Consultancy Services for the Engineering Design of

Solar Powered Mini-Grids in

Etten and Piis Paneu Islands, Chuuk State

D4 Draft Concept Design

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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D4. Concept Design Report

Deliverable #4

Related Documents	**Type of document**	**Draft/final**	**Date of submission**
D1 Demand Assessment Report	Pdf/Word	Final	March 6, 2023
D2 Concept Design Report 1.1	Pdf	Final	December 8, 2023
D3 Technical Specifications and BoQ 2.0	Pdf	Final	February 16, 2024
Etten and Piis Design Brief	Pdf	Final	March 07, 2024

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PRESENTATION This report contains the deliverable #4 of the project. The authors of this report are Nicolas Antoine, Alberto Jerónimo, Lucas Mosca, and Reena Sayani.

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 involve separate partnerships with the EU, the FSM and implementing partners.

Component 2, the 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 critical 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 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.

During the first phase of the project, TTA supported CPUC for the concept design of the electrification of Fefen by a MV solar mini-grid. The three deliverables D1, D2, and D3 focused on this objective. The next deliverables D4 (this very document) and D5 focus on the electrification of the islands of Etten and Piis.

TTA will support CPUC for the Etten and Piis Paneu islands' concept design of mini-grids to achieve reliable and sustainable 24-hour access to electricity for the communities. The concept design may also identify options for households or buildings suitable for standalone systems, such as solar home systems, where needed.

1.2 Assignment

The objective of the current assignment is to provide services to CPUC to support the household, business, and institution surveys, technical site assessments, and designs of solar-powered mini-grids for the Etten and Piis Paneu Islands. This assignment includes activities and deliverables shown in Figure 1.

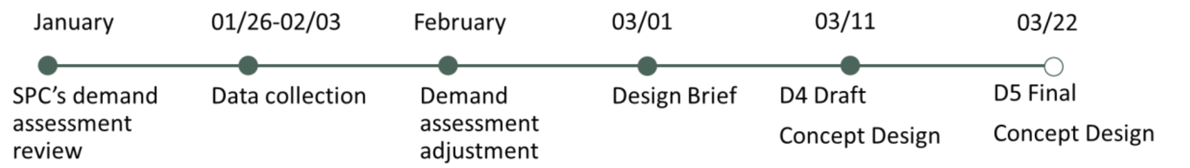

Figure 1. Activities and deliverables of the assignment

The Consultant received the data collected by CPUC and SPC in Etten and Piis in January 2024. TTA reviewed the data and conducted a short field mission to conduct site specific tailored *end-user* and *focus group discussion* surveys in KoboToolbox to reassess the data.

1.3 D4 Concept Design report

This report presents the deliverable D4, which is the first deliverable of the project concerning Etten and Piis. It aims to: (i) establish a socio-economic baseline for Etten and Piis Paneu Islands, characterizing the communities visited and providing relevant information for the electrification strategy, (ii) estimate the baseline electricity needs from the islands and identify anchor loads to inform the design of the generation and distribution assets, and (iii) elaborate the technical specifications and costs estimates for the electrification of the islands.

The demand assessment for Etten and Piis Paneu is based on TTA field missions for data collection and surveys in January 2024. Additionally, SPC's demand assessments conducted in May-June 2023 also complement the demand estimation from these two islands.

Table 1. Communities

	Etten	Piis Paneu
Households	48*[1]	72
Independent businesses	2	1
Institutes	3	2
Anchor loads	1	3

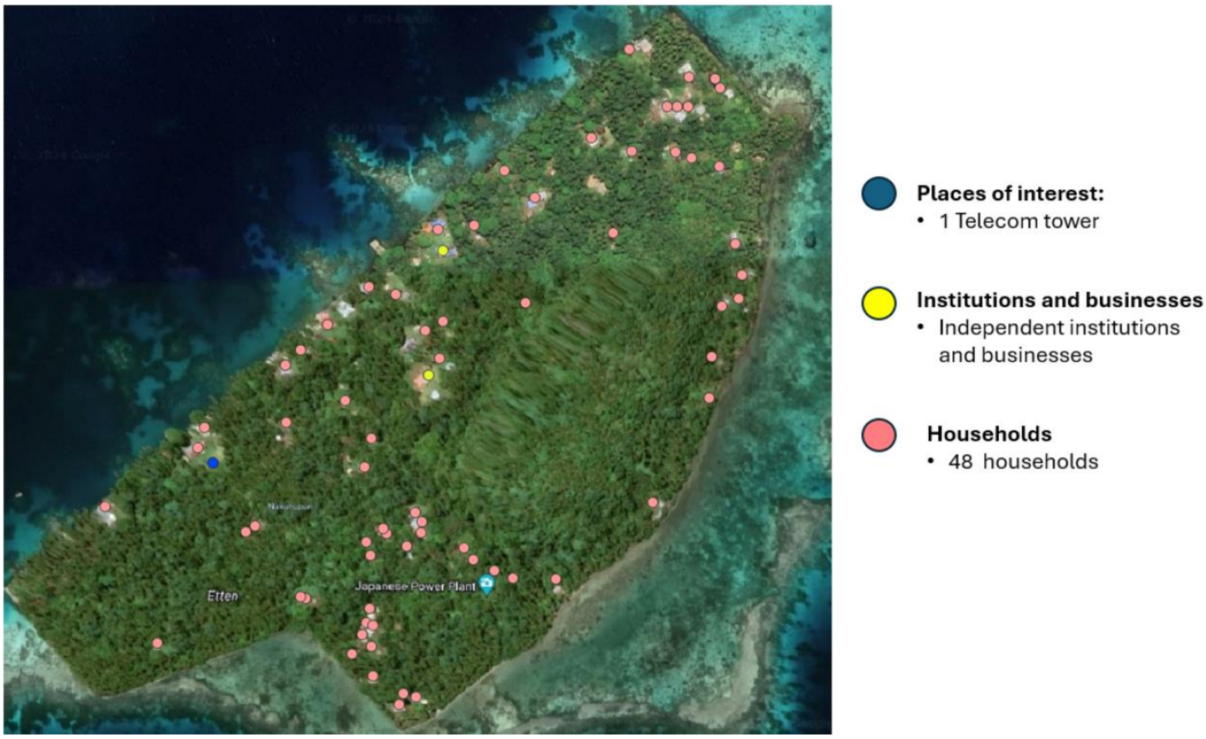

Figure 1. Etten geographic area

[1] Seven households expatriated are included within the 48 households established in Etten

Figure 2. Piis Paneu geographic area

2. Electrification Approach

2.1 Electrification scope for Etten & Piis Paneu

Etten and Piis Paneu are two small islands of around 1 km by 0.4 km. Considering initial demand assessment, future increase of demand and distribution network characteristics, it was concluded that utilizing one low voltage (LV) distribution mini-grid per island would be the best solution in a techno-economic point of view, for the electrification of Etten and Piis. The installation of two standalone solar systems will optimize the electrification of Etten, for a 100% coverage of each island.

The electrification of Etten and Piis is proposed to provide electricity service to **132 users**: **120 households** (two of those served with Solar Home System (SHS)), **5 institutions** and **8 businesses**[2]. The users will be powered by a solar PV + battery generation plant with a diesel back-up generator for each island.

