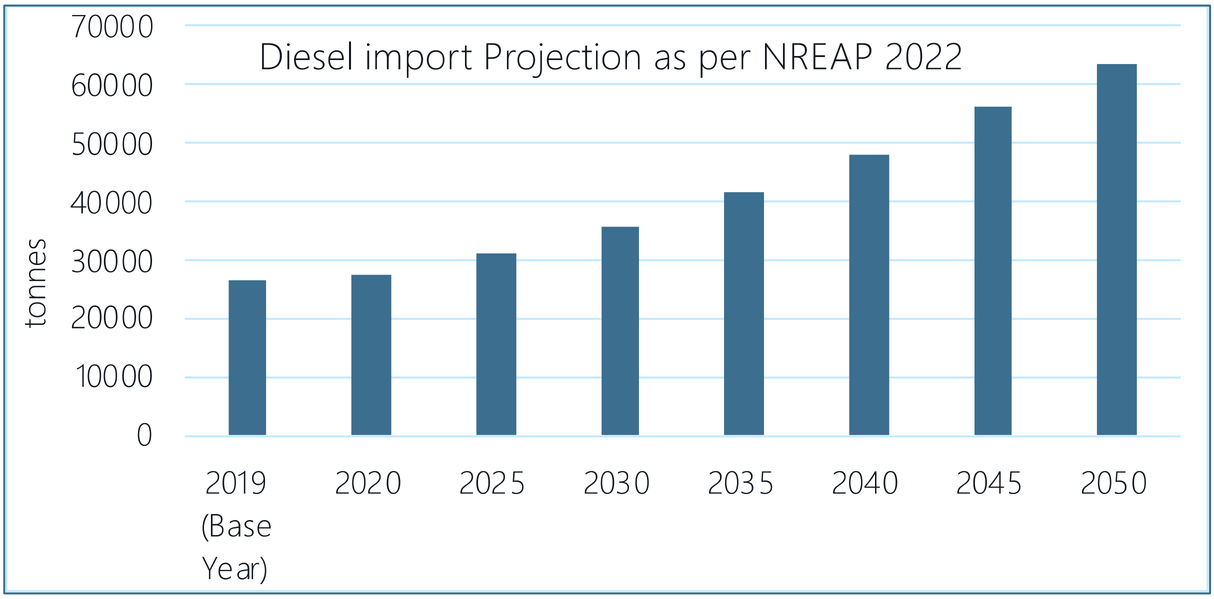


Figure 115: Projected diesel import considering 2019 as the base year

The country's current electricity demand is 110 GWh per year, which is likely to increase based on the electrification plan and progress in economic activities. If annual growth is 10%, the electricity demand by 2030 will be 177 GWh per year, and the average electrical power demand will be 19 MW with a peak power demand of about 27 MW, as presented in Table 20.

Table 20: Projected electricity power and energy demand and São Tomé and Príncipe

	Units	2024-25	2025-26	2026-27	2027-28	2028-29	2029-30
Average and peak power demand	MW	12 (17)	13 (18)	14 (20)	16 (22)	17 (24)	19 (27)
Electricity demand	GWh	110	121	133	147	161	177

More than 80% of diesel fuel imported to the country is used for electricity generation. Transitioning to renewable energy generation with battery energy storage will substantially reduce diesel fuel consumption for power generation. The government provides a subsidy on diesel for power generation by EMAE @1.00 USD per litre.

Three scenarios have been created to estimate the potential reduction in diesel consumption, considering the present electricity demand and diesel consumption as the base case. The base case timeline is 2024-25, and three scenarios are created based on projected electricity demand by 2029-30. Assumptions for the base case and different scenarios are explained below.

Base case: In the base case, electricity demand is 110 GWh per year, with an average of 12 MW and a peak of 17 MW. Diesel generators primarily supply electricity. Other sources of electricity supply are considered 1 MW hydropower, 2.2 MW_p central solar power plants and 1.24 MW_p distributed solar power plants. The operating capacity of diesel generators is 15.6 MW. The electricity demand and supply scenario on a typical day in a 15-minute time block is presented in Figure 116.

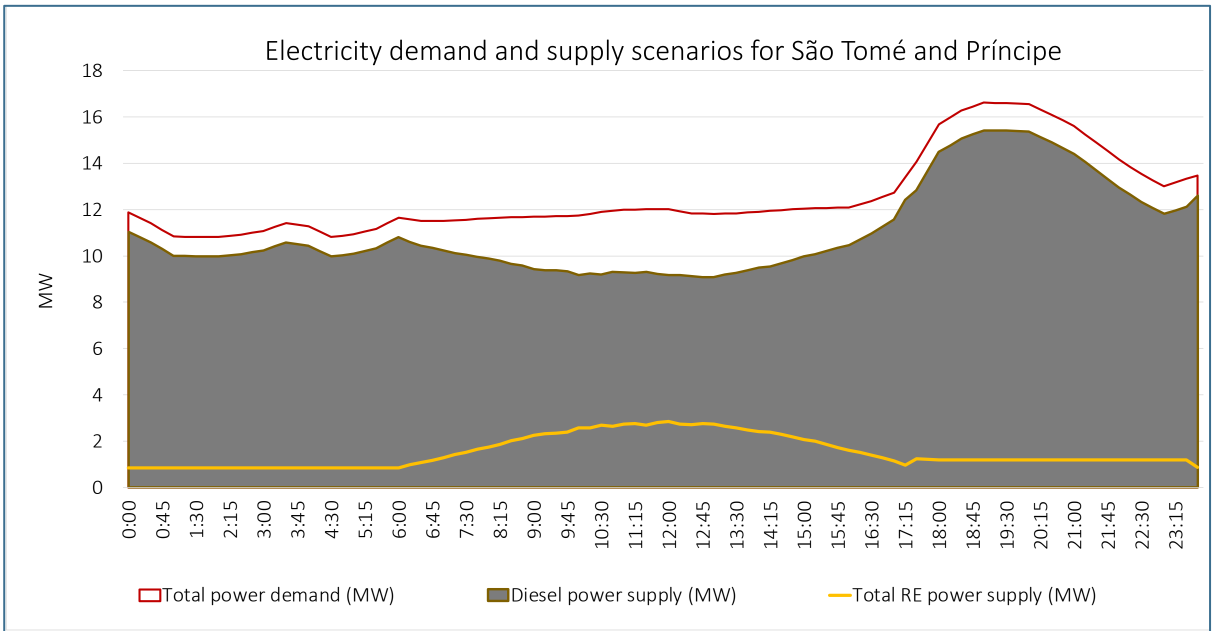


Figure 116: STP electricity demand and supply scenario (Base case – typical day)

In the base case, the estimated electricity demand is 110 GWh/year, of which diesel generators supply 89.35%. The share of renewable electricity is 10.70% from 1.0 MW hydropower plant, 2.2 MW_p central solar power plant, and 1.24 MW_p distributed solar plants. The estimated reduction of diesel consumption due to integrating renewable energy sources into the grid is 4.35%.

Scenario 1: In this scenario, the estimated projected electricity demand is 177 GWh per year. The average power demand is 19 MW, and the peak is 27 MW. The total renewable energy capacity added to the grid is 23.74 MW, out of which 17.2 MW_p centralised solar power plants, 1.24 MWp decentralised solar power plants and 5.3 MW hydropower generators, including 4.3 MW rehabilitated hydropower plants as per the NREAP. The electricity demand and supply scenario on a typical day in a 15-minute time block is presented in Figure 117.

In this scenario, renewable electricity accounts for 35.23% of total electricity demand. Maximum diesel power demand is 21.5 MW, contributing 64.77% of total electricity demand. The estimated reduction of diesel consumption after integrating renewable energy sources into the grid is 29.45%.

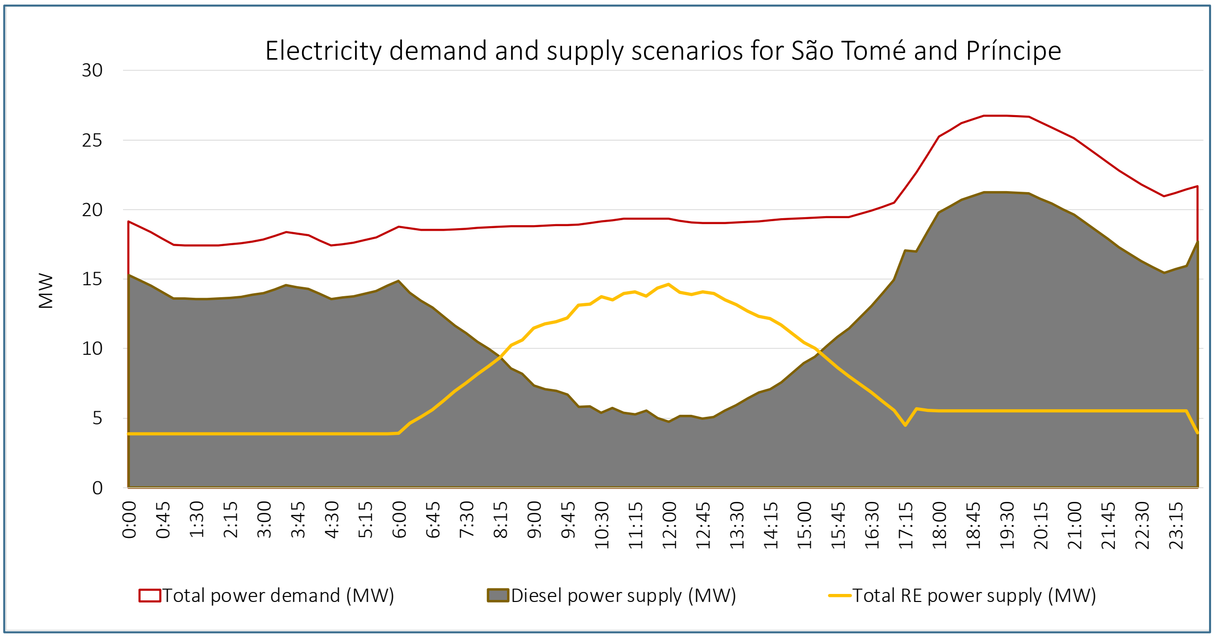


Figure 117: STP electricity demand and supply scenario (Scenario 1 – typical day)

Scenario 2: In this scenario, the estimated projected electricity demand is similar to scenario 1. The total renewable energy capacity added to the grid is 38.14 MW, out of which 27.2 MW_p centralised solar power plants, 3.64 MW_p decentralised solar power plants and 7.3 MW hydropower generators, including 2 MW new hydropower plant and 4.3 MW rehabilitated hydropower plants as per the NREAP. The electricity demand and supply scenario on a typical day in a 15-minute time block is presented in Figure 118.

