Consultancy Services for the Design of Solar Powered Mini-grid in Fefen Island, Chuuk State

Draft D2 Concept Design Report

Prepared for: Chuuk Public Utility Corporation

Financed by: EU FSM Sustainable Energy and Accompanying Measures (SEAM) – RENEWABLE ENERGY AND ENERGY EFFICIENCY PROJECT (FSM. SE)

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Client:	Chuuk Public Utility Corporation
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D2. Concept Design Report

Deliverable #2

Related Documents	**Type of document**	**Draft/final**	**Date of submission**
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Financed by:	EU FSM SUSTAINABLE ENERGY ACCOMPANYING MEASURES – RENEWABLE ENERGY AND ENERGY EFFICIENCY PROJECT (FSM. SE)

PRESENTATION This report contains the deliverable #2 of the project. The authors of this report are Nicolas Antoine, Alberto Jerónimo, Maryam Karimah, and Lucas Mosca.

1. Introduction

1.1 Background

The European Union EDF-11 Federated States of Micronesia Sustainable Energy and Accompanying Measures (EU-SEAM) financing agreement, signed by the European Union (EU) and the Federated States of Micronesia (FSM) in November 2019, has an overall objective to enable the FSM population to utilize affordable, reliable, and environmentally sound energy services and benefit from transparent and efficient management of public funds. The EU-SEAM financing agreement budget is EUR 14.2 million and has five components which involves separate partnerships with the EU, the FSM and implementing partners.

Component 2, FSM Sustainable Energy Project (FSM.SE), is implemented by SPC in partnership with FSM Resources and Development and has funding of EUR 11.625 million. The specific objective of the FSM.SE is to increase access to renewable electricity and support private sector investment in energy efficiency and renewable energy. There are four key outputs for the project:

- Output 1: Policy, institutional and legislative structures are reviewed
- Output 2: Capacity building in energy planning and management, and monitoring and evaluation
- Output 3: IPPs and jointly funded grid-connected renewable energy and energy efficiency projects
- Output 4: Renewable energy systems and technologies are promoted especially in remote communities and among youth and women with a focus on the Chuuk State.

Under Output 4, CPUC is supporting the FSM SE project in conducting feasibility studies for ten islands which were endorsed by the Chuuk State Energy Working Group. The selected islands were Fefen, Etten, Sopou & Manaio, Polle, Lekinioch, Moch, Nema, Houk, Onoun, Nomwin, and Piis Paneu.

TTA will support CPUC for the Fefen Island feasibility study to develop the design for a reliable, sustainable, and efficient hybrid solar-powered mini-grid system, providing 24-hour access to electricity for the communities in Fefen. The feasibility study will also identify users that are better electrified with standalone solutions.

1.2 Assignment

The objective of the current assignment is to support CPUC with the households, businesses and institutions surveys, defining the socioeconomic profile of the communities, conducting technical site assessments and developing the concept design of a solar powered mini grid to electrify the communities in Fefen. This assignment includes activities and deliverables shown in Figure 1.

- Figure 1. Activities and deliverables of the assignment.

The Consultant submitted the data collection guidelines to CPUC in August 2022 for CPUC to inform and facilitate the site visits. Tailored *end user* and *focus group discussion* surveys in KoboToolbox were created and shared.

The Demand Assessment was submitted by TTA in June 2023 and updated in August 2023.

1.3 D2 Concept Design report

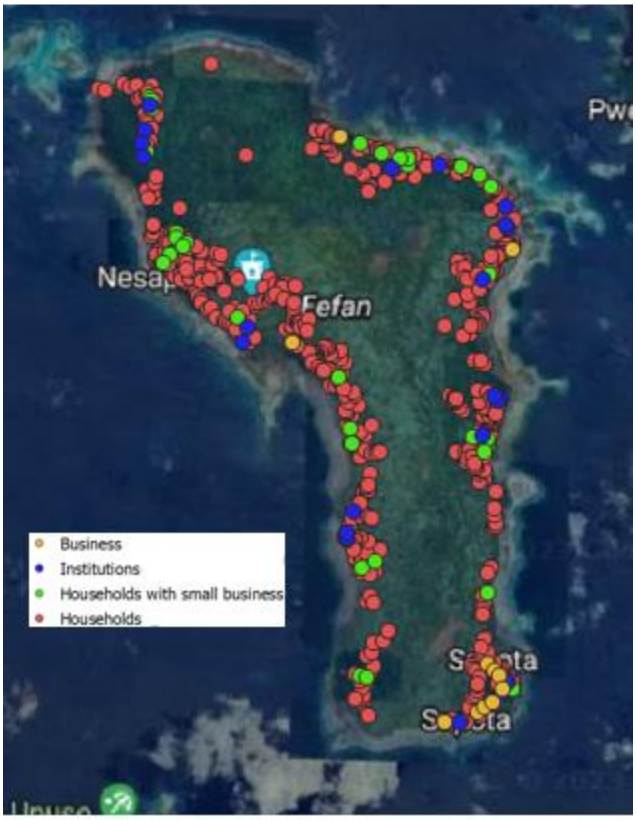
The Deliverable 2 – Concept Design Report - provides the conceptual design for the generation sites, technical rooms, controllers, and distribution network.

2. Electrification Approach

2.1 Electrification scope for Fefen

Initially, the Consultant grouped all geolocated users into different services areas. The grouping of users was done based on end-users spread and location of potential generation sites, to ensure optimal mini-grid utilization and low-voltage distribution network layout and distance. This resulted on a total of five independent services area. However, after a review of the demand assessment that resulted in the increase in demand with respect to the initially defined baseline, and further assessment of distribution network losses, it was concluded utilizing low voltage (LV) distribution alone would not be possible and stepping up to medium voltage would be necessary. In consequence, the Consultant concluded that a centralized distribution system would be more optimal as it would limit the number of different power generation sites to minimize land access difficulties, facilitate the overall control mechanism by centralizing it and ensure a more efficient operation of the mini-grid. This study presents the technical approach to electrify Fefen as a whole island using a centralized distribution network.

The electrification of Fefen is proposed to provide electricity service to **652 users**: **618 households** (two of those served with Solar Home System (SHS)), **23 institutions** and **11 businesses**[1]. The users will be powered by a solar PV + battery generation plant with a diesel back-up generator.



- Figure 2. GPS mapping of users in Fefen.

[1] Some other businesses were found during the field assessment but most of them were inside households, and their energy needs have been considered in the corresponding household.

3. Site Assessment

This section describes and summarizes the results of the analysis conducted with the data collected on site. It provides an overview of the socio-economic circumstances of the communities, and their estimated demand.

- Table 1. Summary of GPS points collected for end-users

Type of end users	Total GPS end-users
Business (BB)	11
Business inside Household (HB)	39
Household (HH)	579
Institution (II)	23
TOTAL	**652**

3.1 Socio-economic profiling

The average monthly income resulting from the household surveys is 281 USD/month or approximately 3,371 USD/year. Over 80% of the respondents have an average monthly income lower than 400 USD, 12% between 400 and 800 USD per month and the remaining more than 800 USD.

Upon examining historical records in the Chuuk State Census Report for the year 2000, it was found the average annual income for households in Fefen is $4,945 USD, a figure notably higher than the income reported in the recently conducted household surveys. Given the substantial 23-year gap between the survey and the historical census data, it would be reasonable to expect an increase in income levels by 2023. However, it's crucial to note that Fefen has experienced limited development during this period, particularly reflected in the small number of businesses on the island.

Table B19a. Income in 1999 by Municipality of Usual Residence, Chuuk: 2000
[For definitions of terms and meanings of symbols, see text]

Household Income Family Income Income by Type	Total	Northern Namoneas				Southern Namoneas					
		Total	Weno	Piis-Paneu	Fono	Total	Tonoas/Etten	Fefen	Siis	Uman	Parem
Households with income	6,385	1,881	1,779	53	49	1,541	573	502	65	359	42
Less than $1,000 .	1,632	272	238	13	21	293	90	93	3	102	5
$1,000 to $1,999 .	1,022	199	176	13	10	294	102	114	7	63	8
$2,000 to $2,999 .	694	204	194	8	2	195	76	60	15	38	6
$3,000 to $3,999 .	508	154	147	3	4	146	51	43	13	35	4
$4,000 to $4,999 .	391	150	140	5	5	113	52	23	5	28	5
$5,000 to $7,499 .	754	259	249	6	4	192	76	49	12	47	8
$7,500 to $9,999 .	427	158	153	3	2	101	47	28	4	21	1
$10,000 to $12,499	286	109	108	1	-	95	33	46	3	13	-
$12,500 to $14,999	143	67	66	-	1	39	15	19	-	3	2
$15,000 to $19,999	202	114	113	1	-	37	13	18	1	4	1
$20,000 to $24,999	112	55	55	-	-	21	9	5	2	3	2
$25,000 to $34,999	98	59	59	-	-	13	8	3	-	2	-
$35,000 to $49,999	54	35	35	-	-	2	1	1	-	-	-
$50,000 or more. .	62	46	46	-	-	-	-	-	-	-	-
Median (dollars) .	2,776	4,743	4,961	2,063	1,350	2,941	3,363	2,733	3,577	2,382	3,500
Mean (dollars) . .	6,195	10,180	10,603	3,175	2,398	4,720	5,136	4,945	4,782	3,683	5,111

- Figure 3. Chuuk State Census Report for the year 2000

The census report also notes a similarity in the average annual income with Tonoas, reporting an average income of $5,136 USD per year. Since normally there is a correlation between income level and electricity demand, the Consultant suggests that the electricity consumption in Fefen may potentially mirror the consumption pattern observed in Tonoas.

Furthermore, the Consultant conducted an analysis based on real demand data from Tonoas. This analysis revealed a daily household electricity demand of 2.47 kWh/day/HH, nearly doubling the demand estimate presented in the Demand Assessment Report (D1) Consultant. Consequently, it is essential to update the demand assessment for Fefen as this is a key input into the sizing of the mini-grid.