[2] 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. Demand 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 2. Summary of GPS points collected for end-users by SPC

Type of end users	Etten	Piis
Anchor loads	1	3
Business (BB)	2	1
Household (HH)	48	72
Institution (II)	3	2
TOTAL	**54**	**78**

3.1 Methodology

The effective demand (or the electricity demand backed by the financial resources to pay for it) for the baseline year, as well as the forecast demand, is assessed in three steps:

1. Generate load profiles. The methodology to generate indicative load profiles differs for different types of customers.

Residential customers

The Consultant creates a Willingness-To-Pay table showing energy packages and corresponding price options based on the knowledge of the type of service and the needs of the community. A survey from a sample of current energy use or market research in the region provides such insights. The Consultant characterizes every energy service package table with: (i) Service provided, (ii) Energy requirements to supply the service and (iii) a monthly price.

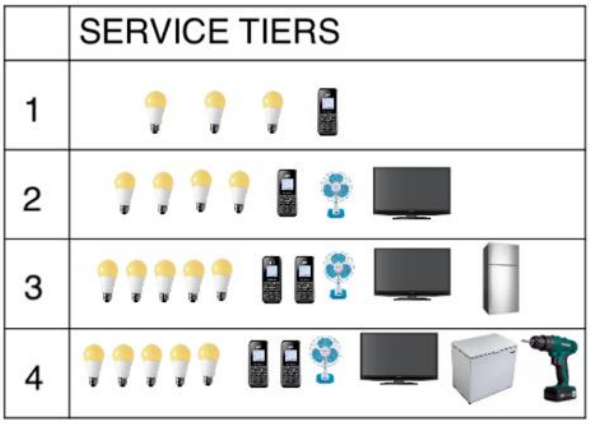

Figure 3. Service provided according to sel;ected service tier

Once the households interviewed have selected the desired package, the distribution of the selected packages by the interviewed sample will be prorated to the total population of the site, based on the geotagging exercise (to be done in small sites), or other assessment of the number of residential customers (based on satellite imagery and other data for large sites). WTP is cross-checked using the income level or the income/energy expense ratio. If the monthly energy cost looks unrealistic, corrective factors will be applied, such as decreasing the utilization factor of each appliance or moving the customer to the lower energy package.

Businesses and Institutions

Commercial and institutional loads are assigned with packages similar to the household's, according to the willingness/ability to pay identified during the interviews. Commercial and Industrial (C&I) and institutional customers' willingness to pay is informed by the collected data on the quantity and current energy expenditure with existing appliances.

Anchor loads

Users that are not reflected in the proposed packages i.e. anchor loads are assigned a customized package. The package is tailored to the current energy consumption estimated using current energy expenditure (fuel, etc) and generation capacity (SHS or Generator size) or based on interviews with relevant stakeholders.

2. Generate effective demand at the baseline year. Effective demand (energy consumption in kWh) should be derived for the baseline year. The baseline year is when 100% of initial target customers are connected and 100% of the initial load per customer is reached. It is the year for which the mini-grid assets are sized. The Consultant estimates the ramp-up rate for load per connection and the number of connections until the baseline year. The customer survey contains specific questions to assess how quickly customers would likely connect to the mini-grid. The Consultant also considers whether to apply corrective factors when estimating effective demand at the baseline year.

3. Forecast effective demand. The Consultant then forecasts effective demand beyond the baseline year for the whole project lifetime. This forecast is necessary to complete the financial analysis over the project life (e.g., 20 years). The Consultant may assume a certain growth rate in the medium-term (e.g., 5 years after baseline year), and no demand growth beyond this point, given uncertainties in the longer term. The Consultant will estimate growth in connections and load per connection by assessing growth in-demand, based on statistical and theoretical relationships between demand growth drivers and increase in connections and load per customer:

- Growth in connections should be based on expected population growth and the expected share of people who would connect among new potential customers. Migration trends should be considered, where applicable
- Growth in load per connection is an indication of economic growth in the community. It may be projected based on macroeconomic indicators like forecasted economic growth, or based on microeconomic analysis of how the demand curve of different customers might shift over time.

3.2 Socio-economic assessment

This chapter presents an analysis of the data gathered from end-user interviews conducted through the Kobo platform in both Etten and Piis Paneu Islands by SPC and complemented by TTA field mission. A total of 35 interviews were carried out, including the interview with the village leaders and analysis of the four anchor loads. Additionally, 54 GPS points from Etten and 78 from Piis Paneu were taken from existing SPC data, providing the location of all potential mini-grid end-users in Etten and Piis Paneu.

The majority of surveyed buildings were households, with some institutions such as churches and schools. There's a health center in Etten, two businesses (boat repair shops), household-run grocery shops, and other independent businesses in Piis Paneu. Both islands have a prospective anchor load in the form of a telecom tower. A productive use community center is also planned in Piis Paneu, which will include anchor loads like an ice-making plant and water system.

Table 3 provides a summary of the interviews conducted and the total number of households, businesses, businesses within households, and institutions identified through the GPS mapping exercise. For analysis purposes, the business within the household (HB) has been considered HH in the demand assessment since their demand would not be significantly different from that of HH. Based on TTA field mission observations, it was noted that these businesses primarily consist of small grocery shops or retail stores operating within their premises. Additionally, the usage of appliances in these establishments is similar. Therefore, based on these findings, their energy requirements closely resemble those of household demand. In addition, businesses within households will be serviced by the same energy meter and pay only one bill. The Consultant also identified two households in Etten that would not be viable for using a mini-grid due to their remote location, which is far from other communities. Therefore, the Consultant proposes a stand-alone Solar Home System (SHS) for both households.

Table 3. Data collected in each site

Island	Total					Interview
	BB	HB	HH	II	Anchor loads	
Etten	2		48	3	1	14
Piis Paneu	1		72	2	3	21
Grand total	**3**	**0**	**120**	**5**	**4**	**35**

3.2.1 Source of income

The inhabitants of Etten and Piis Paneu islands have multiple sources of income such as farming, fishing, business or employment in the public sector.

From the survey conducted by SPC, it is identified that in Etten farming is the main source of income for a quarter of households while for Piis Paneu 69% households reported fishing as main source of income.

From TTA's field mission, the Consultant has found that 37% households have secondary income from remittances from relatives; this is likely reported as 'other' source of income in SPC survey. Additionally, the survey revealed that working as a public worker, small shops inside households, repair shops were also popular sources of income, with approximately 8-25% of respondents indicating that these activities were their primary sources of income in both the islands.