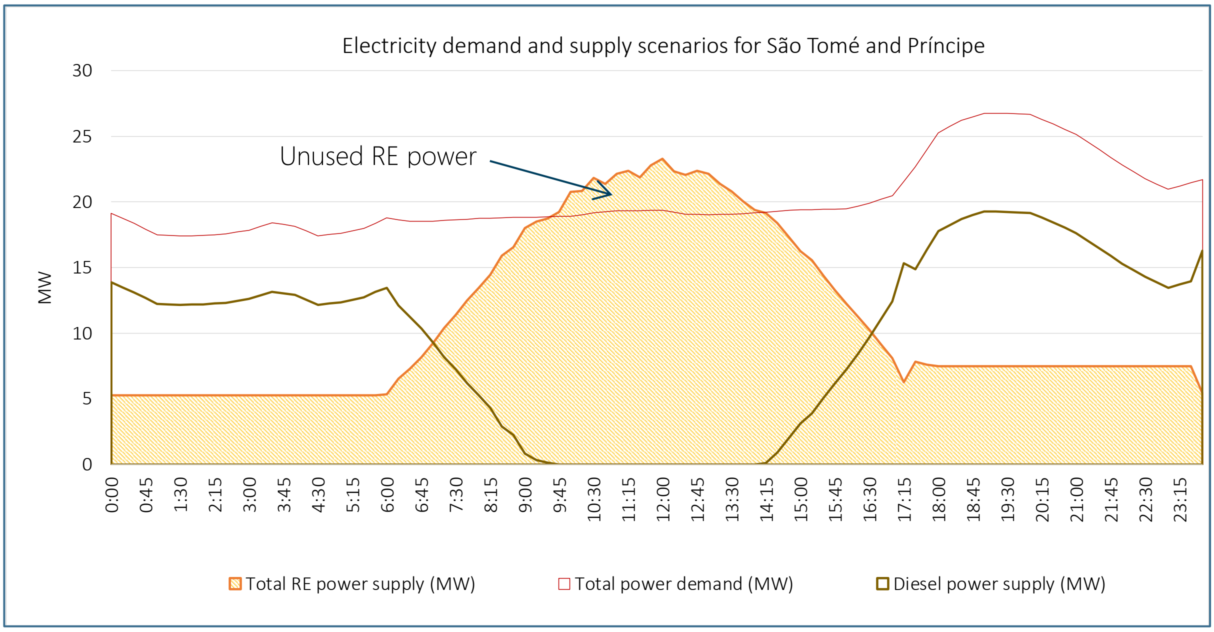


Figure 118: STP electricity demand and supply scenario (Scenario 2 – typical day)

In this scenario, renewable energy contributes 50.94%, and diesel power contributes 49.06% of total electricity demand. The estimated reduction of diesel consumption after integrating renewable energy sources into the grid is 45.81%. In this scenario, 3.88% (3.65 GWh/year) of renewable energy will remain unused due to a mismatch between demand and supply profiles. This access energy will be unused during the daytime and can be stored using battery energy storage (BESS) or pump storage systems. The stored energy can be used to meet peak power demand in the evening hours.

Scenario 3: In this scenario, the estimated projected electricity demand is similar to scenario 2. The total renewable energy capacity added to the grid is 71.33 MW, of which 47.2 MW_p centralised solar power plants, 2.4 MW_p decentralised solar power plants, 17.3 MW hydropower generators, and 4.68 MW biomass power plant as per the NREAP. The electricity demand and supply scenario on a typical day in a 15-minute time block is presented in Figure 119.

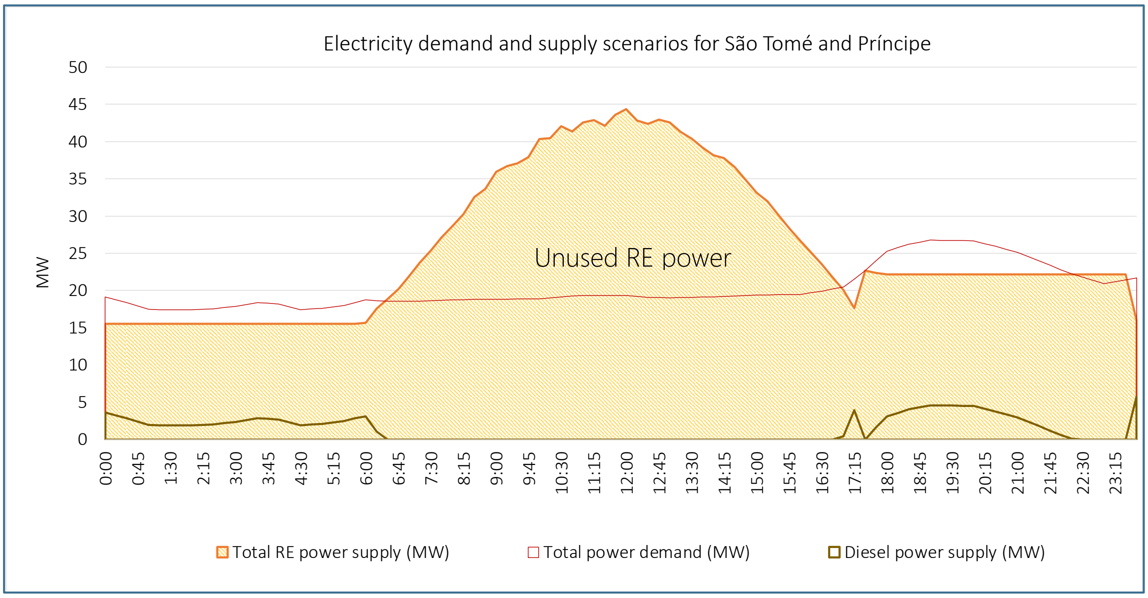


Figure 119: STP electricity demand and supply scenario (Scenario 3 – typical day)

In this scenario, renewable energy contributes 90.10%, and diesel power contributes 9.9% of total electricity demand. The estimated reduction of diesel consumption after integrating renewable energy sources into the grid is 87.27%. In this scenario, 27.24% (59.81 GWh/year) of renewable energy will remain unused due to a mismatch between demand and supply profiles. This access energy will be unused during the daytime and can be stored using battery energy storage (BESS) or pump storage systems. The stored energy can be used to meet peak power demand in the evening hours.

Table 21 and Table 22 summarises renewable energy capacity and energy generation in different scenarios, and Table 23 summarises renewable energy fraction and diesel savings in different scenarios.

Table 21: Summary of Renewable Energy capacity in different scenarios

Renewable energy options	Units	Base case	Scenario 1	Scenario 2	Scenario 3
Existing solar (central)	MW	2.2	2.2	2.2	2.2
Operational hydro	MW	1.0	1.0	1.0	1.0
Distributed solar	MW	1.24	1.24	3.64	2.40

Renewable energy options	Units	Base case	Scenario 1	Scenario 2	Scenario 3
Central solar power plant	MW	0	15	25	45
Rehabilitated hydropower plant	MW	0	4.3	4.3	4.3
New hydropower plant	MW	0	0	2	12
Biomass power plant	MW	0	0	0	4.68
Total renewable power	MW	4.44	24	38	72

Table 22: Summary of Renewable Energy Generation in different scenarios

Renewable energy options	Units	Base case	Scenario 1	Scenario 2	Scenario 3
Existing solar (central)	GWh/y	3.20	3.20	3.20	3.20
Operational hydro	GWh/y	6.60	6.60	6.60	6.60
Distributed solar	GWh/y	1.80	1.80	5.30	8.20
Central solar power plant	GWh/y	0	21.90	43.70	65.20
Rehabilitated hydropower plant	GWh/y	0	28.00	28.00	28.00
New hydropower plant	GWh/y	0	0	13	79.00
Biomass power plant	GWh/y	0	0	0	20.50
Total renewable energy	GWh/y	11.6	61.5	99.8	210.7

Table 23: Summary of RE fraction and diesel savings in different scenarios

Parameters	Base Case	Scenario 1	Scenario 2	Scenario 3
Estimated electricity demand (GWh/year)	110	177	177	177
Fraction of electricity demand met by RE (% of total electricity demand)	10.70%	35.23%	50.94%	90.10%
Estimated diesel savings due to solar power generation (kiloliters/year)	1000	5380	10440	15320
Estimated diesel savings due to hydropower generation (kiloliters/year)	1320	6920	9520	22720
Estimated diesel savings due to biomass power generation (kiloliters/year)	-	-	-	4100
Total diesel savings due to RE power generation (kiloliters/year)	2320	12300	19960	42140
Total amount saved from reduced diesel import for power generation (Million USD/year)	3.48	18.45	29.94	63.21
Government revenue saved from avoided subsidy on diesel for power generation (Million USD/year)	2.32	12.30	19.96	42.14

Note: Diesel saving is estimated considering 200 kilolitres of diesel per GWh at 75% loading

5 PROJECT IMPLEMENTATION ROADMAP

The National Renewable Energy Action Plan (NREAP 2022) laid out an implementation plan for renewable energy projects. The NREAP has specific recommendations for implementing solar PV and BESS projects, as presented in Figure 120.