3.2 Estimated demand in Fefen

Upon the client's approval, the Consultant redefined and updated the demand assessment following the daily demand level recorded for households in Tonoas. The methodology employed for updating the demand assessment is outlined as follows:

1. Survey data continues to be utilized for the updated demand assessment, with adjustments made to account for changes in income levels. It is assumed that these adjustments will bring the average income levels closer to the reference depicted in Figure 3.
2. Given the adjustments made to income levels, the updated demand assessment will employ the Ability to Pay method instead of selecting package distribution based on the Willingness to Pay method. This new approach utilizes a threshold of 22.5% of income. The adoption of a higher threshold is justified by the likelihood that incomes are higher than assumed.

The following hypothesis have been considered to obtain the final total demand and load profile in Fefen island.

- **Connection rate**:
    - A ramp up period is considered for Households with a duration of three years: 70% of households are considered to consume estimated demand on year 1 (Y1) whereas 100% of households are considered to consume estimated demand by year 4 (Y4).
    - 100% of businesses are connected in year 1.
    - 100% of institutions are connected in year 1.
- **Daily Load Profile**. The load profiles assigned to each type of user are based on TTA's own experience and considering the local habits perceived during the field missions.
- **Demand annual growth forecast**:
    - Between Year 4 and Year 10, the yearly demand growth is set to 0.5% only as the demand in Y1 is considerably high.
    - No additional growth is considered after Year 10.
- **Utilization Factor** (UF): set to 85%, based on TTA experience on similar communities.
- **Street Lighting:** The Consultant held discussions with CPUC and estimated a total of 49 streetlights on Fefen Island. This calculation amounted to approximately 1.86% of the total daily demand.

3.3 Demand and load profile in Fefen island

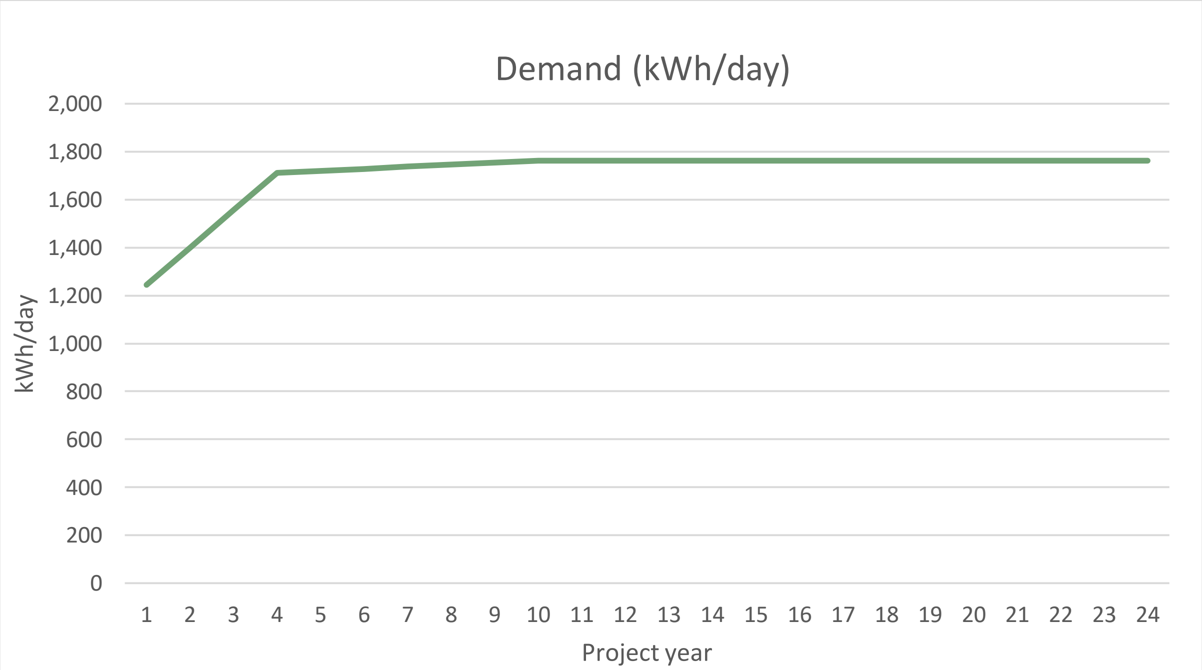
The total number of end-users identified in the Fefen island are 652, two of those to be served with a SHS. The service packages that have been assigned to the users are summarized in Table 2.

- Table 2. End-users package distribution in Fefen Island.

User type	Package	#	EDA (Wh/day)	Total demand Y4 (kWh/day)
Household	Package 2	230	550	126.5
Household	Package 3	38	2200	83.6
Household	Package 4	348	3850	1339.8
Business	Shop (P2)	5	550	2.75
Business	Shops Fridge (P3)	3	2200	6.6
Business	Shops freezer (P4)	3	3850	11.55
Institution	Basic school (P3)	2	2200	4.4

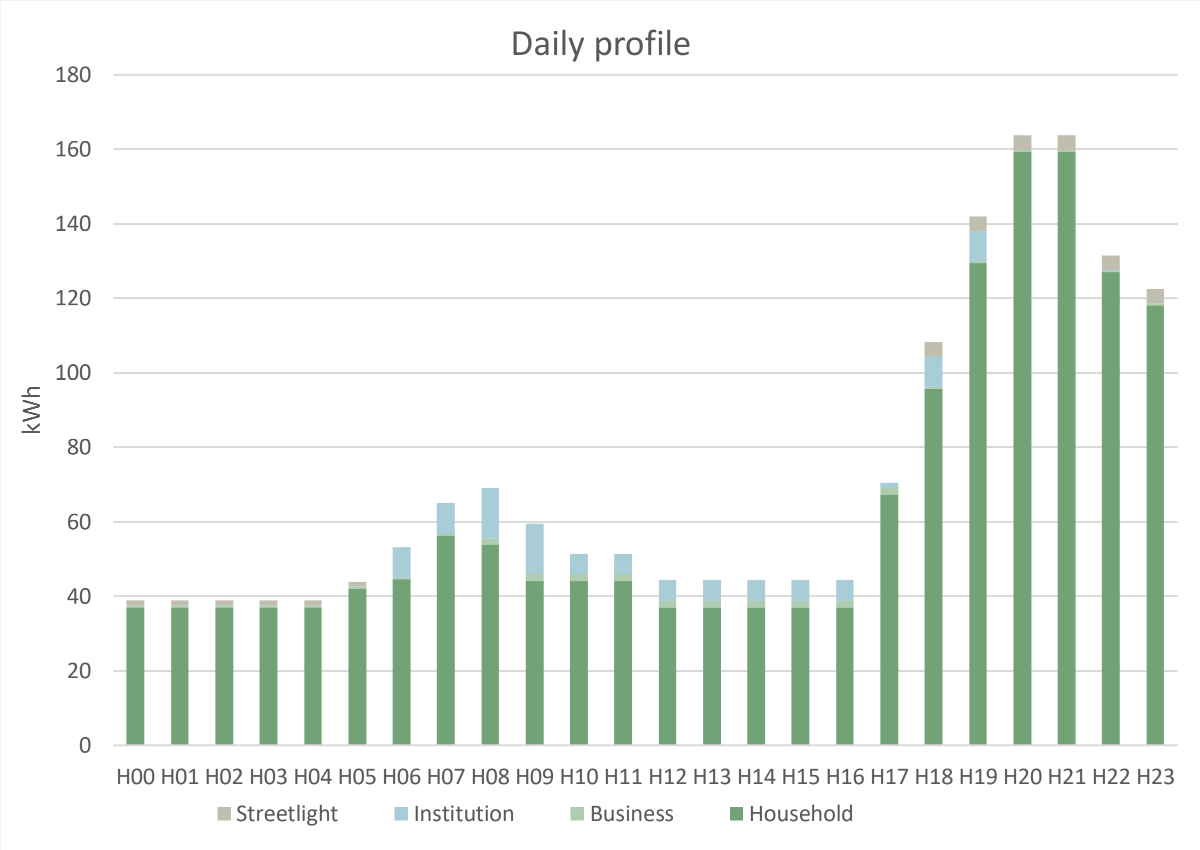
Institution	Large school	3	4400	13.2
Institution	High demand school	3	6500	19.5
Institution	Church (P3)	3	2200	6.6
Institution	High demand Church	1	8500	8.5
Institution	Large church	6	5500	33
Institution	Clinic (P4)	1	3850	3.85
Institution	High demand Health Center	1	6500	6.5
Institution	Governmental office (P3)	1	2200	2.2
Institution	Governmental office (P4)	1	3850	3.85
Institution	Community building (P1)	1	275	0.275
Streetlights	Streetlights		31112	31.112
Total (kWh/day)				**1703.787**

The ramp rate of connection (Y1 to Y4) and the demand growth are displayed in Figure 4. The demand stabilizes after year 10 around 1755kWh/day.



- **Figure 4. Estimated demand evolution along project lifetime in Fefen**

Finally, the load profile in Fefen is displayed in Figure 5. The share of each type of user is marked with different colors. The demand peaks during the evening between 6 pm and 10 pm.



- **Figure 5. Daily load profile in Fefen**

3.3.1 Solar Home Systems (SHS)

The identification of users for electrification through SHS was conducted during the Demand Assessment Report (D1) phase and will undergo further evaluation in the design phase. However, the definition of the required stand-alone solutions is covered within the scope of a separate assignment and, therefore, it is not part of this report.

4. Technical Design

This section provides details on the system design to electrify Fefen.