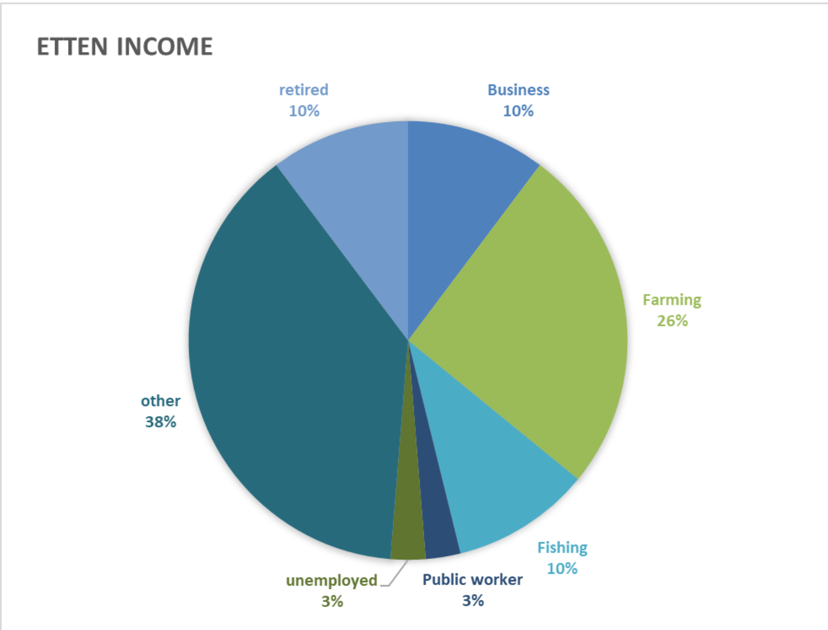

Figure 4. Main income-generating activities in Etten from SPC data

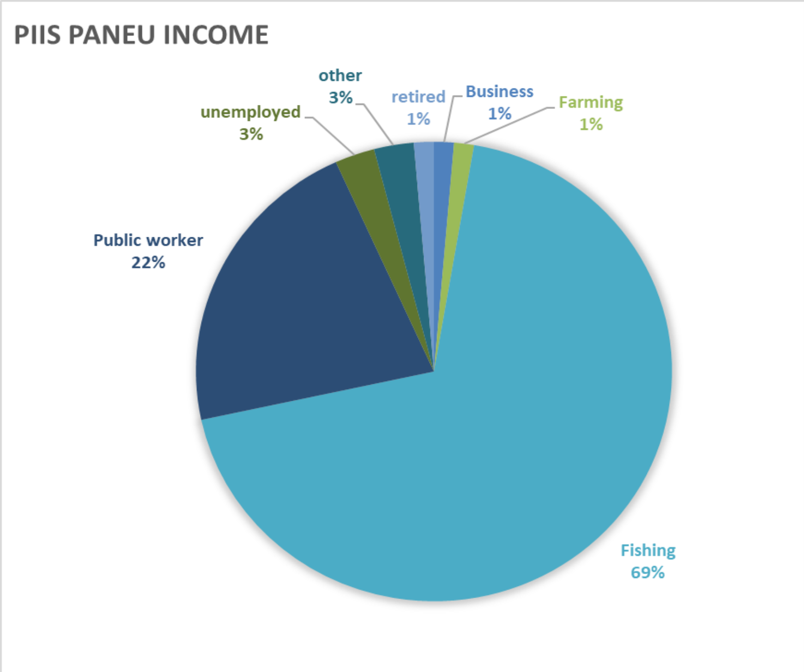

Figure 5. Main income-generating activities in Piis Paneu from SPC data

Based on SPC data, the average income of a household in Piis Paneu is $632 per month ($7,588 annual) and median income is $800 per month. The average income of a household in Etten is $362 per month ($4,344 annual) and median income is $300 per month.

Upon examining historical records in the Chuuk State Census Report for the year 2000, it was found the average annual income for households in Etten was $5,136 USD which is slightly more than the average income reported from SPC's data. In the case of Piis Paneu it was $3,175 USD, a figure notably smaller 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 in Piis Paneu. Additionally, the small decline in average income in Etten may be linked to the migration of certain households to foreign countries.

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 Total	Weno	Piis-Paneu	Fono	Southern Namoneas 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 6. Chuuk State Census Report for the year 2000

Since usually there is a correlation between income level, electricity demand and geography (i.e. inside Chuuk's lagoon), hence the Consultant suggests that the electricity consumption in Etten and Piis Paneu may potentially mirror the consumption pattern observed in Tonoas or Fefen.

3.2.2 Willingness to Pay (WTP)

Based on end-user income levels and their response regarding choice of service tier, the Consultant characterizes energy service packages with: (i) the service provided, (ii) the daily energy requirements to supply the service and (iii) a monthly price. The energy requirements are defined as Energy Daily Allowances (EDA) corresponding to the maximum amount of kWh that the user can consume in one day with the assigned package.

Survey participants were requested to choose their preferred price for the packages displayed in Table 4, based on their willingness to pay for each service tier.They were given four reference prices for their selection since the actual tariff is yet to be determined. The lower-end price would correspond to the average tariff in Weno (approx. 0.5 USD/kWh) while the higher-end considers a tariff of 1 USD/kWh. If the respondent would not be willing to pay either of the proposed prices, the enumerator then asks for the price they would be willing to pay.

Table 4. Packages offered to respondents by TTA during the mission

Package	Service	EDA *(Wh/d)*	Power *(W)*	Price 1 *(USD/ month)*	Price 2 *(USD/ month)*	Price 3 *(USD/ month)*	Price 4 *(USD/ month)*
Package 1	Lights and phone	275	100	4	5	7	8
Package 2	Lights, phone, fan, TV	550	200	8	11	14	17
Package 3	Lights, phone, fan, TV, fridge	2200	600	34	43	56	66
Package 4	Lights, phone, fan, TV, freezer, power tools	3300	1000	59	75	98	116

3.3 Current use of electricity

The majority of respondents in Etten and Piis Paneu rely on private generators as their primary source of electricity, and most cases a generator is shared between few households. The generators used to serve only one household usually have a capacity of less than 1 kW, but the surveys noted power capacities up to 7 kW. A small share of the households had installed Solar Home Systems (SHS), battery lamps, and PV lamps. Figure 7 and Figure 8 show the share of current electricity sources used in Etten and Piis Paneu respectively.