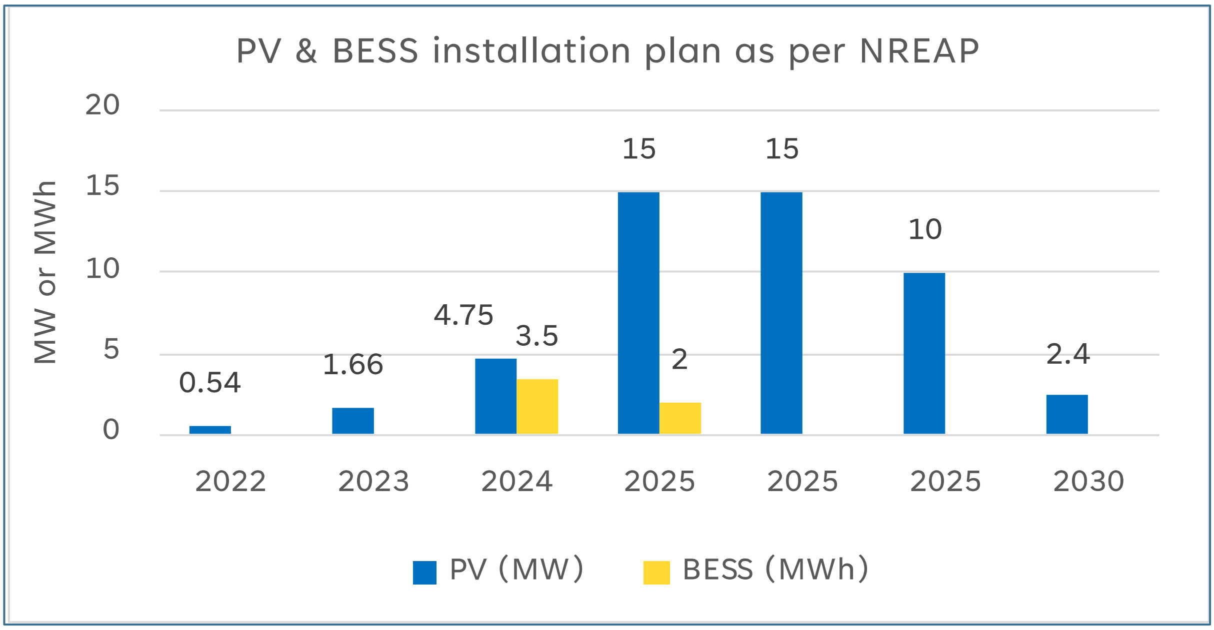


Figure 120: Implementation of solar power projects in STP as per NREAP

Solar PV projects in São Tomé and Príncipe can be implemented through (1) distributed generation systems and (2) centralised generating plants. Potential business models for the implementation of distributed generation systems and central generating power plants are elaborated in the following sections:

5.1 IMPLEMENTATION OF DISTRIBUTED SOLAR SYSTEMS

Distributed solar systems in São Tomé and Príncipe can be implemented through either the Capital Expenditure (CAPEX) or the Operating Expenditure (OPEX) business model. The OPEX business model can be implemented for either single users or multiple aggregated users. All three business models have been elaborated in the following sections:

5.1.1 CAPEX BUSINESS MODEL

In the CAPEX business model, the building owner, the electricity consumer, directly funds the implementation of their own solar PV system. The funds may be taken from the owner's budget or financial assistance from government agencies or donors. The PV system can be developed via a qualified solar company chosen through an open bid process. The building management team arranges the operation and maintenance of the PV system. An illustration of the CAPEX business model is given in Figure 121. The system is generally installed for captive power generation to reduce grid electricity consumption with or without a net metering arrangement. The system shall be synchronised with the existing diesel generator to work in tandem in the absence of a grid during a power outage. A grid-connected PV system with battery storage can be installed using multimode or hybrid inverters, which will enable the system to perform when there is no grid and no diesel generator. This system can also replace the existing diesel generator.

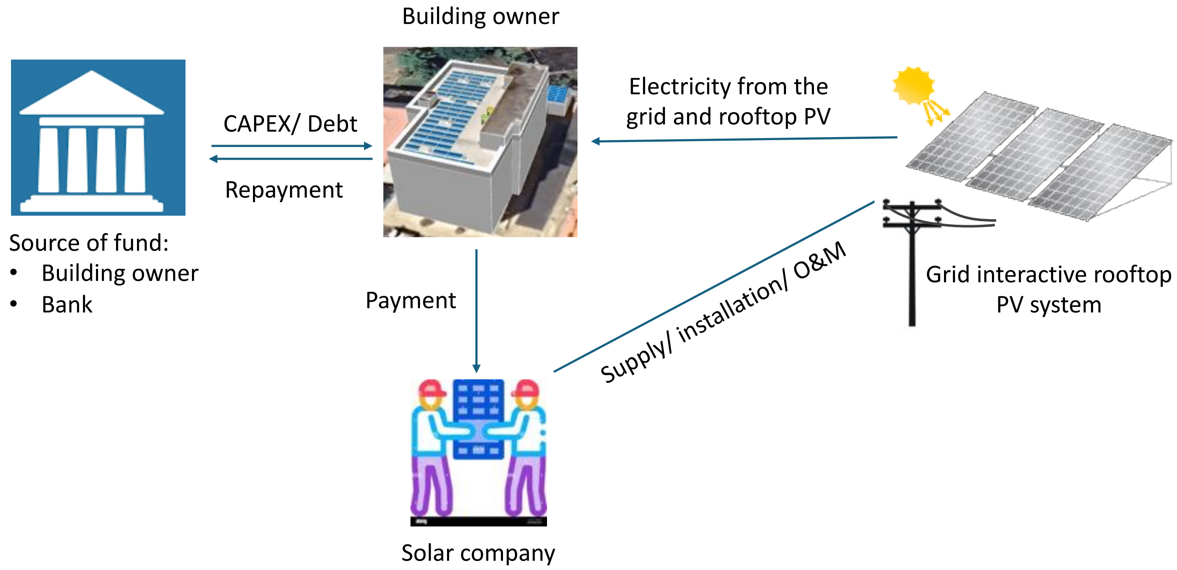


Figure 121: CAPEX business model for solar PV installation

5.1.2 OPEX BUSINESS MODEL (SINGLE USER)

In the OPEX single-user business model, the building owner engages a Renewable Energy Service Company (RESCO) to install and operate the solar PV system. In this case, the RESCO funds the PV project by taking loans from a bank or financial institution, and the owner procures electricity as per a power purchase agreement (PPA). The operation of the PV plant can be done either under a Build Own and Operate (BOO) model or a Build Operate and Transfer (BOOT) model. Under the BOO model, the RESCO will develop, own, and operate the PV plant for its entire lifetime. Under the BOOT model, the RESCO will operate the plant for a mutually agreed period and then transfer the plant to the owner after this period ends. An illustration of the OPEX business model is given in Figure 122. The system is generally installed for captive power generation to reduce grid electricity consumption with or without a net metering arrangement. The system shall be synchronised with the existing diesel generator to work in tandem in the absence of a grid during a power outage.

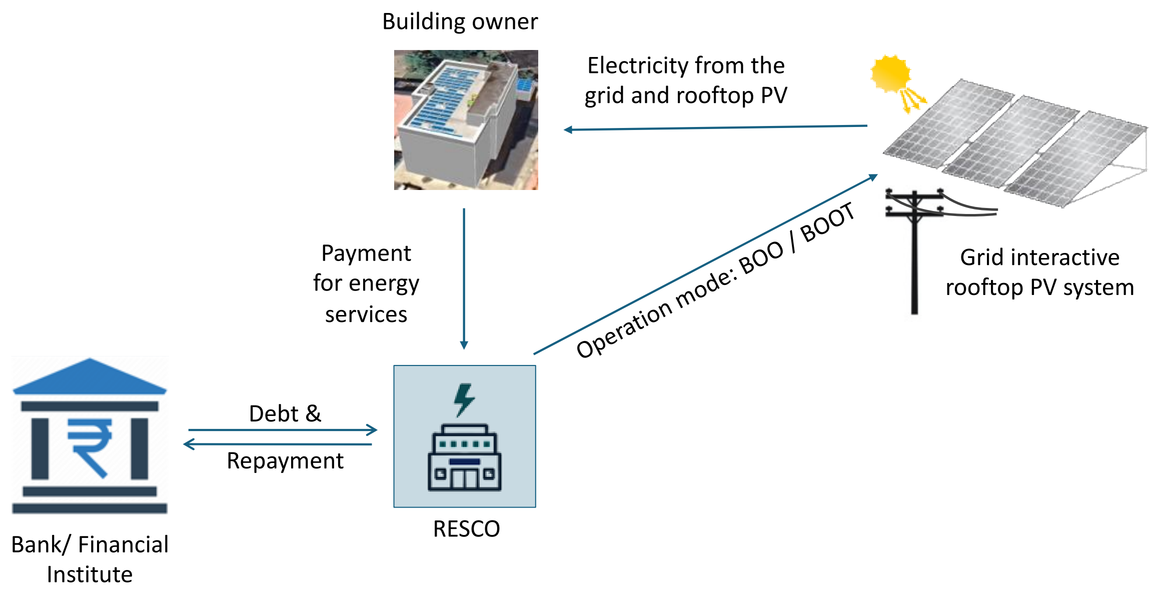


Figure 122: OPEX business model (single user) for solar PV installation

5.1.3 IMPLEMENTATION TIMELINE FOR SINGLE ROOFTOP PROJECT

The implementation timeline for rooftop PV plants of different capacities up to about 250 kW will be 7 - 8 months in the country. All major equipment, such as PV modules, inverters, and batteries, will be imported to the country, which will take about 3-4 months. An implementation schedule outlining the sequence of major activities and the time required for engineering, procurement and construction of a single rooftop PV plant is presented as a bar chart in Table 27 below.