4.1 Methodology

The Consultant used HOMER Pro® microgrid software by HOMER Energy for sizing the components. This software allows to simulate the power system (PV, battery, battery inverter) and identify the optimal size based on key performance targets, selected according to the project scope. These performance targets are:

- maximize renewable generation penetration with a minimum RE fraction of 96.5%;
- optimize the renewable energy penetration;
- minimize LCOE

4.2 Homer results

Table 3. Summary of main Homer simulation parameters

Component	Unit	Capital Cost[2]	Replacement cost	Lifetime (years)
PV Module	USD/kWp	1900	1900	25
Battery -LFP	USD / kWh	750	750	12
Battery Inverter	USD / kW	900	900	12
Generator	USD / kW	750	750	20
Input	**Unit**		**Value**	
Fuel cost	USD/l		1.59[3]	
Inflation (applied to fuel cost too)	%/year		2.5[4]	
Demand evolution	%/year		Site specific	
Discount rate	%		12	
Fixed CAPEX	USD		Site specific	
Fixed OPEX	USD/Year		Site specific	
Fixed OPEX escalation	%/Year		2	
Diesel escalation	%/Year		2.5	

Table 4. HOMER result summary

	Demand Y4 (kWh/day)	PV (kWp)	Battery (kWh)	Battery inverter (kW)	RE fraction (%)	Battery anatomy (h)	Indicative LCOE (USD/kWh)
Fefen Island	1560	700	1500	180	96.5	21.3	0.767

4.3 Existing equipment

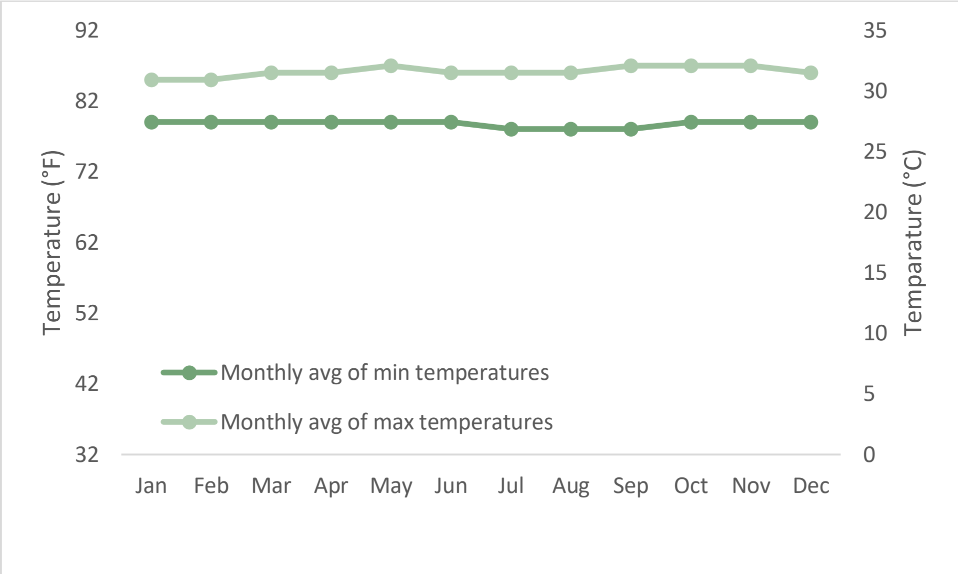
At the moment, all existing electrical assets in the community consist of some privately owned small fuel generators and SHSs. This is not envisioned to have an impact on the design of the mini-grid as it is neither possible nor required to integrate them into the to-be-installed mini-grid.

[2] All utilized costs are EPC prices deducted from the Udot and Satowan costs.
[3] Based on survey
[4] Average of the inflation of the last five years in FSD (source: https://www.worlddata.info/oceania/micronesia/inflation-rates.php)

4.4 Local environmental conditions

4.4.1 Temperature

Figure 6 shows the monthly average temperature from the island of Weno, which is considered to be the same than in Fefen.



- Figure 6. Monthly average of max. and min. temperatures recorded in FSM.[5]

4.4.2 Radiation

- Table 5. Average daily radiation for Weno weather station, PVGIS-ERA5 database[6].

Month	Average daily radiation GHI (kWh/m2/day)
Jan	4.9
Feb	5.4
Mar	5.6
Apr	5.9
May	5.4
Jun	5
Jul	5.7
Aug	5.7
Sep	5.6
Oct	6.2
Nov	4.7
Dec	4.5
Average	5.4

[5]From 2015 to 2023. Source: Weatherspark. https://weatherspark.com/y/150385/Average-Weather-in-Chuuk-Islands-Micronesia-Year-Round

[6] https://re.jrc.ec.europa.eu/pvg_tools/en/

4.4.3 Risk of high wind speeds

Wind speeds can be notorious in Chuuk islands and they shall be considered when designing the supporting PV structures. The Typhoon Maysak that came through Chuuk in March 2015 had sustained winds in the range of 70-80 mph (113-129 km/h) and higher peaks. Wutip Typhoon reached 160 km/h in 2019 in few Chuuk's outer islands (category 2 in Saffir-Simpson scale) and could have passed through Fefen as well. as per current projections, it is considered that a severe tropical cyclone will impact Chuuk every 6 to 10 years. Consequently, the minimum design winds speed is set to be 110mp/h (177km/h).

- Table 6. Saffir-Simpson Hurricane Wind Scale (Source: National Hurricane Centre)

Category	Sustained Winds	Types of Damage Due to Hurricane Winds
1	74-95 mph 64-82 kt 119-153 km/h	**Very dangerous winds will produce some damage:** Well-constructed frame homes could have damage to roof, shingles, vinyl siding and gutters. Large branches of trees will snap and shallowly rooted trees may be toppled. Extensive damage to power lines and poles likely will result in power outages that could last a few to several days.
2	96-110 mph 83-95 kt 154-177 km/h	**Extremely dangerous winds will cause extensive damage:** Well-constructed frame homes could sustain major roof and siding damage. Many shallowly rooted trees will be snapped or uprooted and block numerous roads. Near-total power loss is expected with outages that could last from several days to weeks.
3 (major)	111-129 mph 96-112 kt 178-208 km/h	**Devastating damage will occur:** Well-built framed homes may incur major damage or removal of roof decking and gable ends. Many trees will be snapped or uprooted, blocking numerous roads. Electricity and water will be unavailable for several days to weeks after the storm passes.
4 (major)	130-156 mph 113-136 kt 209-251 km/h	**Catastrophic damage will occur:** Well-built framed homes can sustain severe damage with loss of most of the roof structure and/or some exterior walls. Most trees will be snapped or uprooted and power poles downed. Fallen trees and power poles will isolate residential areas. Power outages will last weeks to possibly months. Most of the area will be uninhabitable for weeks or months.
5 (major)	157 mph or higher 137 kt or higher 252 km/h or higher	**Catastrophic damage will occur:** A high percentage of framed homes will be destroyed, with total roof failure and wall collapse. Fallen trees and power poles will isolate residential areas. Power outages will last for weeks to possibly months. Most of the area will be uninhabitable for weeks or months.

4.4.4 Logistics and accessibility

The island of Fefen is located the Chuuk Lagoon, approximately 5 km away from the main island of Weno (Figure 7).

- **Figure 7. Location of Fefen island.**

4.4.4.1 *Means of transport to site*

The following list provide key information related to transportation into Fefen:

- **Imports in country**.
  Most of the material required for the construction of a solar mini-grid in Chuuk needs to be imported. This type of equipment is normally imported to Weno island by sea cargo in 20 and 40ft containers. Weno receives regular cargo from the US (tranship in Guam) and China (tranship in Busan).
- **Transport between Weno and Fefen.**
  Fefen can be reached by small boats from Weno with landing possibilities in few existing jetties and beach landing locations distributed around the island. The duration of the trip is approximately 20 to 40 minutes depending on sea conditions and location of arrival in Fefen. Barges with capacity to carry 20' containers can land and unload containers at the Mesa or Ununo (UFO) jetties. However, the containers need to be uploaded on the landing places as container cannot be transported around the island.
- **Transport within Fefen**.
  Fefen have a circular road where cars used to circulate in the past. The road has not been maintained in years and there are sections that are not in good condition. Light trucks can access to parts of the island and excavators can access most places. All villages within Fefen have a small jetty for manual loading and unloading of material. Light weight tricycles (or similar vehicles) with a small trailer could be used to transport material around the island. In some sections, particularly in creek crossings, the road is not in good condition and would require some backfilling in order for vehicles to circulate. The vegetation next to the road is trimmed by the communities.

Table 7 provides a summary of ways of transportation to each generation location.

- Table 7. Details of transport access to each community.