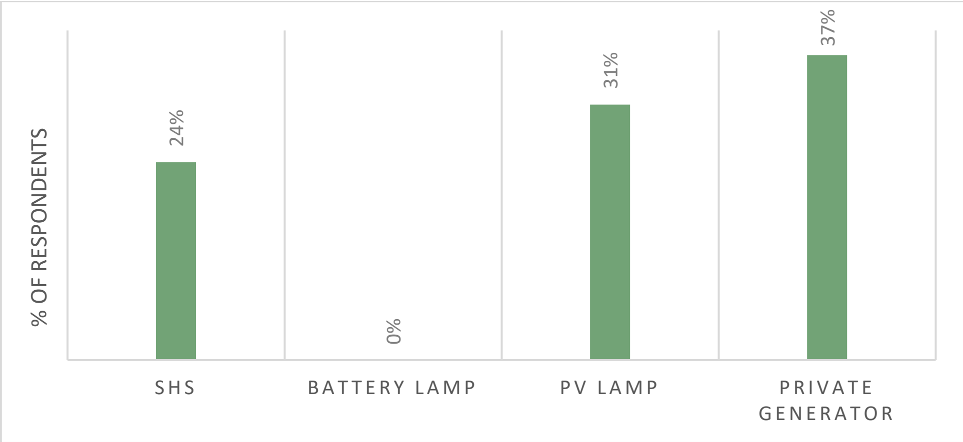

Figure 7. Existing electricity sources in Etten, based on SPC data

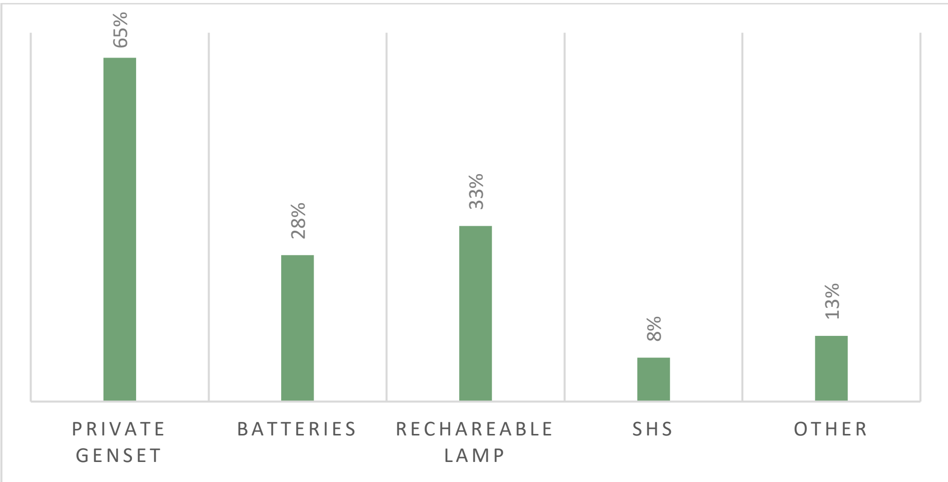

Figure 8. Existing electricity source in Piis Paneu

3.3.1 Appliances in use

The main use of electricity in Etten and Piis Paneu is lighting and phone charging. Fans are another common appliance being present in more than half of the households surveyed as well as in church and schools. Less frequently, other appliances are also used, such as washing machines[3], freezers, TVs, speakers, radios and working tools.

Alongside the current ownership, the survey also identifies desired appliances through asking the choice of packages to be used given access to mini-grids. Figure 9 and 10 respectively represent appliance ownership and desired appliances in Etten and Piis Paneu.

[3] From TTA field mission, the Consultant has identified a total of 9 washing machines were in use in Etten

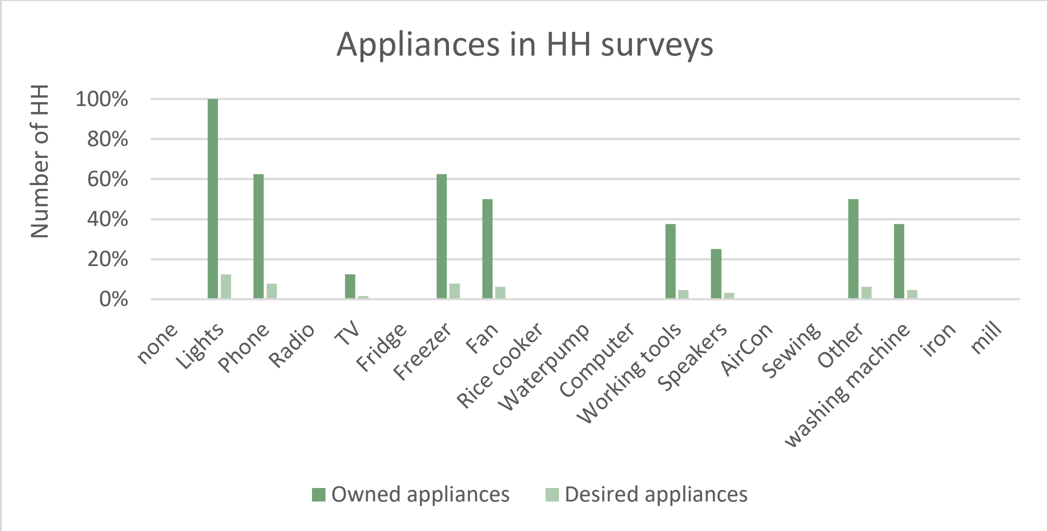

Figure 9. Existing appliance ownership in Etten

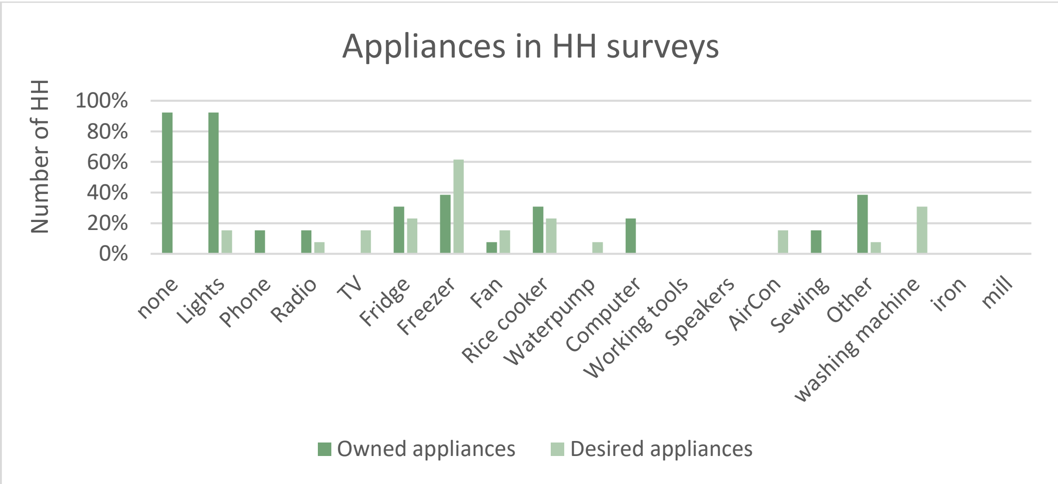

Figure 10. Existing appliance owernship in Piis Paneu

3.4 Assumptions in demand assessment

The total demand estimation for Etten and Piis Paneu encompasses demand from households, businesses, and institutions. Upon client approval, the Consultant has also factored in the demand assessment, which includes demand from potential anchor loads on both islands. The methodology for updating the demand assessment is as follows:

1. Household demand data is gathered through a survey, considering factors such as Willingness to Pay (WTP), Ability to Pay (ATP), or Energy Daily Allowance (EDA) based on end-user categories.
2. In the case of Etten, one anchor load—specifically, a Telecom tower—is considered. In Piis Paneu, a total of three different prospective anchor loads (water system, ice-making plant, Telecom tower) are taken into account. These considerations have been made following discussions with the clients.
3. Based on appliance packages chosen, income levels and willingness to pay for package of appliances, the daily load profiles and demand evolution, total load profile at design year is estimated for each category of end-user.

The following hypothesis has been considered to obtain the final total demand and load profile in Etten and Piis Paneu islands.

- **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 in 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 12 streetlights on Etten Island and 15 on Piis Paneu. This calculation amounted to approximately 2-3% of the total daily demand.

3.4.1 Anchor loads

Telecom towers

Based on discussions with clients and local stakeholders, both Etten and Piis Paneu islands are anticipated to receive upgrades on their telecom towers in the near future. To prepare for this anticipated demand, the Consultant has assessed the existing telecom tower in Tonoas, currently operating at a nominal power of 0.7 kW, similar to the telecom towers currently in operation in Etten and Piis. Plans are to upgrade these towers to 3G/4G within the next 1 to 2 years, leading to an estimated constant load of 1.83 kW, similar to the demand seen in telecom tower in Parem island. Insights from meetings with FSMTC's General Manager and field technician on February 20th and 28th, 2024, indicate that a connection will be established after a year. Additionally, there are plans to remove existing 3.5 and 4.4 kWp solar systems (and the upcoming increase of power by FSM TC to fulfill the future upgrade) from Etten and Piis by FSM TC, redirecting them to another unelectrified island after connection to the mini-grid.