Table 24: Implementation schedule for rooftop PV project up to about 250 kW capacity

Sl. No.	Task/Activities	Plant construction period in months							
		1	2	3	4	5	6	7	8
1	Contracting / Vendor/RESCO finalisation								
2	Site layout planning design								
3	Detailed electrical and structure design								
4	Materials procurement and delivery at site								
5	Installation of mounting structure								
6	Mounting of PV Modules								
7	Installation of Inverters								
8	Wiring and cabling work								
9	Testing and Commissioning								

5.1.4 OPEX BUSINESS MODEL (AGGREGATED USERS)

In the OPEX business model for aggregated users, a group of buildings is aggregated to form a cluster. The PV systems are installed, operated, and maintained by a single RESCO. Like in the OPEX single-user model, the RESCO will fund, build, and operate the PV systems. Figure 123 illustrates the OPEX business model.

For example, the relevant government department or private entity can aggregate a group of buildings under its control, which will act as the aggregator in this case. The aggregator will invite a RESCO to deploy the solar PV systems in that cluster of buildings. This business model is also attractive for solar developers due to its large total capacity. A power purchase agreement (PPA) will be made between the RESCO and the individual building owners as consumers and the government department as facilitator/ guarantor. If the government department collectively pays the electricity bills for multiple users (e.g. schools), the PPA can be signed directly with the concerned department.

Under this business model, sizable projects can be deployed swiftly via private investment. The government department would primarily focus on supporting private investors in executing the project. This involves offering viability gap funding to enhance the investment's attractiveness and ensuring power purchase for a specified duration at a competitive predetermined tariff.

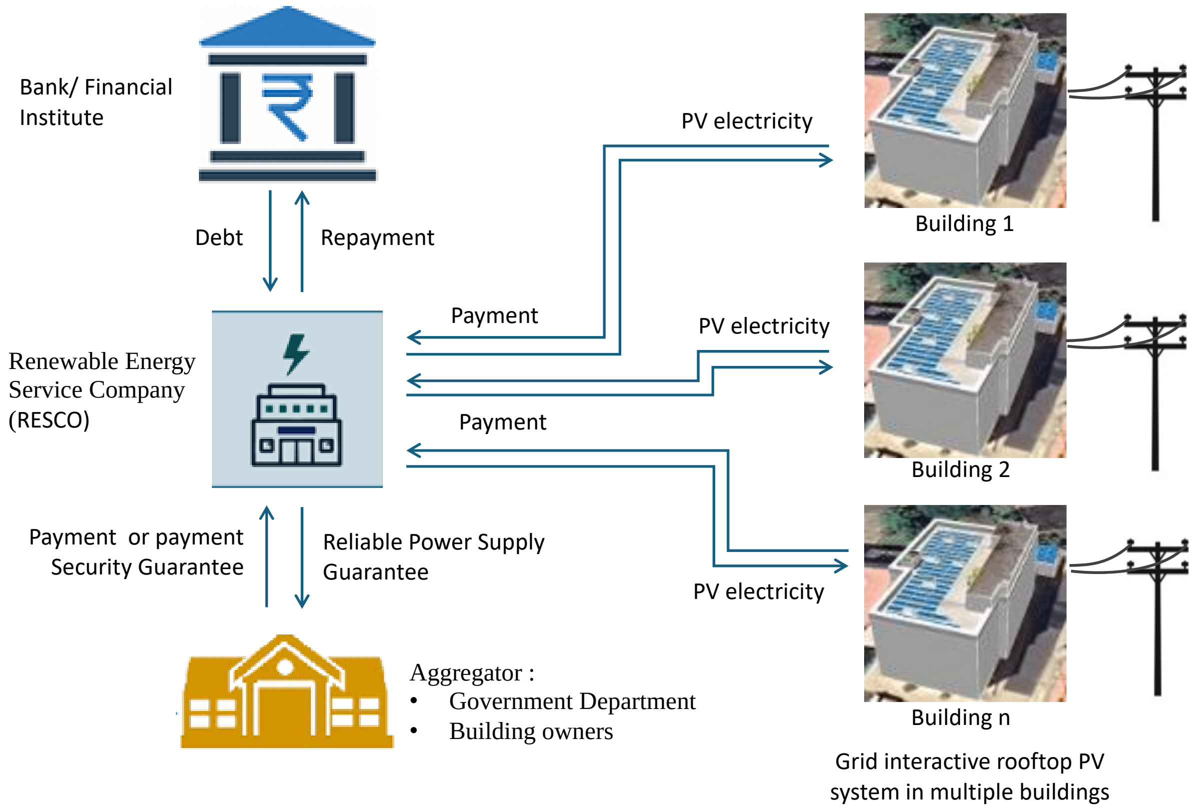


Figure 123: OPEX business model (aggregated users) for solar PV installation

5.1.5 IMPLEMENTATION TIMELINE FOR AGGREGATED OPEX MODEL

The implementation timeline for rooftop PV plants under the aggregated Opex business model will be around 12 months. Project preparation activities, such as the aggregation of customers and the bidding process, will take about four months. All major equipment, such as PV modules, inverters, and batteries, will be imported to the country, which will take about four months. An implementation schedule outlining the sequence of major activities and the time required for engineering, procurement and construction of a single rooftop PV plant is presented as a bar chart in Table 28 below.

Table 25: Implementation schedule for aggregated rooftop PV projects

Sl. No	Task/Activities	Plant construction period in months											
		1	2	3	4	5	6	7	8	9	10	11	12
1	Project preparation and aggregation												
2	Tender preparation bidding process												
3	Bid evaluation and selection of developers												
4	Site layout planning design												
5	Detailed electrical and structure design												
6	Materials procurement and delivery at site												
7	Installation of mounting structure												
8	Mounting of PV Modules												
9	Installation of Inverters												
10	Wiring and cabling work												
11	Testing and Commissioning												

5.2 IMPLEMENTATION OF CENTRALISED SOLAR SYSTEMS

Centralised solar PV systems are implemented under the Capital Expenditure (CAPEX) business model by a utility company or an Independent Power Producer (IPP). An IPP is a private entity not owned by the national utility company or any public utility. These business models are illustrated in Figure 124 and Figure 125.

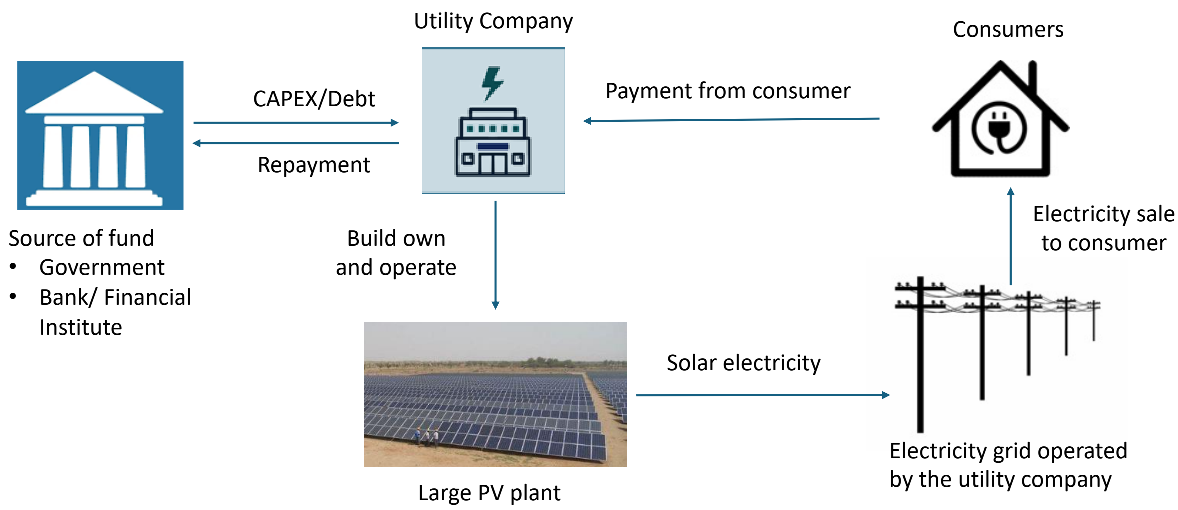


Figure 124: CAPEX business model for Utility Company

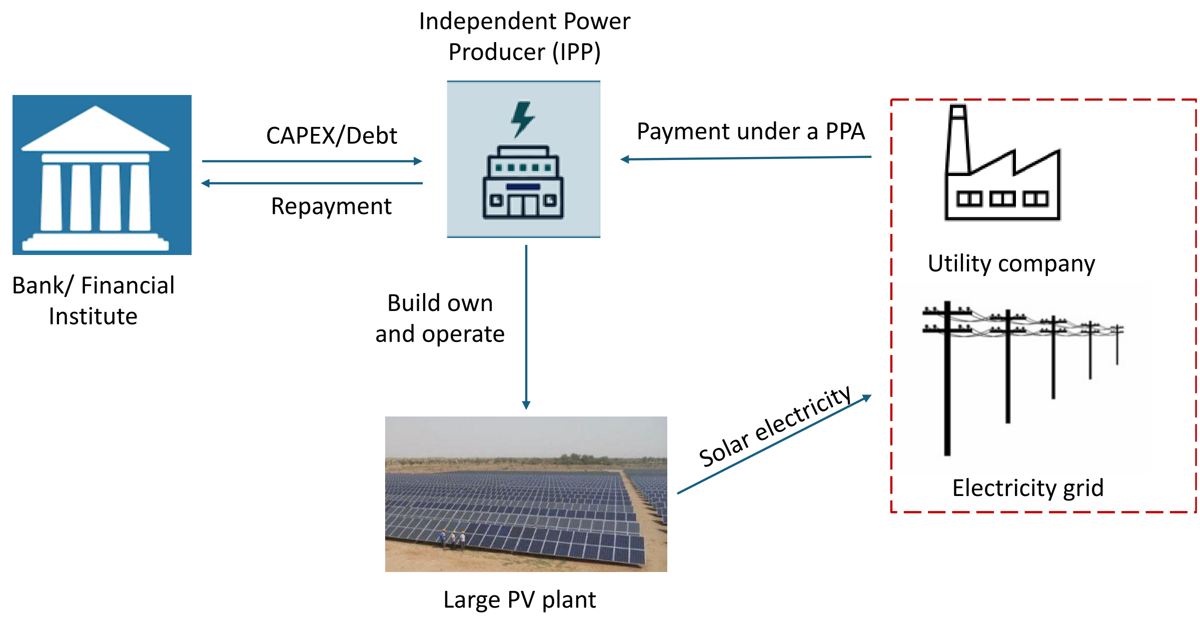


Figure 125: CAPEX business model for Independent Power Producer (IPP)

Centralised solar power systems can be installed in three different categories of sites:

1) Sites with existing diesel-generating stations
2) Government establishments with a large rooftop area
3) Land parcels identified for ground-mounted PV systems

Centralised solar power systems can be installed in sites with existing DG sites connected to the grid. This facilitates the connection of the PV plant to the grid network, as the required infrastructure already exists. An example is the 2.2 MW_p ground-mounted grid-connected PV plant in Santo Amaro.