Generation location	Location	Road access	Deck access	Barge access
G1	Sapota	Yes, not in good conditions	Yes	No
G2	Fein	Yes, not in good conditions	Yes	Yes
G3	Mesa	Yes, not in good conditions	Yes	Yes

4.4.4.2 *Weight and volume limitations in transport*

A summary of the available shipping agents is provided in Table 16

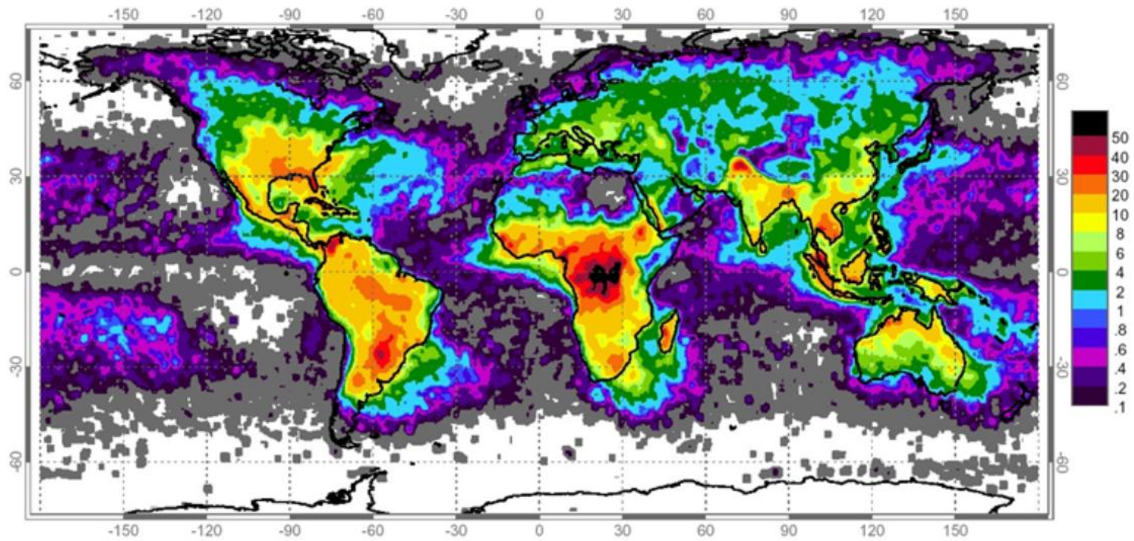
Shipping Agent	Carrying Capacity (Weight)	Carrying Capacity (Container)	Route	Cost Estimates
Matson	N/A	20 and 40 ft	Guam to Chuuk	20’ container +$2000 40’ container +$2900 (depends on weight and goods)
Kyowa	N/A	20 and 40 ft	China to Chuuk	20’ containers $3600 40’ containers $6,000 to $7,000
Brutons	6 tons	N/A	Weno to Fefen	1,800 USD per ton
Vital carrier	75 tons	Four 20’ containers or two 40’ container	Weno to Fefen	Whole day: $5,250 (one round-trip) + $60/ton

4.4.5 Soil composition

The soil in Fefen is made of compacted coral soil with rain flooding events. They are some rocks in the main road and soft soil in most sites. Installations shall not be too close to the seashore to avoid potential impact of waves during storm conditions and avoid impact of coastal erosion.

4.4.6 Lightning strikes

There are no records of lightning strikes in Fefen. The consulted CPUC staff declares that there is lightning activity in Fefen, although it is reported to be not very frequent. There are no reports of damages or casualties caused by lightning strikes, and the map of lightning density measured by the NASA shows low values (Figure 8). Therefore, lighting strikes is not considered to be a major hazard in the region.



- **Figure 8. World map showing the lightning density (Ng). Source: Nasa**

4.4.7 Marine environment

All powerplants are going to be in coastal areas. Therefore, all components and structures shall be protected from corrosion and comply with quality standards for marine environments.

4.5 Generation plants

The PV production on the island will be divided into 3 main locations. Figure 9 shows Fefen island with :

- The main generation locations G1, G2, G3
- MV line around the island (in orange)
- The end users (in purple)

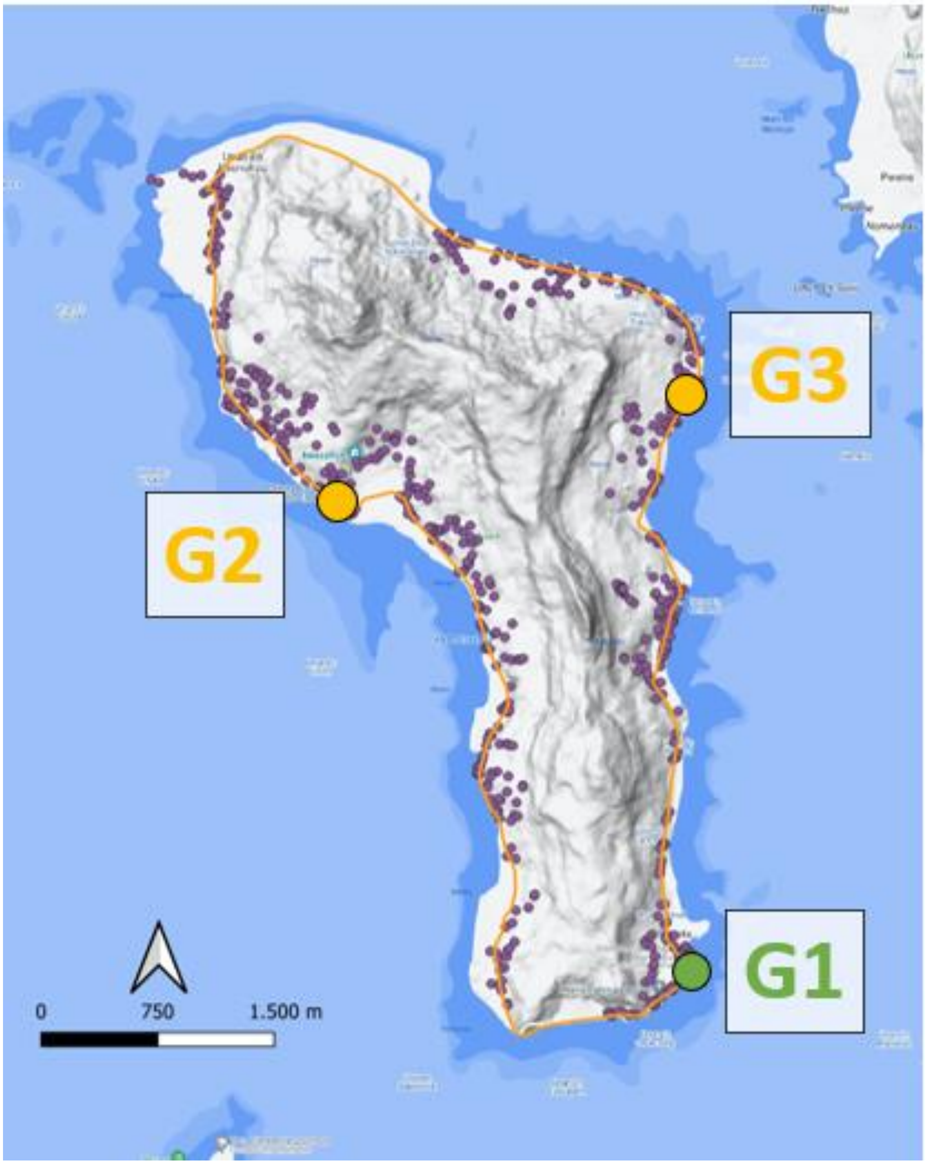


Figure 9. The 3 power generation locations on Fefen island.

To enhance operational efficiency and facilitate maintenance, the Consultant has restricted the number of generation sites on the island to three different areas.

The mini-grid consist of a 3 power generation plants connected to a Medium-voltage (MV) distribution line. **The master generation plant (G1)** has photovoltaic generators, the battery energy storage system (BESS), the hybrid controller and the back-up generator.

In each of the generation locations, the PV inverters AC output will be connected together to an AC bus, which then will go through a step-up transformer to inject the PV output in the MV distribution grid.

The mini-grid is designed to provide a 24/7 service with minimal weekly service disruptions and with voltage and frequency levels always maintained to guarantee optimal usability of desired appliances.

4.5.1 PV plants description

Fefen, like many other Pacific islands, suffer a scarcity of available land and related disputes for land ownership. Therefore, for the installation of the PV arrays, rooftops of institutional buildings, such as churches and community buildings, are prioritized. In sites where no suitable roof is available, ground-mounted solar canopies are used always prioritizing land owned by institutions. Canopies provide shelter from sun and rain and the community can still use the space underneath for other activities.

The power plants are composed of:

- PV generation subsystems, including PV modules and the PV support structure (rooftop or canopy)
- Power conversion subsystem, including PV inverters;
- earthing subsystem;
- a LV switchboard including:
  - An AC bus, combining all inverters AC outputs.
  - A pad-mounted step-up transformer
  - Control and communication subsystem, including energy/power meters;
- weather sensors;
- communication equipment;
- accessories such as electric boards including switchgear and protections, cabling, trenching, etc.;
- all other necessary equipment and materials required to ensure the correct and safe operation of the power plant.

For the master location G1, the additional components on site are:

- battery energy storage system, including Li-ion batteries and the Battery Management System (BMS);
- hybrid controller;
- monitoring platform;
- back-up generator;
- technical building;
- satellite connection including the modem.

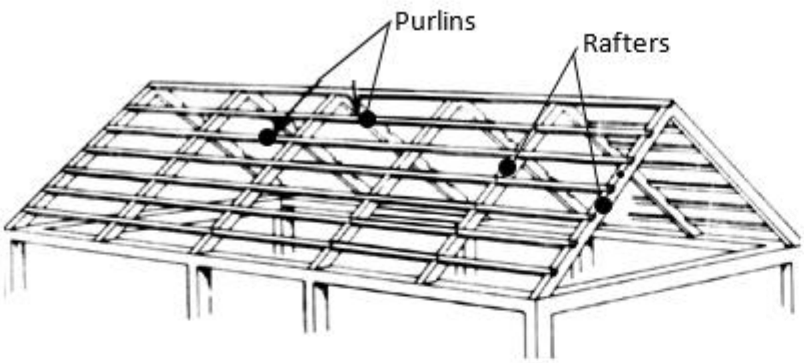
4.5.1.1 *Rooftop installation*

In the project, rooftop installations have been prioritized in order to take advantage of available surfaces on public institutions. PV installations on rooftop are planned on either churches, schools, or government office buildings.

For rooftop installations, it is important that the roofing sheet to be used will last for at least as long as the solar modules that will be installed on it, minimum 25 years. This is why it’s planned to remove all corrugated metal sheet and install new ones.

The contractor will have to validate the resistance of the rooftop structures with a static study during final design. All information on actual structural elements needed to evaluate if reinforcement/replacement will be needed is provided in Annex.