Water system

In Piis Paneu, a new water supply project funded by the Asian Development Bank (ADB) is set to replace a non-operational project. As communicated by the ADB team, the commissioning of this new project is scheduled for this year. Additionally, the expected daily demand for the system to be installed is estimated to be around **10 kWh per day,** with 8 kWh to be utilized during the daytime and 2 kWh during nighttime. The proposed location for the system is within the technical room of the mini grid, if feasible.

Ice-making machine.

Currently, there is an out-of-service ice making plant in Piis Paneu. However, there are new plans to install a replacement. Through conversations with the local community, it has been determined that the total demand for ice per day is estimated to be around 250kg, enough to support 8 to 10 fishing boats on the island. Previous experiences suggest that producing 1kg of ice typically requires approximately 100Wh of electricity. Taking this into account, the specified daily demand for the ice-making machine has been set at **25kWh/day**.

3.5 Estimated demand and load profiles

3.5.1 Total demand with anchor loads

The total number of end-users identified in the Etten is 54 and 78 in Piis Paneu, two households in Etten to be served with SHS. The service packages that have been assigned to the users are summarized in Table 5.

Table 5. End-users package distribution in Etten and Piis Paneu

User type	Package	Etten	Piis Paneu	EDA (Wh/day)	Total demand based on EDA in Etten	Total demand based on EDA at Piis Paneu
Household	Package 1	5	4	275	1,375	1,100
Household	Package 2	5	6	550	2,750	3,300
Household	Package 3	10	28	2,200	22,000	61,600
Household	Package 4	21	34	3,850	80,850	130,900
Business	Shops freezer (P4)	2	1	3,850	7,700	3,850
Institution	Basic school (P3)	1	1	2,200	2,200	2,200
Institution	Church (P3)	1	1	2,200	2,200	2,200
Institution	Clinic (P4)	1	0	3,850	3,850	0
Institution	Streetlights	12	15	350	4,200	5,250
Anchor load	Telecom tower	1	1	44,000	44,000	44,000
Anchor load	Water plant	0	1	10,000	0	10,000
Anchor load	Ice-making machine	0	1	25,000	0	25,000
	Total (kWh/day)				**169 kWh/d**	**289 kWh/d**

The ramp rate of connection (Y1 to Y4) and the demand growth are displayed in figures 11 and 12 respectively. The demand stabilizes after year 10 around 169 kWh/day in Etten and 289 kWh/day in Piis Paneu. It is worth noting that the growth is only considered in households and anchor loads are considered constant over the years.

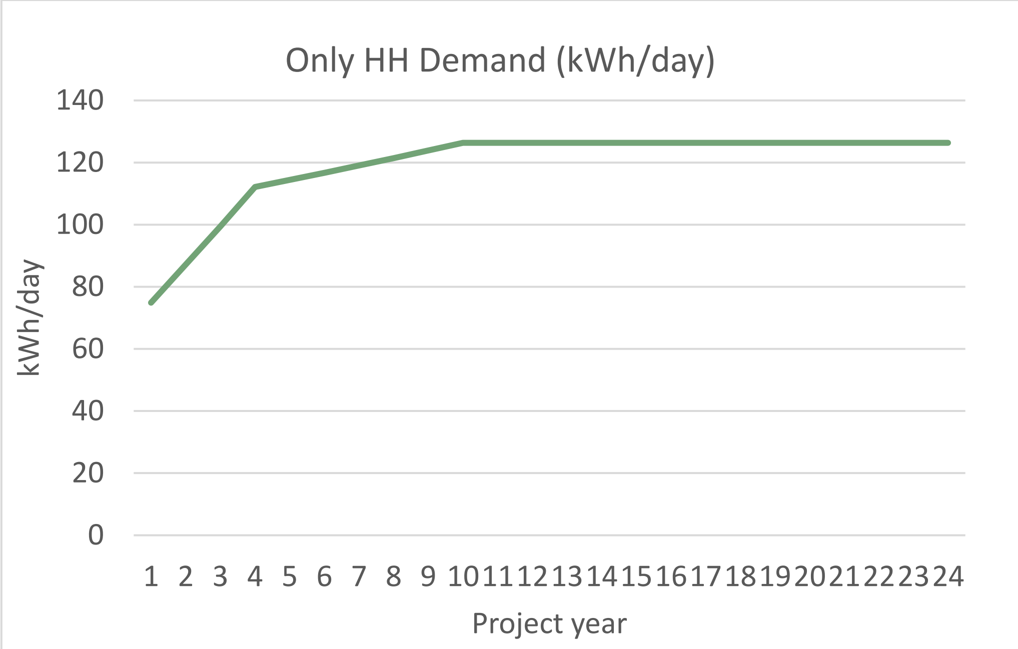

Figure 11. Estimated demand evolution along project lifetime in Etten

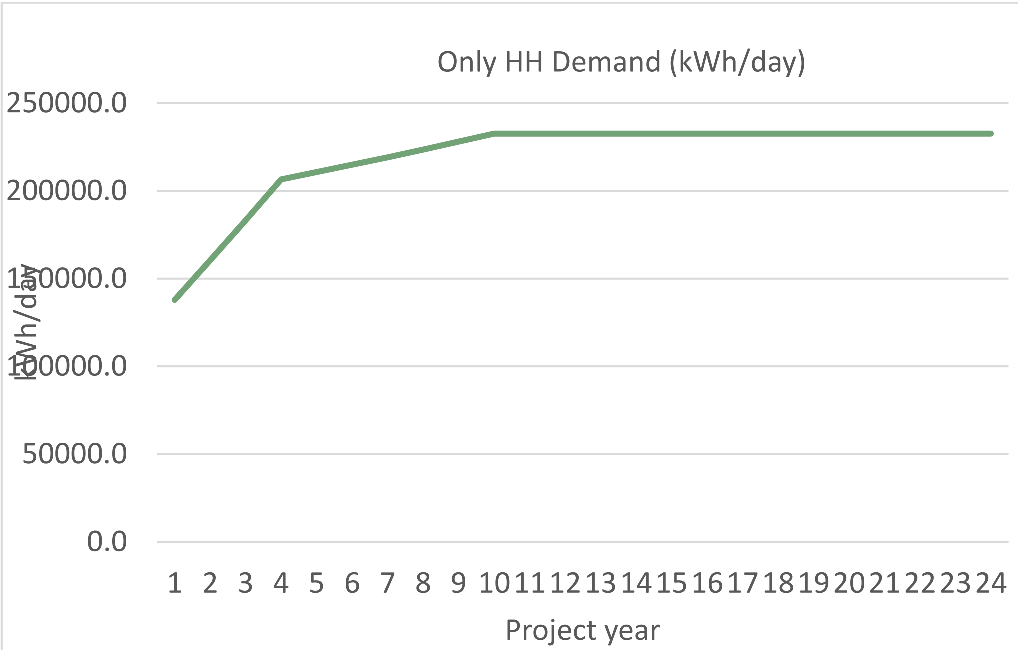

Figure 12. Estimated demand evolution along project lifetime in Piis Paneu

3.5.2 Load profile with anchor loads.

Finally, the daily load profiles in design year at Etten and Piis Paneu with consideration of anchor loads are displayed in figures 13 and 14. The share of each type of user is marked with different colors. The demand peaks during the evening between 6 pm and 10 pm. The constant high demand from anchor load in both islands is attributed to telecom tower.