Any establishment with an adequately large rooftop area can implement centralized solar power systems. For example, Mercado de Bobo Foro (Site No. 15 in this report), with an estimated PV capacity of over 900 kW_p, could be implemented as a centralized solar power system.

Centralised solar power systems could be implemented in identified land parcels suitable for ground-mounted PV systems. The available shadow-free flat area and grid connectivity for the desired capacity are important factors in selecting a land parcel to install a large ground-mounted system.

The locations of existing grid-connected DG sites in São Tomé and Príncipe are mapped out in Figure 126:

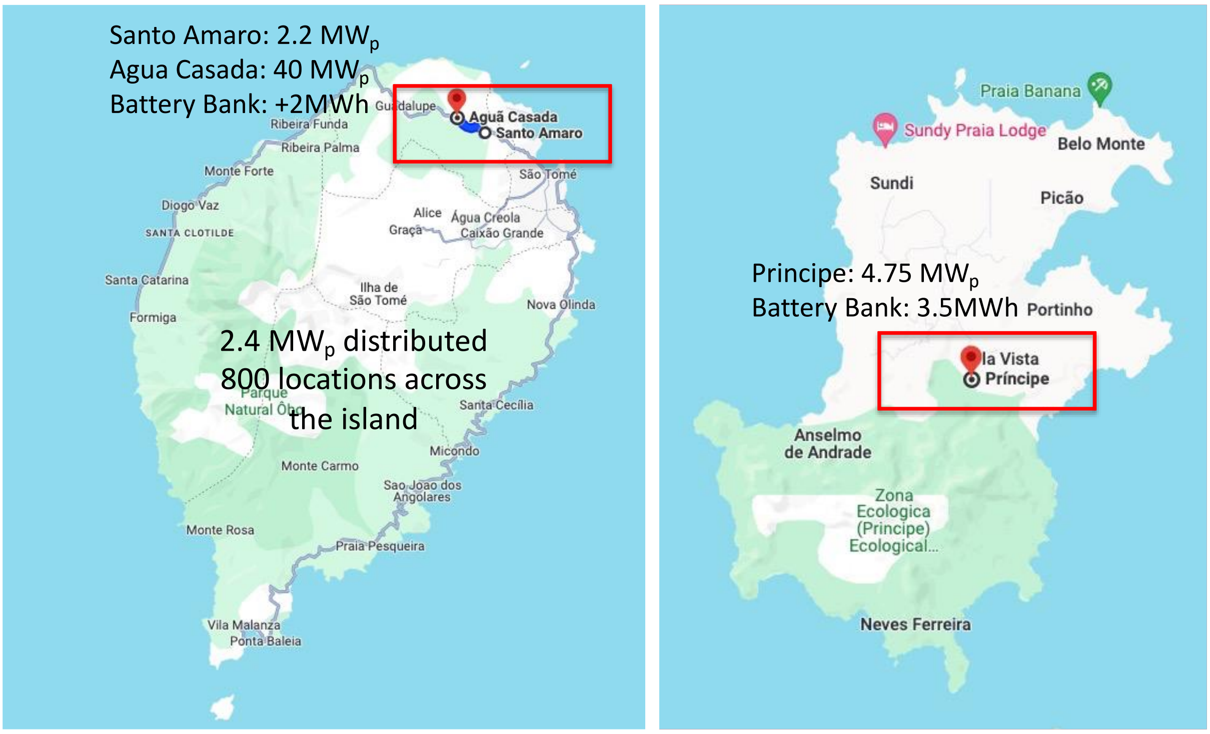


Figure 126: Tentative locations for central solar power plants with BESS in São Tomé and Príncipe

Figure 127: Site No. 15 (Mercado de Bobo Foro) with an estimated PV capacity of 937 kW_p

Table 29 presents the financial parameters of a MW-scale central solar power plant. The internal rate of return (IRR) is 14.8%, and the payback period is 7.07 years when the electricity selling price is considered US$ 0.15 per kWh (STN 3.40 per kWh). The primary factors influencing financial parameters are capital cost, bank interest rate, energy generation and electricity selling price.

Table 26: Financial parameters for central solar power plant

Sl. No.	Financial Parameters	Values	
1	Levelized cost of electricity	US$ 0.069 per kWh	STN 1.61 per kWh
2	Electricity selling price	US$ 0.148 per kWh	STN 3.46 per kWh
3	Internal Rate of Return (IRR)	14.80%	
4	Project payback period	7.07 Years	

5.2.1 IMPLEMENTATION TIMELINE FOR UTILITY-SCALE PV PLANTS

The implementation timeline for utility-scale PV plants will be around 12 months after government clearance and statutory approval, including the signing of the power purchase agreement. Project preparation activities, such as bidding and vendor finalisation, will take about three months. All major equipment, such as PV modules, inverters, and batteries, will be imported to the country, which will take 4-5 months. An implementation schedule outlining the sequence of major activities and the time required for engineering, procurement and construction of a single rooftop PV plant is presented as a bar chart in Table 30 below.

Table 27: Implementation schedule for utility-scale PV power plants

Sl. No.	Task/Activities	Plant construction period in months											
		1	2	3	4	5	6	7	8	9	10	11	12
1	Contracting / Vendor Finalisation												
2	Site survey and plant layout planning												
3	Detailed Design												
4	Materials procurement and delivery at site												
5	Site development & preparation												
6	Civil work – site development,												
7	Civil work - electrical and mechanical												
8	Installation of mounting structure												
9	Earthing Work												
10	Mounting of PV Modules												

11	Installation of DCCB, Inverters and ACCB												
12	Installation of Transformers & switchgears												
13	Civil work for cable layout												
14	Laying of LV cables												
15	Laying of MV/HV cables												
16	Testing and Commissioning												
17	Synchronization with Grid												

5.3 ENERGY METERING FRAMEWORK

Two metering arrangements are used to measure the generation and utilisation of energy from a grid-connected solar PV plant: gross metering and net metering. Both metering arrangements have been elaborated in the following sections:

5.3.1 GROSS METERING AND FEED-IN-TARIFF POLICY

Under gross metering, all the energy generated by the solar PV system is exported to the grid, while the energy consumed by the on-site facilities is drawn from the grid. The consumer receives two separate line items on their utility bills, one for energy consumption and the other for exported energy. These line items are independent of each other. Gross metering arrangements clearly demarcate energy flows, simplifying billing processes and grid management. However, from the consumer's perspective, the financial incentives may vary based on the prevailing feed-in tariffs or compensation rates for exported energy. Figure 128 illustrates the gross metering arrangement.

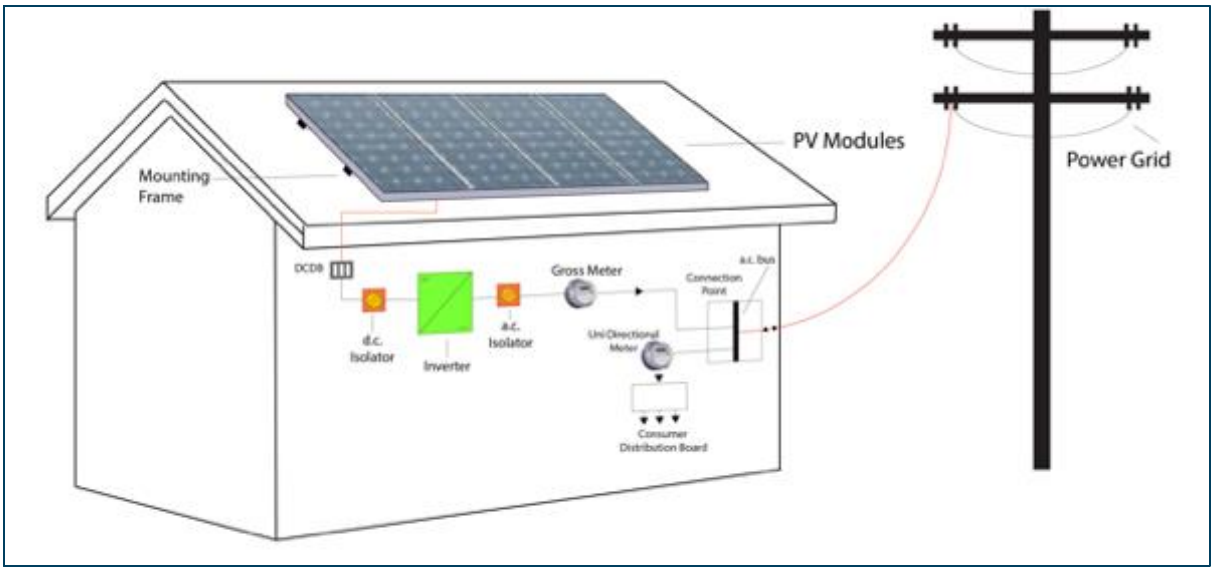


Figure 128: Gross metering arrangement

To implement the gross metering framework, feed-in-tariff rates for solar electricity are to be determined in advance or on a project basis with or without incentives under a feed-in-tariff regulation.