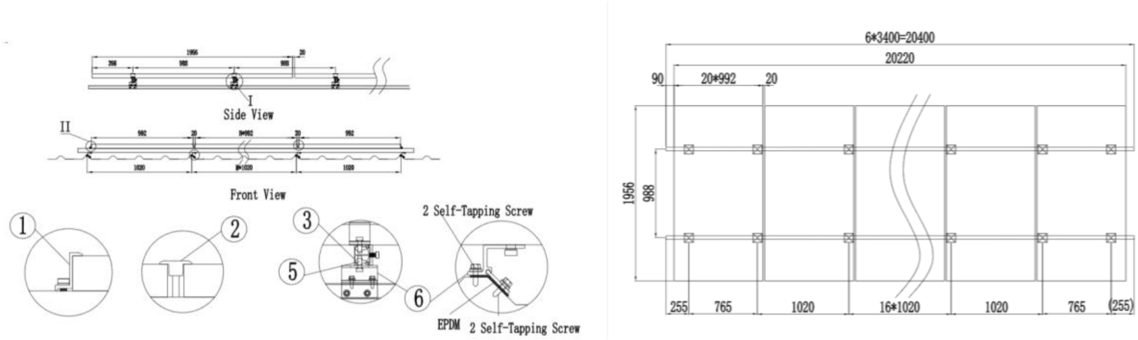
Most of rooftops are gable roofs with structural elements as shown on Figure 10.



- Figure 10. Typical structural elements of a gable roof.

PV modules installation will be on flush-mounted rails and water will have to be collected through rain gutters, and stored in drinking-water-rated water tanks as it will be used by the community.

- Figure 11. Example of flush-mounted structure solution



- Figure 12. Example of drawing for flush-mounted structure

4.5.1.2 Canopy

Solar canopies are recommended for installing the PV modules in sites where building's rooftops are limited or not available. Although the cost of these structures is higher than ground-mounted structures, they keep the space underneath available for installation of a technical room (if needed) and community activities, providing shade and cover, adding considerable value for the community.

Water will have to be collected through rain gutters, to be stored and used by the community. It is expected the supply and installation of water tanks is not within the scope of this project.

The specifications will require the contractor to install a metal sheet under the panels to ensure the waterproofness of the canopy and be able to collect the water and store it for community use. As it happens with the rooftop installations, the roofing sheet to be used will last for at least as long as the solar modules that will be installed on it, minimum 25 years.

- Figure 13. Example of a 3m high canopy installation (those in Fefen will be waterproof). Source: TTA.

Foundations

In remote locations where the access of heavy machinery is not possible, typically concrete footings or ground screws foundations are utilized. Ground screw foundations offer some advantages over concrete foundations. It is considered a more environmental solution as it does not require earthworks, pouring of concrete, sourcing of beach aggregate sand and it allows for an easy decommission and recycling of the foundations. In addition to the environmental advantages, it also provides time and cost benefits. Therefore, ground screw foundations should be prioritized in sites where the soil conditions are favorable and access to heavy machinery is not possible.

To determine the design and right type of foundations to be used in each site, a geotechnical survey should be conducted. However, considering the existing soil composition and the flooding conditions on many sites during king tides and heavy rain, it is likely ground screws might not be a suitable solution. Therefore, **concrete footings should be considered for the ground-mounted canopies structures**. Furthermore, and in order to avoid metal structures to be contact with highly corrosive sea water during flooding experienced on king tide conditions, the concrete footings should have a minimum height of 60cm above ground level.

4.5.1.1 PV inverters

PV inverter must be placed close to the PV installation. They can be installed indoor or outdoor. If placed outdoor, a metallic cage must be installed in order to avoid vandalism, while keeping the inverter well ventilated. The inverter must not be exposed to direct sunlight or rain water.

- Figure 14. Example of a metallic cage that protects outdoor inverters from theft.

4.5.2 PV plants locations

The table below presents a summary of all the PV sites.

- Table 8. Summary of PV sites with capacity to be installed

Label	Village	Institution name	Type installation	Min PV power (kWp)
G1-RT1	Sapota	Elementary school	Rooftop - School	79.2
G1-CP1	Sapota	Elementary school	Canopy	60.7
G1-RT2	Sapota	Sapota Protestant Church	Rooftop - Church	47.6
G1-CP2	Sapota	Sapota Protestant Church	Canopy	58.1
G1-RT3	Sapota	High school	Rooftop - School	63.4
G2-RT1	Fein	Sacred Heart Catholic Church	Rooftop - Church	122.0
G2-RT2	Fein	Old church	Rooftop - Church	50.2
G2-RT3	Fein	Parish Hall	Rooftop - Building	38.7
G3-RT1	Mesa	Elementary School A	Rooftop - School	68.0
G3-CP1	Mesa	Elementary School A	Canopy	95.0
G3-RT2	Mesa	Municipal Office	Rooftop - Building	23.8
G3-RT3	Mesa	Holy Family Catholic Church	Rooftop - Church	44.8
G3-CP2	Mesa	Holy Family Catholic Church	Canopy	18.5
			Total Canopy	232
			Total Rooftop	538
			Total	770

<u>Important note:</u>

All sites where the canopies, step-up-transformer and/or technical building need to be installed are exposed to flooding conditions during heavy rain (20 to 30 cm) and during king tide events. The flooding linked to king tides is going to increase with climate change, therefore all cabinets, technical room and the structural elements of the canopies need to be at least 60 cm above ground level.

Further details on each of the sites is provided in Annex A.

4.5.2.1 G1 (Sapota)

Figure below shows the physical distribution of PV installations that will be constructed in Sapota (G1).

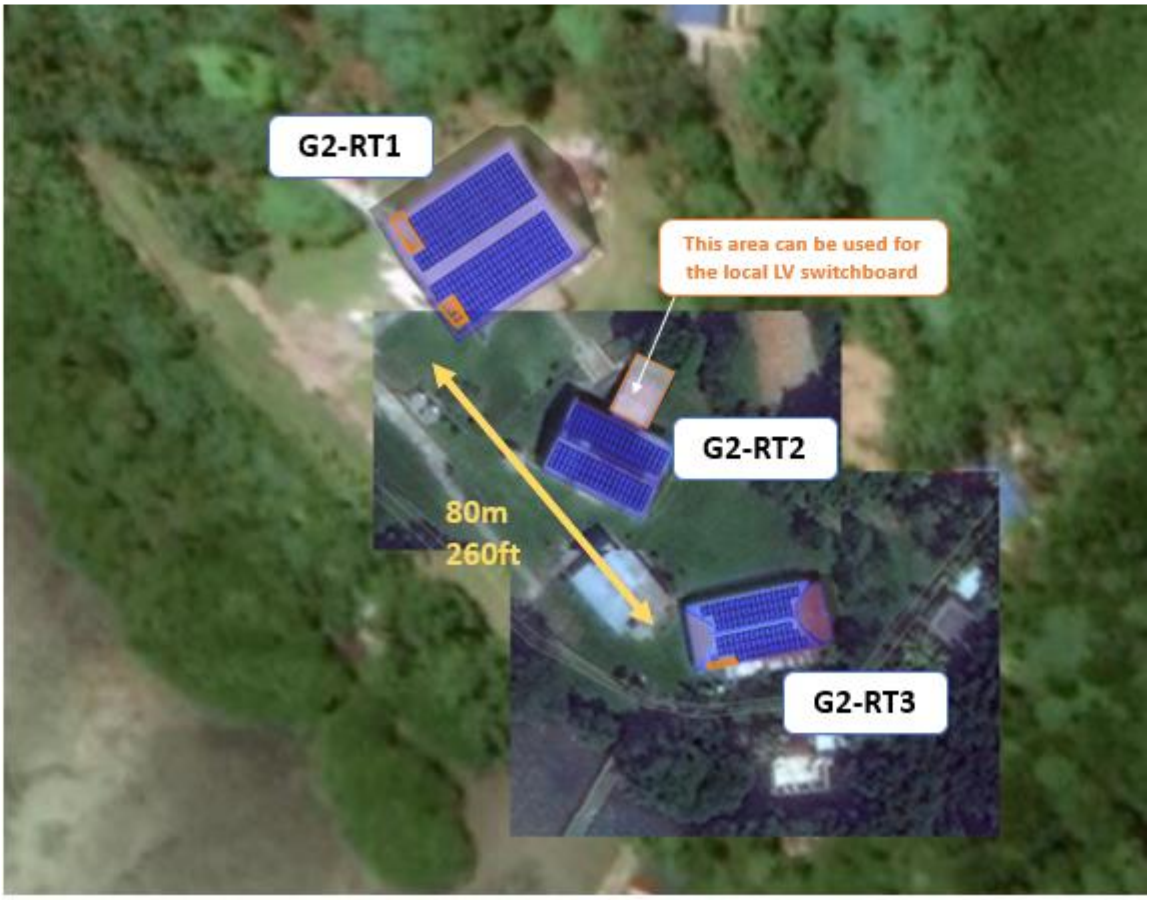
- Figure 15. Top view of PV arrays in G1

- Table 9. Summary of PV capacity in G1

Label	Type installation	Azimuths	Min PV power (kWp)	Min PV inverter (kW)
G1-RT1	Rooftop - School	-80° / 100°	79.2	60
G1-CP1	High Canopy	-80° / 100°	60.7	47
G1-RT2	Rooftop - Church	-130° / 50°	47.6	37
G1-CP2	Canopy	-40° / 140°	58.1	45
G1-RT3	Rooftop - School	-160° / 20°	63.4	49
		Total :	309.0	237

4.5.2.2 G2 (Fein)

Figure below shows the physical distribution of PV installations that will be constructed in Fein (G2).



- Figure 16. Top view of PV arrays in G2

- Table 10. Summary of PV capacity in G2

Label	Type installation	Azimuths	Min PV power (kWp)	Min inverter power (kW)
G2-RT1	Rooftop - Church	-35° / 145°	122.0	94
G2-RT2	Rooftop - Church	-155° / 25°	50.2	39
G2-RT3	Rooftop - Building	-10° / 170°	38.7	30
		Total	210.9	162

4.5.2.3 G3 (Mesa)

Figure below shows the physical distribution of PV installations that will be constructed in Mesa (G3).