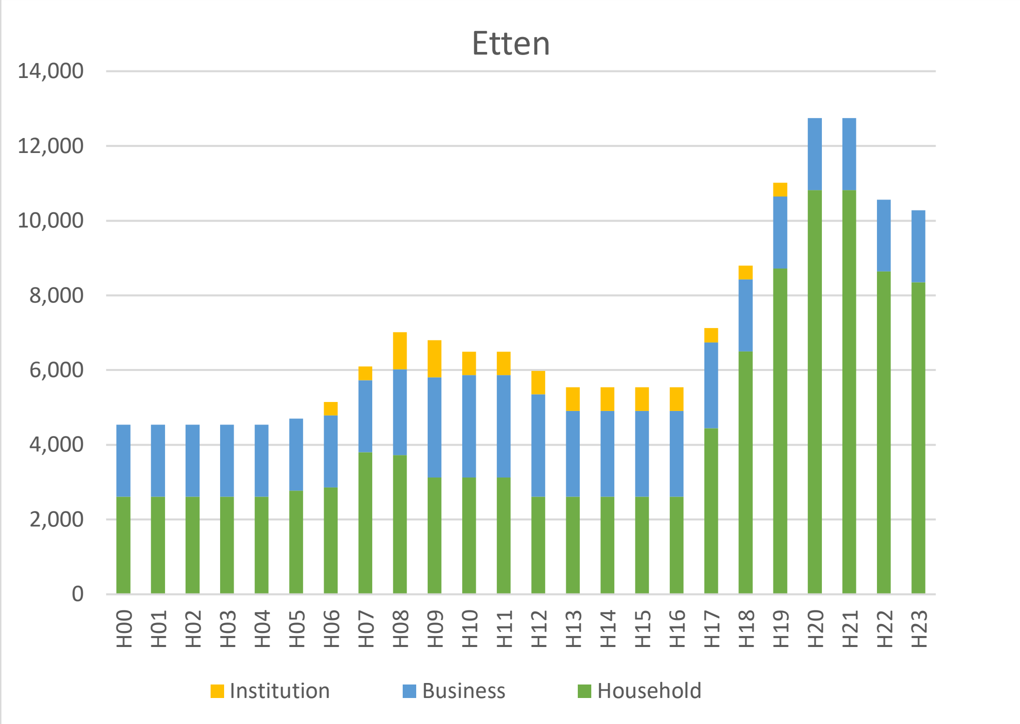

Figure 13. Daily load profile with anchor load at design year in Etten – Year 4

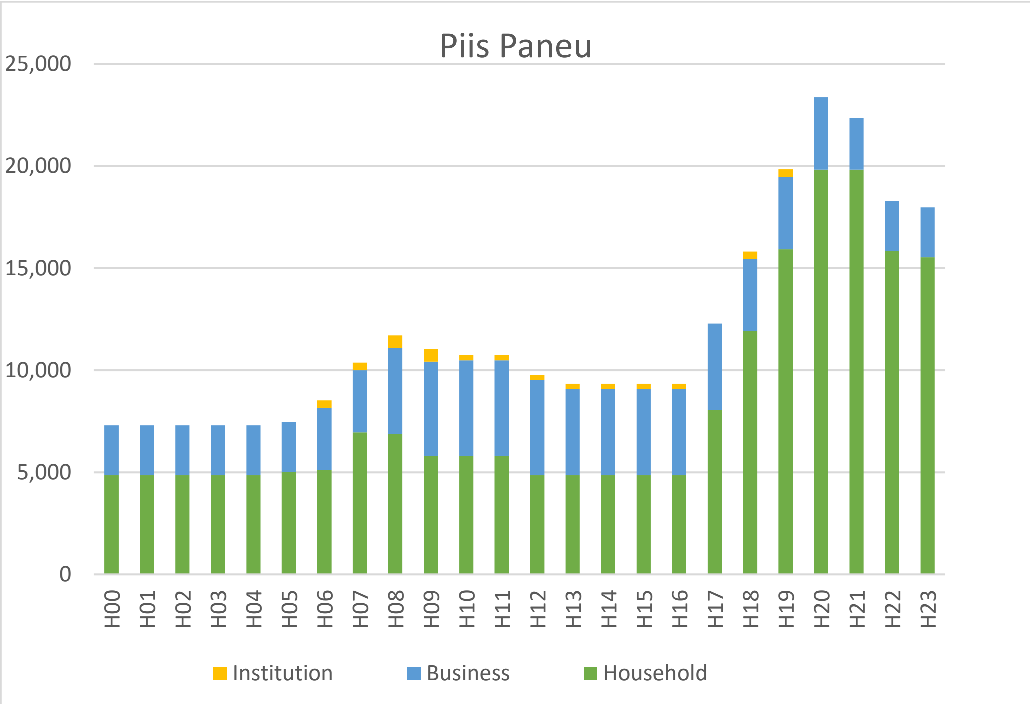

Figure 14. Daily load profile with anchor loads in Piis Paneu – Year 4

The incorporation of anchor loads represents a substantial portion of the total load in both islands. Notably, in Piis Paneu, the three anchor loads previously discussed collectively contribute to 29% of the total load, while in

Etten, a single anchor load—specifically, a telecom tower—contributes to 26% of the total load share in year 4. These proportions are visually depicted in Figure 15.

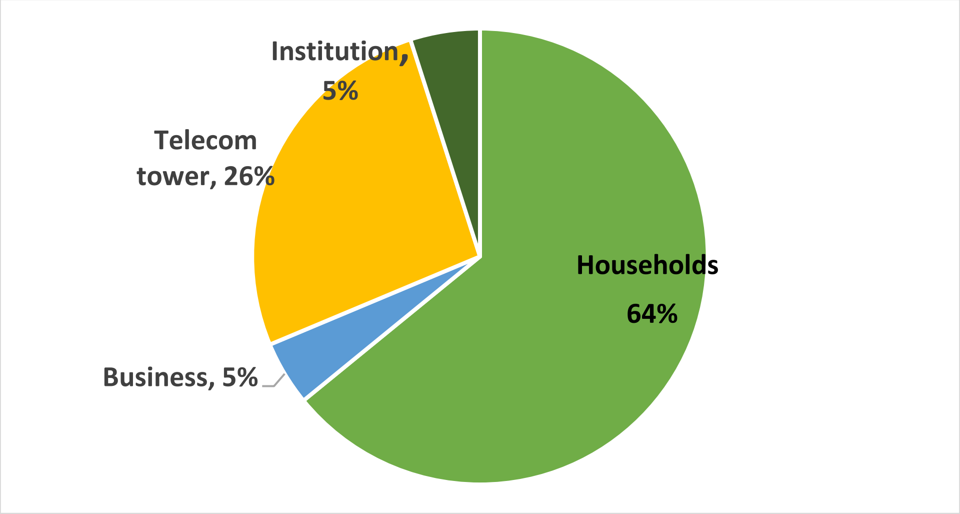

Figure 15. Percentage of total load share in Etten at design year (year 4)