5.3.2 NET METERING AND NET BILLING ARRANGEMENT

Under net metering and net billing arrangement, the energy generated by the solar PV system is first utilized within the facility to fulfil internal energy demands. Any surplus electricity is then exported to the grid through a bi-directional meter, capable of measuring both import and export electricity flow.

In a net metering arrangement, consumers receive an electricity bill that reflects the net energy consumed from the grid, calculated by subtracting the exported energy from the total energy imported. In the net-billing arrangement, the utility pays a different tariff for the electricity exported to the grid. This tariff may be higher than the consumer's electricity tariff when there is an incentive from the government to promote solar systems. The tariff may be lower than the consumer's electricity tariff when the utility company wants to minimise revenue loss due to integrating solar systems into the grid.

Net metering and net billing give consumers greater control over their energy usage and potential cost savings by offsetting imported electricity with exported surplus. Figure 129 illustrates the net metering arrangement.

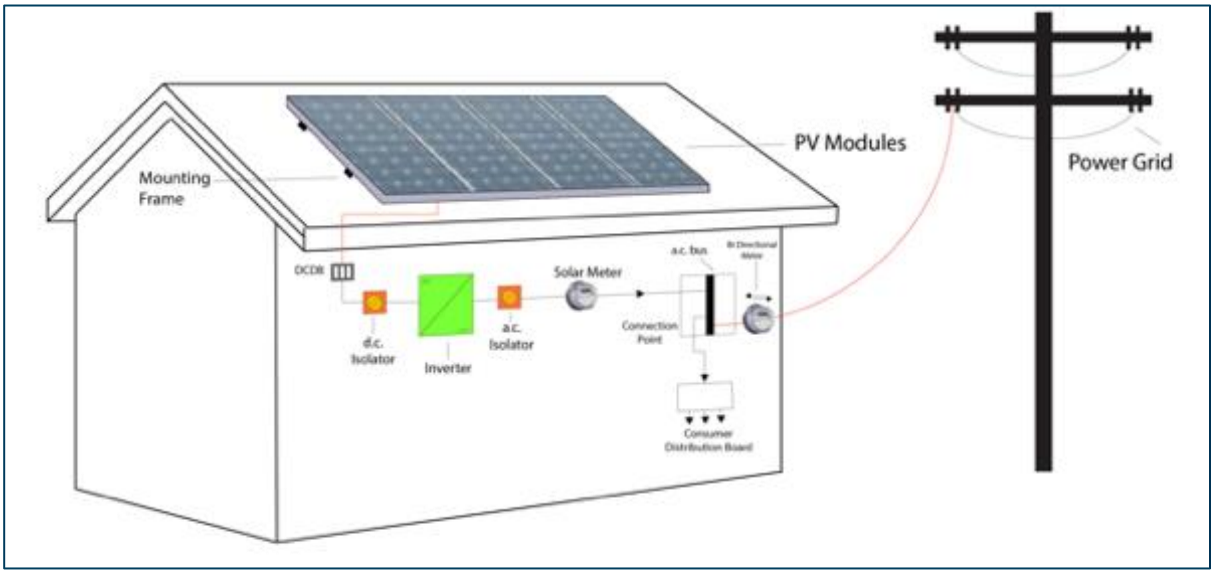


Figure 129: Net metering arrangement

Relevant regulations and guidelines must be established to settle the electricity import and export transactions between the customer and utility company to implement the net-metering or net-billing framework.

Energy metering policies have been widely adopted worldwide owing to their perceived benefits in promoting distributed generation, enhancing grid stability, and fostering renewable energy integration into the existing infrastructure. Choosing between gross and net metering arrangements entails carefully considering regulatory frameworks, financial incentives, technical capabilities, and individual energy consumption patterns.

5.4 ENERGY MANAGEMENT SYSTEM

An energy management system (EMS) must be implemented to supervise and control the grid system, comprising renewable energy (RE) power plants, energy storage systems (ESS), diesel generators, and the main load demand. The main functional requirements of an EMS shall be as follows:

Monitoring:

This function shall be able to receive and store binary data and telemetric data measured from field devices (grid system status). It also needs to inform operators of any changes in running status and abnormalities of the power supply system through the operating monitor display.

Forecasting:

EMS shall forecast the demand for PV and other renewable energy power plants. The output format shall be the base demand forecast for the day. When required, the operator shall be able to edit this base demand forecast manually. Based on weather forecast data and historical data, an approximated base data forecast shall be plotted for every 30-minute interval.

Scheduling:

This function shall create the operation schedule of RE power plants, diesel generators and the ESS using the demand and RE generation forecast results for the day based on calculated results. EMS shall correct operation by considering the actual value. The objective is to operate the system with the highest reliability in an economical mode.

Controlling:

This function shall carry out Load Frequency Control (LFC) and Economic Load Dispatching Control (ELDC) on diesel generators, ESS, and RE systems based on the operation schedule made through the scheduling function. The schedule for ELDC shall be based on the actual output of PV and diesel generators and the status of ESS and grid frequency (Hz).

Charge/Discharge of BESS:

The EMS shall be able to command control charge/discharge of central energy storage systems based on system requirements.

6 CAPACITY DEVELOPMENT PLAN

Based on the ongoing and upcoming solar PV project implementation plan in São Tomé and Príncipe, the following capacity-building activities are to be accomplished on priority.

1) Establish a training centre for hands-on practical training.
2) Equip the training centre with essential facilities as given in Table 28.
3) Organise technical and project management training and exposure visits for EMAE, MIRN, DGRNE, and other implementing agency officials.
4) Organise 2-3 day workshops and seminars for EMAE, MIRN, DGRNE, and other government agency officials on the following topics:
    a) Renewable energy potential and technology options for STP,
    b) Policy regulations and business models for the implementation of solar projects
    c) Economic benefits from solar projects for consumers and utility company
    d) Enterprise development, job creation, and reduction of diesel import
    e) Overall macro-economic benefits
    f) Project costing, financial analysis, tariff determination and source of funding
    g) Policy and incentives, grid-connectivity and metering regulations
    h) The bidding process for project implementation under different business models such as CAPEX, OPEX, demand aggregation and IPP business model
5) Organise workshops and seminars for commercial and institutional electricity customers to raise awareness of technology options, implementation models, funding sources and economic benefits of rooftop PV.
6) Organise workshops and seminars for entrepreneurs on solar PV technologies, business opportunities, business models, economics, funding sources.
7) Organise trainers' training at the centre.
8) Organise exposure visits and practical training for local trainers.
9) Technical and project management training should be focused on the following topics:
    a) Solar PV project development and quality management
    b) Rooftop PV project site assessments and planning
    c) Ground-mounted PV project site assessments and planning
    d) Detailed feasibility study of PV power projects
    e) Design of grid-connected, hybrid and off-grid PV systems
    f) Best practices for PV systems installation
    g) PV system documentation requirements
    h) Operation and maintenance planning for grid-connected PV power plants
    i) PV systems inspection and compliance verification
    j) Practical training on PV systems inspection and compliance verification
    k) Exposure visits to functional rooftop and ground-mounted PV projects
    l) Training for the customers who intend to instal or have already installed PV systems

Table 28: List tools, equipment and facilities for the solar training centre at São Tomé

Sl. No.	Training facility, tools and equipment	Purpose of use
1.	Training room with audio-visual equipment for presentation and facility for conducting practical sessions	Training session delivery
2.	Grid-connected rooftop PV plant (2-3 kW_p)	Demonstration and practical sessions
3.	PV power plant components – PV modules, inverters, structure and electrical components	Demonstration and practical
4.	Personal Protective Equipment	Demonstration and practical
5.	General mechanical and electrical tools	For demonstration and to perform practical activities during training and inspection
6.	Electrical measuring equipment	For measuring electrical parameters during training and system inspection
7.	Solar Pathfinder with sun path diagram	Shadow analysis during site assessment/ inspection
8.	Infrared camera	Inspection of PV modules hotspot/ defects, quality of electrical contacts/ connectors, inverter/ battery heating
9.	Current-Voltage tracer (I-V Tracer)	To trace I-V curve of PV modules for performance and degradation test and detection of defect
10.	Electroluminescence tester (Camera) with DC power supply and accessories for testing	Electroluminescence (EL) image of module to detect microcracks, snail trail and PID loss on modules after preliminary test of thermal image and IV tracing.
11.	Irradiance meter (Solar Intensity Meter)	To measure instantons solar irradiance ($Watt/m^2$)
12.	Ultrasonic thickness gauge	To measure thickness of protective coating of structure
13.	Torque tester	To measure torque level of fasteners
14.	TDS meter	For demonstration and testing of water hardness
15.	Software - PVSyst/ Solar Lab/ Helioscope/HOMER Grid	Planning and Design Simulation
16.	IEC Standards relevant to solar PV systems design, installation, documentation, O&M and monitoring	Design, installation, inspection, testing

7 RISK ASSESSMENT AND MITIGATION

Successful implementation of solar PV projects highly depends on risk management to achieve a satisfactory return on investment. Risks are interrelated and vary from project to project. Some of the main risks potentially impacting solar projects in São Tomé and Príncipe are discussed here.

Quality assurance:

The major risk in the technical aspect is failure in site planning and engineering design, selection of quality equipment and balance of system, poor installation and inadequate O&M practice. These risks can be mitigated by adequate capacity development and skill development of human resources at different levels. At the initial phases of implementation, an independent and competent third-party engineering company should be engaged for quality control and project management services. A well-defined terms of reference (ToR) for the design, selection and procurement of equipment, technical specification, quality control assurance and adherence to applicable engineering and product standards is of utmost importance. A quality assurance plan (QAP) must be adhered to for all project implementation work and processes.

Operation and maintenance:

PV systems are generally exposed to various losses due to environmental factors, device limits and manufacturing defects. Such losses include – soiling, shading, manufacturer's tolerance, temperature, voltage drop, inverter efficiency, orientation and tilt angle of the module(s), degradation of the solar module(s) and any other location-specific factors that could have an impact on the plant's performance. Favourable solar radiation and the best equipment cannot alone perform well if the system is not designed, installed and maintained appropriately.