- **Figure 17. Top view of PV arrays in G3**

- **Table 11. Summary of PV capacity in G3**

Label	Type installation	Azimuths	Min PV power (kWp)	Min PV inverter (kW)
G3-RT1	Rooftop - School	-140° / 40°	68.0	50
G3-CP1	Canopy	-140° / 40°	95.0	73
G3-RT2	Rooftop - Building	-10° / 170°	23.8	18
G3-RT3	Rooftop - Church	-15° / 165°	44.8	30
G3-CP2	Canopy	-15° / 165°	18.5	14
		Total	250.1	186

4.5.3 Battery technology

The battery technology for the project is Li-ion batteries.

The two most common Li-ion battery technologies for PV applications are Lithium Nickel Manganese Cobalt Oxide (NMC) and Lithium Iron Phosphate (LFP). NMC cells have a high gravimetric energy density (Wh/kg) which makes them a great solution for mobile applications, allowing automobiles and scooters to be more compact and lighter. On the other hand, NMC cells do not have good thermal stability, and they can catch up on fire easier than other Lithium chemistries if they are not perfectly protected both electrically and mechanically. LFP batteries have high cycling capacity, remarkable thermal stability and are intrinsically safe. Considering the typical load profile of rural electrification and the remote locations and climatic conditions, it is recommended to place safety as a priority, making **LFP the preferred option**.

4.5.4 Battery inverter

The battery inverter will have the following features:

- output voltage: 400V or 480V, three phases;
- must be bidirectional;
- must be grid-forming;
- must be able to provide the specific features of functional requirements section;
- have a minimum power of 500kVA.

The future hourly peak demand of Fefen communities is expected to be around 180kW. However, in the case of Fefen, the AC-rated peak output of the solar generation to be installed in the island will exceed the peak demand. Therefore, the battery inverter must be designed based on expected peak PV power output, to be able to store produced electricity at all times.

Detailed specifications will be provided in the technical specifications.

4.5.5 Technical room

The main technical room for the mini-grid will be situated in Sapota (G1).

The space for technical room area is currently occupied by 3 buildings.

1. Existing technical room of CPUC.
   CPUC uses it for the battery, electronics and other things but agreed for the project to demolish it and rebuild the technial building of the future mini-grid. CPUC will empty the building.
2. Storage building for the school.
   Same than above, also possible to use it as available area.
3. Guardian box.
   If needed according to final design of the technical room, the guardian box could be removed and a dedicated area will be place in the new technical building at the entrance of the zone.

- **Figure 18. Top view and satellite view of the spaces available for technical room and storage in G1.**

Between the back of the high school building and the fence, there a 2.5m wide space. This space is not sufficient to locate the genset, the battery room or any auxiliary building as it would bock a considerable amount of light coming through the windows.

- **Figure 19. Back of the high school building.**

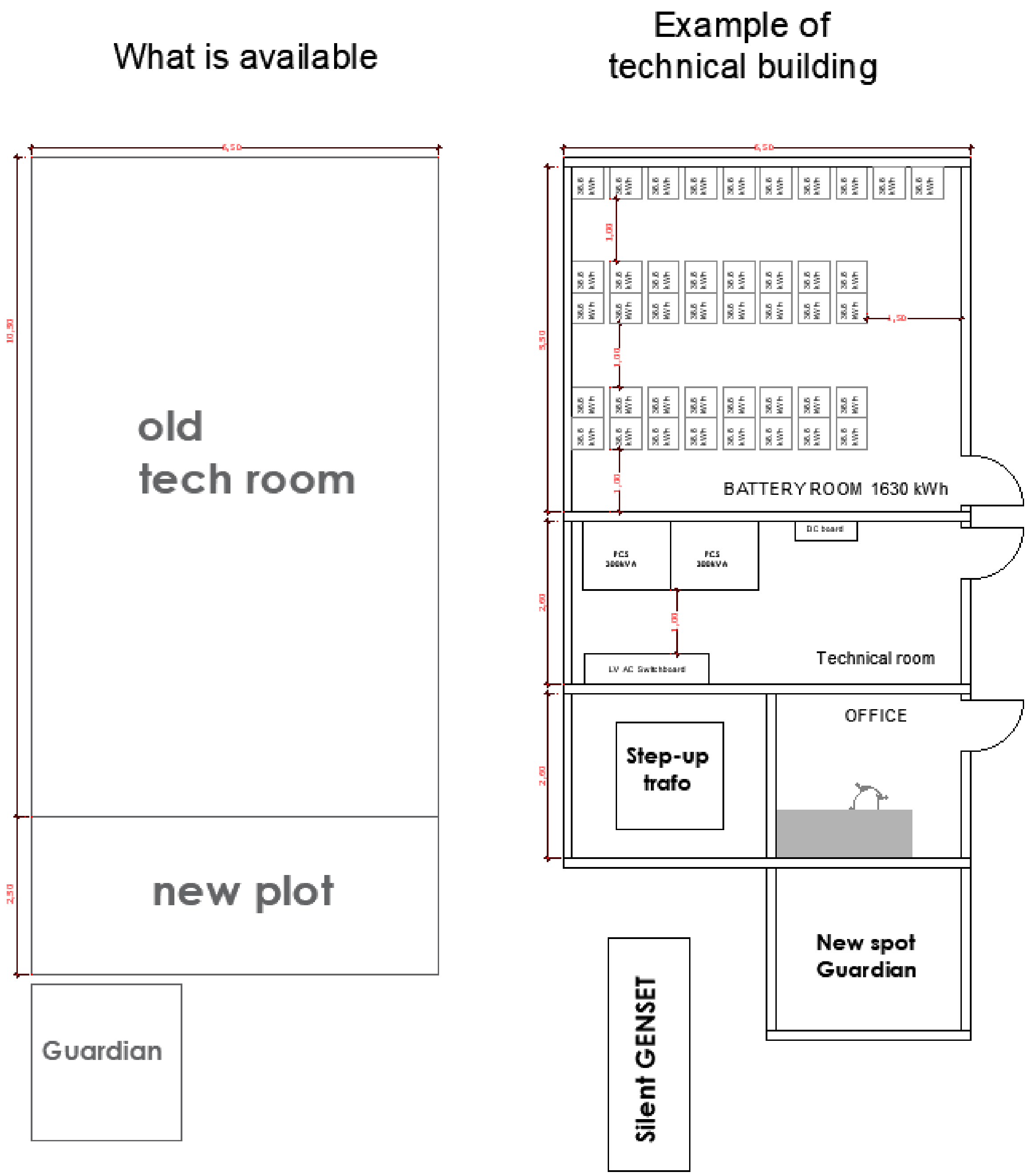
The technical building shall be divided into 3 main rooms:

- Battery room
  - Battery and AC unit
- Technical room
  - Battery inverter
  - DC Board
  - AC Board¨
  - Hybrid controller
- Office
  - Office desk for the operator
  - Monitoring platform

The step-up transformer can be placed inside or outside, as preferred by the contractor according to his final design (considering that the safety of the users has to be ensured).

The building must be elevated by 60cm above ground level to mitigate potential flooding issues.

A waste disposal space (to gather electrical waste from island) will have to prepared by the contractor. Final location will be defined during the final design.



- Figure 20. Available area and offered layout of the new technical building.

The detail drawing is included in Annex B.

4.5.6 Back-up generator

The backup generator should have the following main features:

- should be able to work automatically with the hybrid controller;
- must be soundproofed (silent generator);
- must be adapted for marine environment.

More details will be provided in the technical specifications.

The rated power of the generator will be minimal 250kVA.

4.5.7 Standardization of components

The standardization of components between the PV generation sites facilitates the operation and maintenance of the system as a whole and reduce considerably the need for spare parts as inventories are compatible for the all mini-grids. Standardization with projects of Satowan, Weno and Udot (to some extent because these are LV mini-grids of much smaller capacity) will be promoted to the greatest possible extent in the design. Even if each rooftop and canopy installations have their own characteristics, the number of different key components (like model of inverters) will be minimized and standardize as much as possible.

4.5.8 Functional requirements

The power plant shall be three-phase with a nominal voltage of 400 Vac or 480Vac and a nominal frequency of 60 Hz.

The power plant shall work at least under the following functional modes:

1. Hybrid mode.
    a. The BESS act as a grid-forming plant. All PV inverters shall be grid-following. The generator shall be used as back-up generator when load cannot be served by the BESS+PV.
    b. If the PV output is higher than the demand, the PV generator will charge the battery and supply the loads; the backup generator is off and the grid is formed by the battery inverters. If the battery is fully charged, the control system shall curtail the PV power in order not to over-charge the battery. This curtailment will be done by the hybrid controller. In case of failure of communication between the PV inverters and the hybrid controller, the curtailment will be done by increasing the frequency (droop control).
    c. If the PV power is lower than the demand, the battery inverter shall discharge the battery to cover the difference. The control system shall manage the battery to avoid excessively long or fast discharges, disconnecting it if necessary. The battery's State of Charge (SoC) shall never be below the manufacturer's recommended threshold.
        i. If the SoC arrives at such a minimum threshold, the control system shall automatically start the backup generator. The backup generator shall supply the loads and charge the battery up to 80% of its capacity as a minimum through the battery inverter, the latter acting as a battery charger. After this, the control system shall automatically stop the backup generator, and the battery inverters shall form the grid and supply the loads.

    When the backup generator is on, it shall run at its most fuel efficient loading point and always at least at 30% of its nominal power rating.

2. Bypass mode.
    a. Under maintenance scenarios where the disconnection of the battery is needed or the PV generator is not able to work for several hours/days, it will be necessary to bypass the power plant and operate exclusively with the backup generator. To do so, a Manual Transfer Switch shall be included before the step-up transformer, which shall be capable of isolating completely the PV generators, battery and battery inverters, allowing only the backup generator to supply the loads.