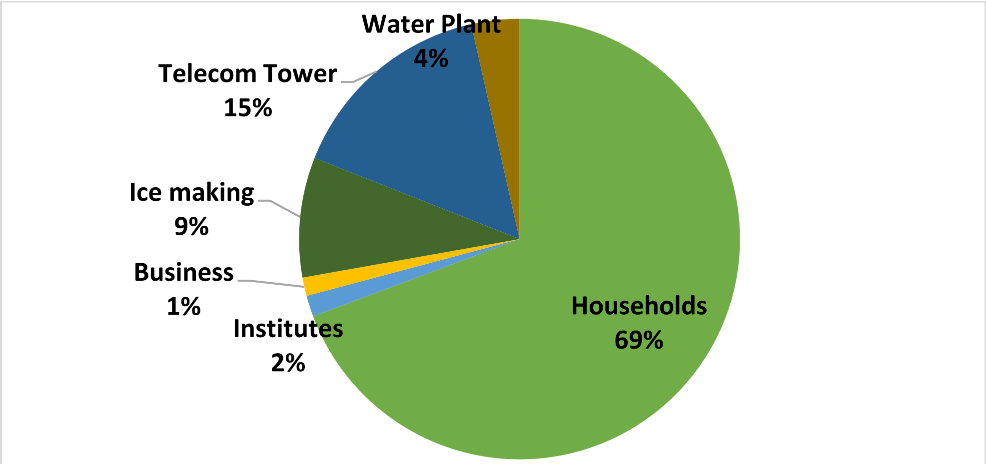

Figure 16. Percentage of total load share in Piis Paneu at design year (year 4)

3.6 Demand comparison with Tonoas

Based on real-time demand data from Tonoas, the Consultant found that the average daily household electricity demand is 2.8 kWh per household. For Etten, the Consultant has found an average of 2.6 kWh per day, while for Piis Paneu, it showed an average of 2.7 kWh per day. These results are aligned and validate the methodology employed in this demand assessment.

4. Technical Design

This section provides details on the system design to electrify Etten and Piis Paneu islands.

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 with a minimum RE fraction of 92.5%.
- optimize renewable energy penetration.
- minimize LCOE of the generation.

4.2 Homer results

Table 6. Summary of main Homer simulation parameters

Component	Unit	Capital Cost[4]	Replacement cost	Lifetime (years)
PV Module	USD/kWp	1800	1500	25
Battery -LFP	USD / kWh	500	450	12
Battery Inverter	USD / kW	900	900	12
Generator	USD / kW	750	750	20
Input	**Unit**		**Value**	
Fuel cost	USD/l		1.59[5]	
Inflation (applied to fuel cost too)	%/year		2.5[6]	
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 7. HOMER result summary

	Demand Y4 (kWh/ day)	PV (kWp)	Battery (kWh)	Battery inverter (kW)	RE fraction (%)	Battery autonomy (h)	Indicative LCOE of gen. plants (USD/kWh)
Etten without anchor load	135.6	50	120	30	92.4	20.2	0.79
Etten with anchor load	164.1	65	160	30	93.4	20.5	0.72
Piis Paneu without anchor load	226.1	85	220	30	92.5	20.2	0.73
Piis Paneu with anchor load	280	110	280	30	92.5	21.1	0.66

[4] All utilized costs are EPC prices deducted from the Fefen costs.
[5] Based on survey
[6] Average of the inflation of the last five years in FSM (source: https://www.worlddata.info/oceania/micronesia/inflation-rates.php)

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.

4.4 Local environmental conditions

4.4.1 Temperature

7 shows the monthly average temperature from the island of Weno, which will be similar in Etten and in Piis.

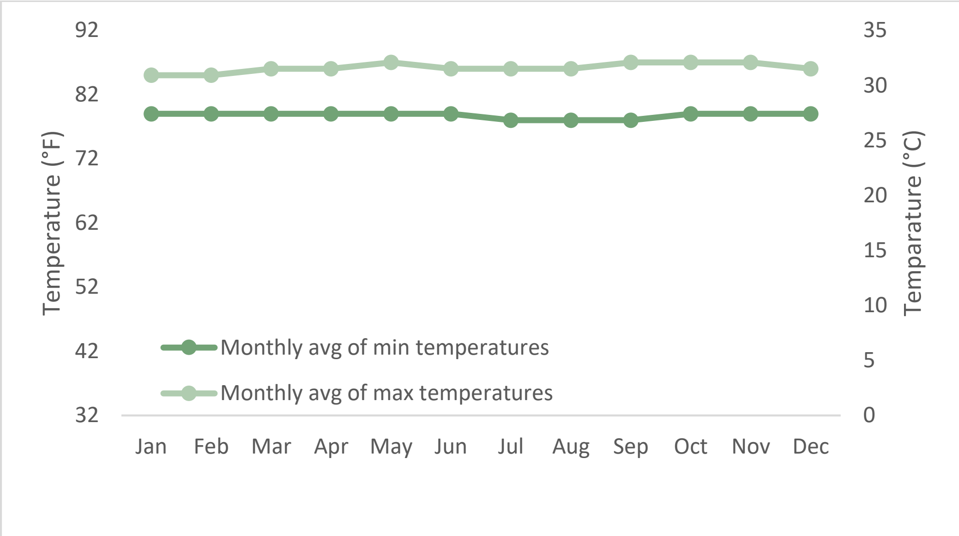

Figure 17. Monthly average of max. and min. temperatures recorded in FSM[7]

4.4.2 Radiation

Table 8. Average daily radiation for Weno weather station, PVGIS-ERA5 database[8]

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

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

[8] 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 9. 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 the 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 of Etten is located in the Chuuk Lagoon, approximately 9 miles away from the main island of Weno, while Piis is located on the reef barrier, approximatively 19 miles away by boat from Weno (Figure 18).