Though there are many factors responsible for the under-performance of a PV power plant, adequate and on-time maintenance is a key strategy to achieve satisfactory performance from a PV plant. For example, the build-up of dirt, including bird dropping on the array, can substantially affect system performance. It is essential to clean the modules regularly to remove general dust but specifically spotted dirt like bird droppings to maximize energy output from a solar power plant and keep the modules safe from creating hotspots. However, wrong cleaning practices, use of low-quality water, and inappropriate cleaning methods may damage the modules and other array components, lowering system performance as well. Training the cleaning personnel on proper cleaning methods and appropriate cleaning tools is also essential. Cleaning procedures must be based on the PV module manufacturer's instructions, site conditions, quality of water and the adopted cleaning mechanism. It is often seen that maintenance people step onto the modules during cleaning and maintenance work, which must be avoided to prevent damage to PV modules from micro cracks.

Inadequate technical skills and local competence for the operation and maintenance of PV systems and non-availability of spare parts for operation and maintenance could be other risks to the effective operation and maintenance of power PV plants. This report provides a detailed preventive maintenance schedule, manpower requirement and list and quantity of spare parts to be kept ready at the site. Local engineers and technicians are to be trained at the site to undertake O&M of the proposed plant. Therefore, practical skill training is important for the successful implementation of solar projects.

Policy and regulations:

Well-defined policies and regulations are necessary for the successful implementation of solar projects. Grid-connectivity and metering regulations must be in place to implement grid-connected PV systems. A feed-in tariff policy and regulation for determining the tariff for solar projects must be in place for the implementation of commercial projects under the RESCO or IPP model.

Financial risks:

The financial risk is largely related to the availability of term loans from local banks and equity investors, the interest rate of term loans and the expected return on equity. Since São Tomé and Príncipe has not experienced commercial grid-connected PV power plants till now, the banks and equity investors may likely perceive it as a high-risk investment and be reluctant to invest in the project. This may cause a delay in availing finance for the project or a financial closure with a higher rate of interest on a term loan and expectation of a higher return by the equity investors. On the other hand, the estimated project cost of solar plants in São Tomé and Príncipe is at a higher end due to the lower economy of scale and higher shipping cost.

Grid infrastructure and stability:

Grid-connected PV power plants require a stable grid connection for their uninterrupted operation. Frequent power outages and unstable grid parameters (voltage and frequency) will interrupt PV power plant operation and lower the performance and electricity generation. Distributed PV systems installed for captive uses can overcome this problem with existing diesel generators or incorporating a BESS system. However, for utility-connected central solar power systems, it is important to maintain a stable and uninterrupted grid for the commercial viability of grid-connected PV systems.

Risk of harsh climate:

The two major concerns are heavy rain and a corrosive environment. Due to the prolonged moist and humid conditions, organisms like algae and lichen grow over solar PV modules. If solar panels are not cleaned regularly, these organisms will grow rapidly and cover the entire surface of PV modules, obstructing sunlight from reaching the cells. Therefore, regular cleaning of PV modules is important in moist and humid conditions, even if no dust is deposited on them. Due to heavy rain, ground-mounted PV projects may be affected by flash floods and soil erosion. To avoid damage to the solar power plants, adequate measures must be taken regarding site layout, field segment placement, drainage system and water flow management planning.

To mitigate any risks from excessive corrosion, all materials used in PV systems must be selected to withstand such a corrosive environment. The type of materials and corrosion protection coating for the mounting structure must be selected accordingly. PV modules used in such an environment must be tested and certified in accordance with IEC 61701:2020 Photovoltaic (PV) modules - Salt mist corrosion testing.

8 RECOMMENDATIONS

All technical, economic, and financial parameters are conducive to implementing distributed and central solar PV projects in São Tomé and Príncipe. Favourable solar radiation, a clean environment, suppressive electricity demand, and the high cost of electricity generated from expensive imported diesel fuel are primary reasons to promote and implement solar PV projects in the country. The following recommendations are made for prompt and successful implementation of grid-connected solar power projects in São Tomé and Príncipe.

Policy and regulatory framework:

It is recommended to implement the following policy, regulatory and technical guidelines on a priority basis:

1) Grid-connectivity and metering regulations grid-connected PV systems with and without BESS.
2) Grid-connectivity and metering regulations grid-connected standalone BESS.
3) A metering regulation covering net metering, net billing and gross metering with a feed-in-tariff framework for implementing decentralised grid-connected PV systems under the CAPEX business model.
4) A feed-in tariff policy for solar projects implemented under the OPEX business model by Renewable energy service companies (RESCO) for a single customer or aggregated customers.
5) A regulation for determining the tariff for solar projects for implementing central solar projects under the Independent Power Producer (IPP) model.
6) A regulation and technical guidelines for implementing a central energy management system to supervise and control the grid system through monitoring, forecasting and scheduling renewable energy (RE) power plants, energy storage systems (ESS), and diesel generators.

Business models for implementation of solar power projects:

The project implementation roadmap is elaborated on in section 4 of the report. The following project development modes are recommended for implementing distributed and central solar projects.

1) Implementation of distributed solar systems under the CAPEX business model for government departments and ministries for captive generation and consumption. These projects should be developed preferably with BESS to replace or reduce diesel generator use. Without a net-metering or net-billing framework, these projects can be implemented using a zero-grid export device.
2) Implementation of distributed solar systems under the OPEX business model for single-user or aggregated customers such as government schools. The government departments responsible for providing electricity to the customers/schools may act as aggregators. These projects are to be developed under a gross metering regime. The electricity produced by

these projects is directly fed to the grid, and utility companies purchase the electricity at a predetermined tariff through a feed-in-tariff policy or a tendering process.

3) The government should prioritize developing/promoting distributed solar projects that first cater to the local load centres. This would reduce transmission and distribution losses incurred in transmitting electricity from diesel power plants.
4) The central solar power projects can be implemented by utility company EMAE, private independent power producers, or public-private partnerships.

Technology and standards:

All design approaches and technology selection for the implementation of solar PV projects should be based on critical site parameters such as topography, slope, minimum and maximum temperature, rainfall, wind loading, humidity, soil conditions, etc. The PV systems are to be designed to suit the building roofs for roof-mounted systems, site topography for ground-mounted systems, optimal performance, safety, ease of maintenance and minimum civil work. System protection and cable sizing must comply with applicable standards, safety regulations and international best practices. Standards applicable for design, installation, O&M and major components are mentioned in the following paragraphs.

Standards for PV system design, installation and O&M:

- IEC 62548- 2016: Photovoltaic (PV) arrays - Design requirements
- IEC TS 62738-2018: Ground-mounted photovoltaic power plants - Design guidelines and recommendations
- IEC 60364-7-712-2017: Low voltage electrical installations - Part 7-712: Requirements for special installations or locations - Solar photovoltaic (PV) power supply systems
- IEC 62446-1-2018: Grid connected systems – Requirements for Documentation commissioning tests and inspection.
- IEC 62446-2-2020: Requirements for Maintenance of PV Systems
- IEC 62446-3-2017: Requirements for IR Testing
- IEC 61724-1-2017: Photovoltaic System Performance Monitoring
- IEC 61724-2-2016: Photovoltaic System Capacity Evaluation Method
- IEC 61724-3-2016: Photovoltaic System Energy Evaluation Method
- IEC 16229-2015: Balance-of-System components for PV systems - Design qualification natural environments
- IEC 61829-2015: PV array – On-site measurement of current-voltage characteristics
- IEC 61727-2014: PV systems - Characteristics of the utility interface

Standards for PV modules:

- IEC 61215: Crystalline Silicon Terrestrial Photovoltaic (PV) modules - Design Qualification and Type Approval
- IEC 61730 (Part 1): Photovoltaic (PV) Module Safety Qualification Part 1 Requirements for Construction

- IEC 61730 (Part 2): Photovoltaic (PV) Module Safety Qualification Part 2 Requirements for Testing
- IEC 61701:2020: Salt mist corrosion testing of photovoltaic (PV) modules
- IEC 62804-1:2015: Photovoltaic (PV) modules - Test methods for the detection of Potential-Induced Degradation.

Standards for Inverters:

- IEC 62109-1:2010 (E): Safety of power converters for use in photovoltaic power systems – Part 1: General requirements. Part 2-Particular Requirements for Inverters
- IEC 62116:2014: Utility-interconnected photovoltaic inverters - Test procedure of islanding prevention measures.
- IEC 61683:1999: Photovoltaic systems - Power conditioners - Procedure for measuring efficiency.
- IEC TS 62910: Utility-interconnected photovoltaic inverters – Test procedure for low voltage ride-through measurements

Standards for BESS:

- IEC 62133 or UL 1642: Safety requirements
- IEC 62281 or UL 1973: Test methods and requirements to ensure safety during transport other than for recycling or disposal.
- UL9540A: Standard for thermal runaway required at the BESS system level.
- IEC 62620: Secondary cells and batteries containing alkaline or other non-acid electrolytes – secondary lithium cells and batteries for use in industrial applications.
- IEC 61508: Functional Safety of Electrical/Electronic/Programmable Electronic Safety-related Systems: Applicable for all Battery Energy Storage Systems.
- IEC 61850: Communications networks and management systems. (BESS control system communication)

Overall techno-economic feasibility:

The solar project's technical and economic feasibility has been established. Potential risks to the project have been identified, and mitigation measures have been suggested. The financial analysis shows that the most sensitive parameters influencing financial results are project cost, annual power generation, electricity tariff, cost of diesel and interest rate on the term loan. The LCOE without BESS is US$ 0.69 per kWh (STN 1.54 per kWh) and US$ 0.172 per kWh (STN 3.24 per kWh) with 3 hours of full load backup of BESS. These values are much lower than the electricity tariff for commercial and institutional customers. The payback period in São Tomé Island is around five (5) years, with savings from grid electricity and reduced diesel consumption. The sites with no diesel generator will have a payback period of around six (6) years as there is no additional saving from reduced diesel consumption. Similarly, in Príncipe Island, payback with a diesel generator is around three (3) years; without a diesel generator, the same is around four (4) years. This difference is due to the higher tariff for grid electricity in Príncipe Island.