The backup generator shall be able to work in two operational modes:

1. Manual mode. The operator shall be able to switch on/off the generator manually.
2. Automatic mode. The operator shall be able to configure the optimum battery thresholds for the automatic starting and stopping of the generator, including at least the following functionalities:
    a. The generator start signal shall be automatically activated when the battery SoC is below the adjustable lower limit and/or when the output power of the battery inverters is greater than their adjustable upper power limit.
    b. The generator stop signal shall be automatically activated when the battery SoC reaches the adjustable upper limit and/or when the output power of the battery inverters is lower than their adjustable upper power limit.

4.5.9 User interface, communication & control

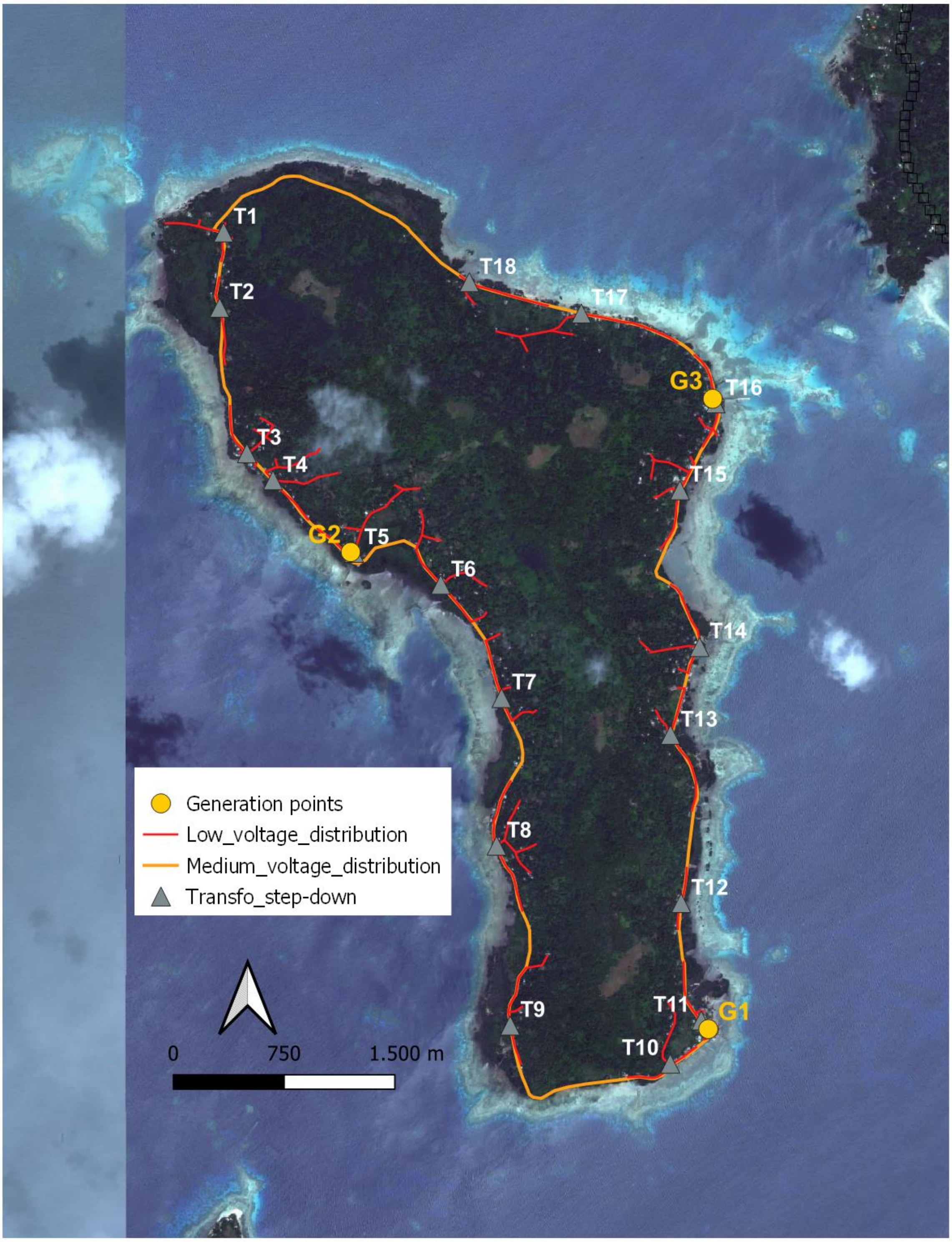
The **mini-grid should be equipped with remote monitoring capabilities**. They should allow real-time performance supervision and visualization as well as control and manage the operation of the facilities when needed. They should include a data logger and the electronic devices and sensors needed to record, process and send to a remote server all relevant operational data from the generation and storage plant. This includes, but is not limited to:

- Monitoring. Real-time measurements of standard parameters, covering, energy, AC power (Apparent, Active and Reactive), voltage (AC and DC), current (AC and DC), battery SOC and temperature, frequency, energy, irradiance (only G1), ambient temperature (only G1), module temperature (1 site in G1), etc. The system shall include alarms to notify in case of failure of any of the plant's major components.
- Data recording and retrieving functionalities. The plant operators shall be able to easily see the monitoring data both locally and remotely (online interface) and shall have the option to retrieve historical data of the plant in an easy way and with a widely recognized file format.
- Control: The integration of a multi-source (hybrid) controller located in Sapota (G1) will be required. The hybrid controller functions are to secure a seamlessly balanced dispatch of solar and the diesel back-up genset. It automates, secures and optimizes energy and power management of multi-source power systems with renewable-based generation and diesel back-up, always allowing manual override. Operators should be able to control some basic features of the plant remotely, including change settings to optimize the system performance.

The remote monitoring and control system will utilize a new communication network, which is yet to be installed. The communication network will consist of :

- 2 optic fiber lines (G1 to G2 and G1 to G3)
- Internet access through satellite in G1.

4.6 Distribution network



- Figure 21. Visualization of Fefen island with the distribution network.

The distribution network is divided in:

- Underground Medium voltage (MV) distribution network three-phase 7970V L-N / 13800V L-L 60 Hz.
    - All power generation plants inject in MV through pad-mounted step-up transformers.
    - 2 switching point (one in G1 and another in the North of the island)

- Underground Low voltage (LV) distribution network split-phase 120AC L-N / 240VAC L-L 60 Hz.
    - Pad-mount step-down transformers
    - Main underground split-phase cables
    - Distribution pillar boxes, which deviate the backbone line to the secondary branches or to the meters.
    - Underground service lines, connecting to each meter.
    - Earthing system.
    - All other necessary equipment and materials for the correct and safe operation of the distribution line.

An underground distribution configuration has been selected to increase the resilience of the system against typhoons.

The conductors shall be placed in PVC raceways installed on the side of the road. All conductors of the same circuit and, where used, the grounded conductor and all equipment grounding conductors shall be installed in the same raceway. Insulated conductors and cables installed in these enclosures or raceways in underground installations shall be listed for use in wet locations and shall comply with NEC article 310.10. The raceways shall be listed by a qualified testing agency as suitable for direct burial without encasement.

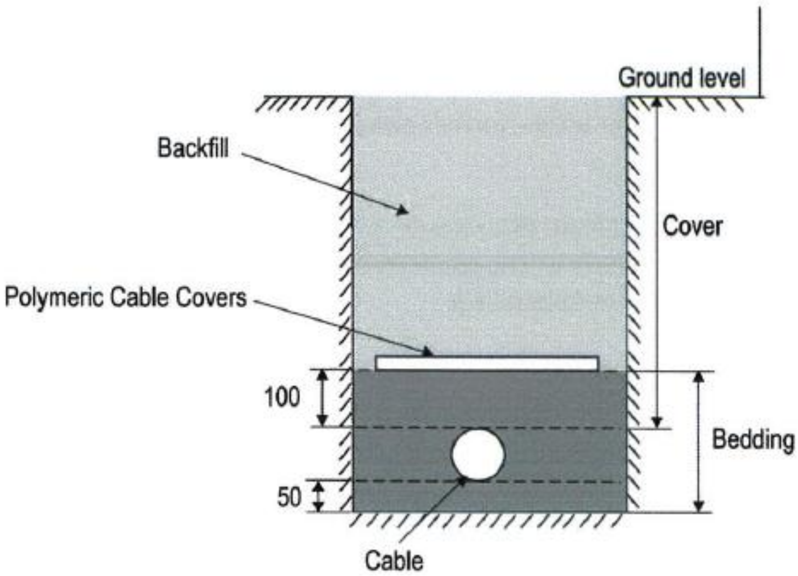
Two different minimum cover requirements shall be considered (according to NEC table 300.5):

- Min 60cm/24in. for wiring circuit under street or roads (or where they might be street or roads in the future)
- Min 45cm/18in. for any other locations.

In order to minimize the cost of the trenches, LV/MV will be placed in the same trench, where possible. A distance of 50cm will be maintained between both system’s raceways in order to avoid any problems.

During site visits, the Consultant identified 2 small 1-meter-wide creeks in G1 and G3. The creeks were nearly dry at time of inspection but erosion sings and report from the community showed that the water level can potentially reach up to 50 cm high during heavy rain conditions. During the construction of the undergrounded distribution lines, the contractor will have to manage this creek crossings every time it happens. It is estimated that it can occur around 20-30 times around the island. To cross these creeks, the conductors should be installed in a metallic raceway, which will be fixed in small manholes at each side of the creek. Other solutions can be proposed, depending on the creek height and conditions

The network shall be designed and installed to be fully compliant with relevant NEC standards.



- **Figure 22. Example of underground cable trench cross-section**

- Figure 23. Example of a creek found on Fefen island.