Reducing diesel import:

Partial implementation of NREAP (scenario 2 of section 3.5) with about 38 MW installed capacity will reduce diesel consumption for power generation by about 46%. Full implementation of NREAP (scenario 3 of section 3.5) with about 72 MW installed capacity will reduce diesel consumption for power generation by about 87%. However, due to a mismatch of demand and generation profile, about 27% of renewable power during solar time will be unused. This additional renewable power can be used by incorporating energy storage systems into the grid and proper power scheduling with the help of smart energy management systems. Diesel imports can be reduced further by increasing the adoption of electric vehicles.

Nationally Determined Contributions:

São Tomé and Príncipe emit 568,663.87 metric tons of CO_2 equivalent. The two largest sources of greenhouse gas emissions are the energy and transport sectors, primarily due to the use of fossil fuels [1]. The country aims to meet the target outlined in the Nationally Determined Contributions (NDC) for 2021, aiming for a 27% reduction in emissions by 2030. According to the UNFCCC standardised baseline recommendation report, the emission factor for grid electricity systems applicable to solar and wind projects is 0.660 tCO_2/MWh. To achieve the goal, 153539 metric tons of CO_2 equivalent must be reduced. This target can be achieved when NREAP is fully implemented. (Scenario 3 in section 3.5).

Electric vehicle:

The transport sector of São Tomé and Príncipe is adopting electric vehicles (EVs). An increase in EVs will generate more power demand, and a sudden jump in power demand will likely stress the distribution network. Distributed solar PV projects can play an important role in overcoming this challenge. Distributed solar power projects installed in commercial and institutional buildings will reduce the power congestion in the grid network. Independent grid-connected solar-powered charging stations can be installed in public places to charge EVs, reducing the load on the grid.

Priority on capacity building:

Capacity-building and skill development activities must be prioritised for the successful implementation and sustainability of upcoming solar PV projects in São Tomé and Príncipe. The following activities are suggested to implement in the next 1-2 years.

1) Organise two—to three-day workshops and seminars on the topics mentioned in section 5 for EMAE, MIRN, DGRNE, and other government agency officials.
2) Organise technical and project management training and exposure visits for EMAE, MIRN, DGRNE, and other implementing agency officials.
3) Organise workshops and seminars for commercial and institutional electricity customers to raise awareness of technology options, implementation models, funding sources and economic benefits of rooftop PV.
4) Organise workshops and seminars for entrepreneurs on solar PV technologies, business opportunities, business models, economics, and funding sources.
5) Establish a training centre for hands-on practical training, as mentioned in section 5.

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10 APPENDICES

10.1APPENDIX 1: PROFIT AND LOSS STATEMENT

Profit and Loss Statement

Figures in Million USD

Sl. No.	Particulars	Year																									
	Project operating period	0	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1	**Income/ Benefits**																										
1.1	Electricity generation from PV plant Million Unit (MU)		4.85	4.81	4.77	4.74	4.70	4.67	4.63	4.60	4.56	4.53	4.49	4.46	4.43	4.39	4.36	4.33	4.30	4.26	4.23	4.20	4.17	4.14	4.11	4.07	4.04
1.2	Price of electricity saved (USD Per Unit)		0.25	0.25	0.26	0.26	0.26	0.26	0.27	0.27	0.27	0.27	0.28	0.28	0.28	0.28	0.29	0.29	0.29	0.30	0.30	0.30	0.31	0.31	0.31	0.31	0.32
1.3	Savings from grid electricity		1.21	1.21	1.22	1.22	1.22	1.23	1.23	1.23	1.23	1.24	1.24	1.24	1.25	1.25	1.25	1.26	1.26	1.26	1.27	1.27	1.27	1.27	1.28	1.28	1.28
1.4	Total savings/ benefit		1.21	1.21	1.22	1.22	1.22	1.23	1.23	1.23	1.23	1.24	1.24	1.24	1.25	1.25	1.25	1.26	1.26	1.26	1.27	1.27	1.27	1.27	1.28	1.28	1.28
2	**Operating Expenditure**																										
2.1	O & M Cost for PV system		0.06	0.06	0.06	0.06	0.06	0.07	0.07	0.07	0.07	0.07	0.08	0.08	0.08	0.08	0.08	0.09	0.09	0.09	0.10	0.10	0.10	0.10	0.11	0.11	0.11
2.2	Operating Expenses		0.06	0.06	0.06	0.06	0.06	0.07	0.07	0.07	0.07	0.07	0.08	0.08	0.08	0.08	0.08	0.09	0.09	0.09	0.10	0.10	0.10	0.10	0.11	0.11	0.11
3	**Net savings**		1.16	1.16	1.16	1.16	1.16	1.16	1.16	1.16	1.16	1.16	1.17	1.17	1.17	1.17	1.17	1.17	1.17	1.17	1.17	1.17	1.17	1.17	1.17	1.17	1.17
4	**Depreciation**		0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
5	**Net savings after depreciation**		1.00	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02
6	**Interest on term loans**		0.31	0.28	0.25	0.22	0.18	0.15	0.12	0.09	0.05	0.02						-	-	-	-	-	-	-	-	-	-
7	**Savings after paying interest**		0.69	0.73	0.76	0.79	0.83	0.86	0.89	0.93	0.96	0.99	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02
8	**Cumulative savings**		0.69	1.42	2.18	2.97	3.80	4.66	5.55	6.48	7.44	8.44	9.45	10.47	11.48	12.50	13.52	14.54	15.56	16.58	17.60	18.62	19.64	20.66	21.68	22.70	23.71

Schedule for Calculations of Depreciation

Figures in Million USD

Sl.No.	Particulars		Year																								
	Project operating period	0	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1	Depreciation (Staright Line method)		0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
2	Depreciation (Battery Replacement)		-	-	-	-	-	-	-	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	Cumulative Depreciation		0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
4	Written down value (WDV)		4.02	3.87	3.72	3.57	3.42	3.27	3.12	2.97	2.82	2.67	2.52	2.37	2.22	2.07	1.92	1.77	1.62	1.47	1.32	1.17	1.02	0.87	0.72	0.57	0.42

10.2 APPENDIX 2: COST OF GENERATION, PAYBACK PERIODAND IRR

Cost of Energy Generation

Figures in Million USD

Sl. No.	Particulars		Year																								
	Project operating period	0	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1	**Income/ Benefits**																										
1.1	Grid electricity saved in Million Unit (MU)		4.85	4.81	4.77	4.74	4.70	4.67	4.63	4.60	4.56	4.53	4.49	4.46	4.43	4.39	4.36	4.33	4.30	4.26	4.23	4.20	4.17	4.14	4.11	4.07	4.04
2	**Expenditure**																										
2.1	Operating expenses		0.06	0.06	0.06	0.06	0.06	0.07	0.07	0.07	0.07	0.07	0.08	0.08	0.08	0.08	0.08	0.09	0.09	0.09	0.10	0.10	0.10	0.10	0.11	0.11	0.11
2.3	Interest on loan		0.31	0.28	0.25	0.22	0.18	0.15	0.12	0.09	0.05	0.02	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2.4	Depreciation		0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
2.6	Total Expenditure		0.52	0.49	0.46	0.43	0.40	0.37	0.33	0.30	0.27	0.24	0.23	0.23	0.23	0.23	0.24	0.24	0.24	0.24	0.25	0.25	0.25	0.25	0.26	0.26	0.26
3	**Generation cost USD./Unit**		0.11	0.10	0.10	0.09	0.08	0.08	0.07	0.07	0.06	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.07
3.1	**Average cost of generation (25, 20 and 10 years basis)**		0.07	0.07	0.08																						

Calculations of Financing Parameters

Figures in Million USD

Sl. No.	Particulars		Year																								
	Project operating period	0	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1	**Cashflow calculations**																										
1.1	Net savings after operating cost and interest		0.69	0.73	0.76	0.79	0.83	0.86	0.89	0.93	0.96	0.99	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02
1.2	Add: Depreciation		0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
1.3	Add: Residual Value		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.4
1.4	Add: Term Loan interest		0.31	0.28	0.25	0.22	0.18	0.15	0.12	0.09	0.05	0.02	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.5	Less: Project cost (capex)	-4.64																									
1.6	Less:Capex for battery replacement									0.00								0.00									
1.8	Free project cashflow	-4.64	1.16	1.16	1.16	1.16	1.16	1.16	1.16	1.16	1.16	1.16	1.17	1.17	1.17	1.17	1.17	1.17	1.17	1.17	1.17	1.17	1.17	1.17	1.17	1.17	1.59
1.9	Cumulative cash flow		1.2	2.31	3.47	4.63	5.79	6.95	8.11	9.27	10.44	11.60	12.77	13.93	15.10	16.27	17.44	18.61	19.78	20.94	22.11	23.28	24.45	25.62	26.79	27.96	29.55
2	**Internal Rate of Return (IRR)**	**24.91%**																									
3	**NPV (Million USD)**	**5.24**	-	-	-	-	1.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4	**Payback Period in years**	**5.20**	-	-	-	-	5.20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

10.3 APPENDIX 3: LIST OF SOLAR COMPANIES IN STP

Sl. No.	Company name	Region	Products	Website
1	Cleanwatts	Portugal	PV modules, battery, solar inverters	https://cleanwatts.energy/
2	AIMS Power	São Tomé and Príncipe	PV modules, battery, solar inverters	https://www.aimscorp.net/Sao-Tome-and-Principe-Power-Inverters-and-Solar-Panels/
3	Off-Grid Installer	São Tomé and Príncipe	PV modules, battery, solar inverters	https://offgridinstaller.com/blog/off-grid-sao-tome-and-principe/