4.6.1 Step-up transformers

Three step-up transformers will be required. Two of them will be used in G2 and G3 with a unidirectional power flow. One will be used in G1 and will have a bi-directional power flow.

The transformers will operate in a step-up function feeding electricity from the LV PV Plants to the MV distribution grid. It is intended for use in tropical weather conditions with a corrosive sea air atmosphere. The specification covers requirements for three–phase, dead-front radial feed, 60Hz, mineral oil filled, 65ºC rise pad mounted type distribution transformers for use with separable insulated high-voltage connectors similar to the ones already used by CPUC (GE PROLEC).

- Table 12. Step up transformer main specifications

LV/MV distribution Transformer sizing	G1	G2	G3	Unit
Power flow	Bidirectional	Unidirectional	Unidirectional	
Primary Rated voltage kV	0.48 or 0.4	0.48 or 0.4	0.48 or 0.4	kV
Secondary Rated voltage (kV)	13.8	13.8	13.8	kV
Maximum Demand Load (planned kWac +20%)	348[7]	162	186	kW
Power factor	0.97	0.97	0.97	kW/kVA
Maximum Apparent Power	359	168	192	kVA
Transformer type	Oil	Oil	Oil	-
Permissible Loading Percentage (%)	80%	80%	80%	%
Calculated transformer rating kVA	449	210.0	240	kVA
Minimum rated power	> 450	>250	>300	kVA

For G2 and G3, the transformers should be installed close to the LV switchboard, according to NEC standards, and elevated by min 60cm from the ground.

For G1, the step-up transformer can be placed inside or outside, as preferred by the contractor according to his final design (considering that the safety of the users has to be ensured).

[7] Here, the design power is equal to the sum of PV inverter of G2 and G3. This allows to charge the battery when peak power is produced from the installations. The load power will be around 160kW.

4.6.1 Step-down transformer

Step-down transformer will be installed around the island to distribute the power to the users. They will have the following features (non-exhaustive, more details in the tender):

- Pad-mounted
- Type II non-PCB mineral oil (ONAN)
- High Grade silicon steel core.
- Aluminum windings
- Pad-lockable door handle.
- NO load tap changer.
- Impedance 5.75% (+/-7.5%).
- 65-degree C rise.

Table below summarizes the assumptions considered for the design of the step-down transformers.

- Table 13. Calculations for peak power per consumer

Description	Value	unit	Comment
Rule of thumb CPUC	0.595	kVA max / consumer	5kVA pour 12 consumers, and assuming diversity factor of 0.7
Margin for future increase in demand	1.5	-	50% additional power increase possibility in the future 20-30 years.
Power factor	0.85	kW/kVA	
Design Peak power per consumer	0.893	kVA max / consumer	
Design Peak power per consumer	0.759	kW max / consumer	
Diversity factor for >24 users	0.5	-	Conservative assumptions. Details on **Error! Reference source not found.Error! Reference source not found.**

According to these assumptions, the maximal number of consumers per transformer can be estimated, as presented below

- Table 14. Estimated number of consumers per transformer capacity

kVA	Number of consumers estimated
10	23
15	34
25	56
37.5	84

According to the interviews and demand assessment, the following factor can be applied to the design peak power in order to perform the voltage drop calculations:

- Table 15. Factor considered for peak power

Code	Description	Factor for peak power
BB	Business	1
II	Institutions	3
HB	Households with small business	1
HH	Households	1

Therefore, institutions will have an equivalent of 3 normal consumers in the calculation of voltage drop.

The diversity factor used for the calculation of voltage drop is the following:

- Table 16. Diversity factor for transformer design

Number of downstream consumers	Diversity factor (ks)
<4	1
<9	0.78
<14	0.63
<19	0.53
<24	0.49
>24	0.49

- Table 17. Design of step-down transformers

Transformer	Nb of equivalent users	Minimal capacity (kVA)	Selected transfo (kVA)
T1	25	11.2	15
T2	23	10.3	15
T3	44	19.6	25
T4	44	19.6	25
T5	38	17.0	25
T6	51	22.8	25
T7	37	16.5	25
T8	47	21.0	25
T9	21	9.4	15
T10	37	16.5	25
T11	55	24.6	25
T12	11	4.9	15
T13	41	18.3	25
T14	54	24.1	25
T15	38	17.0	25
T16	41	18.3	25
T17	52	23.2	25
T18	26	11.6	15
		Total	400

There will be a total of 18 transformers of either 15 or 25kVA.

4.6.2 Earthing and protections

Earthing (or “grounding”) will have to be design according to the NEC standards, and National Electrical Safety Code.

A protection study will have to be provide for the detailed design.

4.6.1 Manholes

From the NEC, details for installation in the manholes: if the conductors of each system (LV and MV) are permanently and effectively separated from the conductors of the other systems and securely fastened to racks, insulators, or other approved supports, conductors of different voltage ratings shall be permitted.

4.6.2 Cable sizing

The size of the cables will be determined when the distribution network and the voltage drop analysis will be finalized. Underground cable that complies with NEC standard shall be used.

CPUC is currently using 2/0 AWG size 7 strand wiring MV cables.

An additional effort should be done to harmonized cable procurement among the various project in Chuuk (Udot, Satowan, …).

For low-voltage aerial distribution, CPUC uses triplex copper wire number 2, 4, and 6.

4.6.3 Distribution pillars box

Low voltage distribution pillars shall be used for the distribution of power. The distribution pillars should be located at the edge of an existing road/path near the cluster of buildings that are going to be connected to the pillar. They should be installed following manufacturer requirements and in compliance instructions with NEC relevant standards.

The distribution pillars used should:

- be capable of housing service fuses and/or disconnect switches as required;
- allow for the disconnection of any user without causing a service disruption to any of the other users serviced from the same distribution pillar;
- be outdoor rated, made of UV stable material rated for marine environments;
- be installed at least 60cm above ground level to prevent ingress of water during flooding conditions.

Figure 24. Example of a pillar box. Source: Transnet

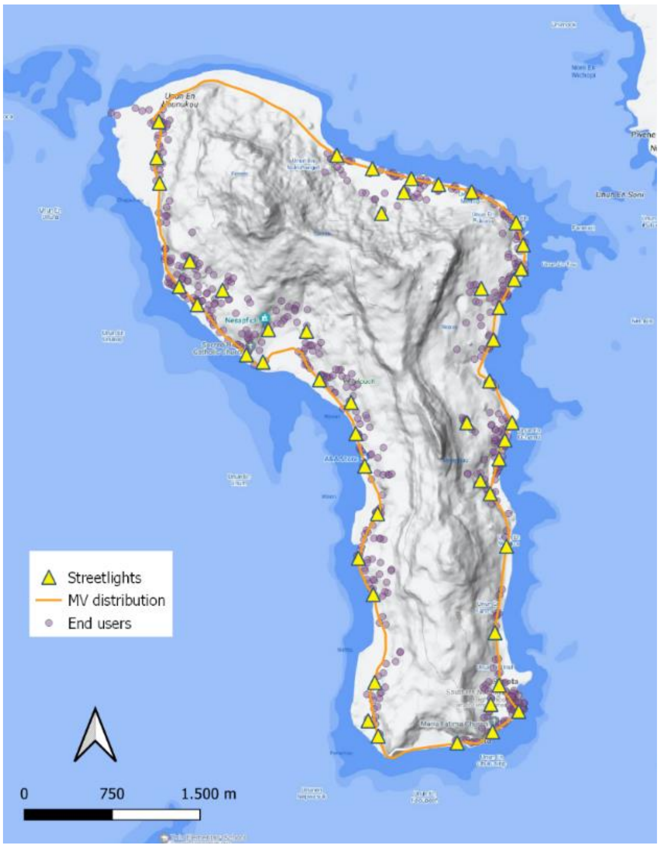
4.7 Electrical single line diagram

A reference electrical single line diagram of the system is provided in Annex C.

4.8 Streetlights

4.8.1 Provision of street lighting

Public streetlights will be installed around the island and will be powered by the mini-grid. A total of 49 public streetlights are planned for Fefen. Locations have been selected by CPUC based on local needs by community. The streetlights are assumed to be operating for 12 hours every day (18:00 to 06:00).



- Figure 25. Public streetlights planned for Fefen island. Source: CPUC

4.8.2 Type of lamps

Programmable IP65 streetlight LED lamps with a wide angle of view and rating of at least 35 Watts and 125 LM/W shall be installed on 5-meter poles.

4.8.3 Material of poles

5-meter galvanized steel poles with a minimum thickness of not less than 2mm shall be used to mount the streetlights on. The poles should be rated for marine environments and to resist a design wind speed of 110mph.

4.8.4 Foundations

Concrete foundations will be used. The foundations should be sized according to a design wind speed of 110mph.

4.9 End-user connection

4.9.1 Meter

The meter will have the following characteristics:

- prepaid meters 240V (split-phase), 60Hz;
- located at the house of each user;
- service-based, energy-based and time-of-use (TOU) tariffs;
- class II;
- LCD screen and LED indicators

4.9.2 Service lateral

The service lateral will connect each meter to its respective pillar box. It must be underground. The sizing of the service lateral should be 10mm2 (5 AWG) for all connections. For demands superior to Service package 4 (expected for some businesses and institutions) the section of the service line will be assessed on a case-by-case basis.

4.9.3 Internal wiring

Internal wiring will be installed by CPUC as it has been done in Tonoas and Satowan and it is to be done in Udot.

4.10 Access to internet on site

3G/4G coverage in Fefen is quite limited and unreliable. The speed of connection never always ranges between 100-500 kb/s. Therefore, a satellite internet connection will have to be installed in G1. Internet in G2 and G3 will be available through optic fiber connection to G1.

Annex A – Detailed Information on PV sites

Annex B – Technical Room Reference Drawing

Annex C – Electrical Single Line Diagram