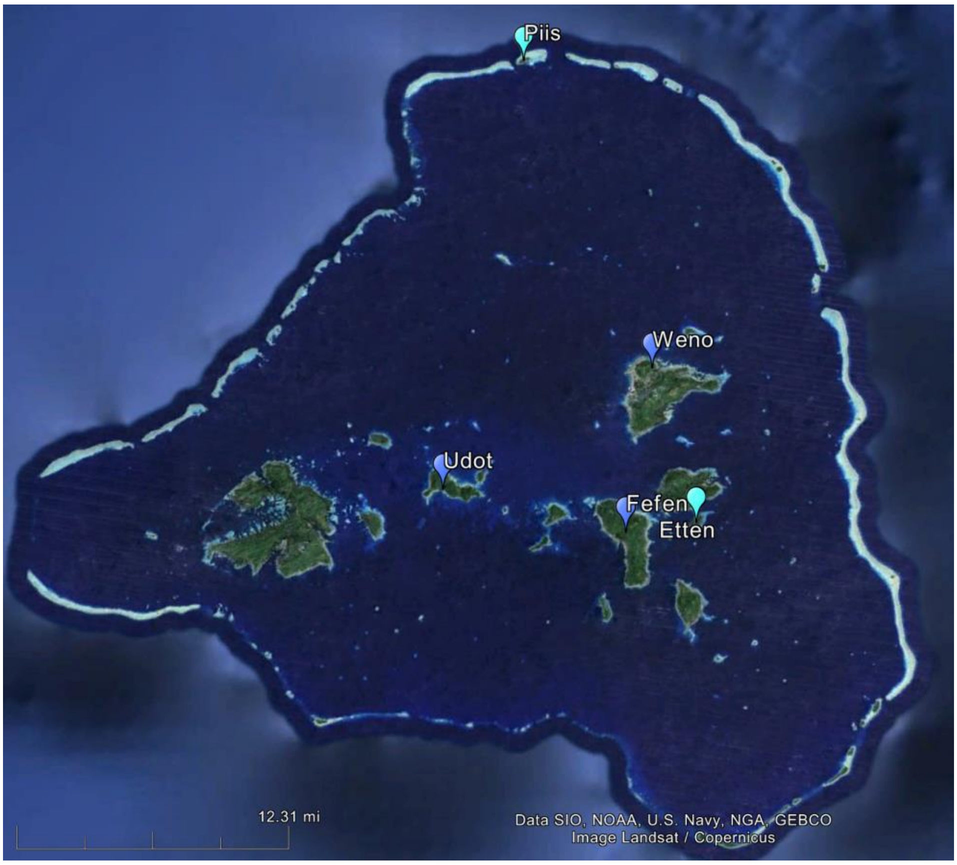

Figure 18. Location of Etten and Piis island

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 (transship in Guam) and China (transship in Busan).
- **Transport between Weno and Etten or Piis.**
  Etten and Piis can be reached by small boats from Weno with landing possibilities in the existing jetties and beach landing locations distributed around the island (but the jetty in Piis is a bit damaged). The duration of the trip is approximately 20 to 40 minutes depending on sea conditions and location of arrival in Etten, and two times more for Piis. Barges with openable front can land on the beaches and carry heavy equipment (like a generator at the maximal), but no containers.
- **Transport within the islands**.
  There are no roads in the islands, Light trucks can access most of the island and excavators can access most places. Light weight tricycles (or similar vehicles) with a small trailer could be used to transport material around the island.

Figure 19. Location of existing jetty in each island

Table 10 provides a summary of ways of transportation to each generation location.

Table 10. Details of transport access to each community

Generation location	Road access	Jetty access	Flat barge access	Barge and container access
Etten	No road, but flat paths	Yes	Yes, landing on the jetty	No
Piis	No road, but flat paths	Damaged	Yes, landing on the sand	No

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 Weno, Chuuk	20’ container +$2000 40’ container +$2900 (depends on weight and goods)
Kyowa	N/A	20 and 40 ft	China to Weno, Chuuk	20’ containers $3600 40’ containers $6,000 to $7,000
Brutons	6 tons	N/A	Weno to Etten or Piis	1,800 USD per ton (Etten)

4.4.5 Soil composition

- In Etten, the topsoil (grass and soil) is only one foot deep, followed by a 1-foot-thick concrete slab that covers the entire island. The concrete slab was poured by the Japanese army during WWII to turn the island into an airplane landing strip. It was likely made with volcanic rocks without reinforcement. Although there have been no reports of coastal erosion, installations should not be placed too close to the shoreline to prevent potential impact from waves or king tides during storms. There are remnants of buildings dating back to WWII in some parts of the island.
- In Piis Paneu, the soil is made of compacted coral and is prone to flooding during heavy rain. The main road has some rocks, and most sites have soft soil. Locals have reported coastal erosion at a rate of approximately 1 foot per year. Therefore, installations should not be situated too close to the shoreline to mitigate the potential impact of waves or king tides during storms. The island's freshwater table reaches a depth of 2 to 4 meters.

Figure 20. Pictures of ground in Etten

4.4.6 Lightning strikes

There have been no records of lightning strikes in Etten and Piis. However, the CPUC staff consulted has stated that there is some lightning activity in these areas, albeit infrequent. 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 21). Therefore, lighting strikes is not considered to be a major hazard in the locations under study.

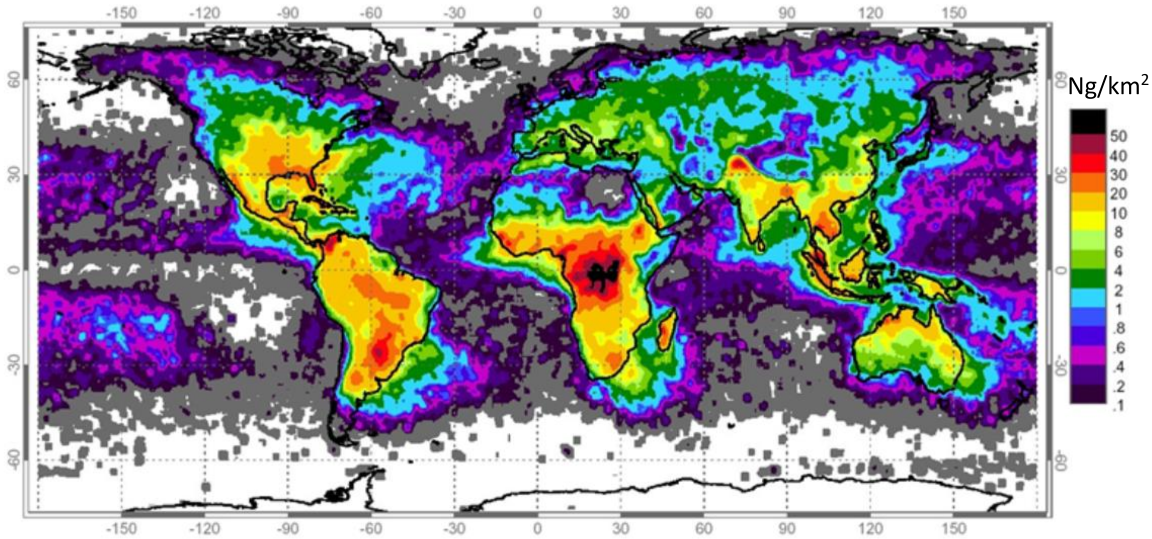

Figure 21. World map showing the lightning density (Ng). Source: Nasa

Note: The lightning density (Ng) is the number of lightning impacts per km² and per year.

4.4.7 Marine environment

Both 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 generation plants will be located on one site for each island. Figure 22 shows Etten Island with the following:

- PV Generation locations (in green).
- LV split-phase distribution network along the island (in red);
- End-users (in purple).

Figure 22. The two PV installations in Etten island

Figure 23 shows Piis Paneu Island and the following:

- PV Generation locations (in green);
- LV split-phase distribution network along the island (in red);
- End-users (in purple).

Figure 23. The two PV installations in Piis Paneu island

To enhance operational efficiency and facilitate maintenance, the Consultant has designed the mini-grids in order to centralize PV installations in only 1 generation location for each island.

Each of the two mini-grids (Etten and Piis Paneu) consist of a 2 PV plants connected to a low-voltage (LV) split-phase distribution line. Each of the power generation location includes:

- 2 separate photovoltaic arrays injecting in the same AC busbar;
- 1 battery energy storage system (BESS);
- 1 back-up generator;
- 1 technical building;
- 1 monitoring and control system.

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

Etten and Piis Paneu, 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 the following.

- PV generation subsystems, including PV modules and the PV support structure (rooftop or canopy)
- Power conversion subsystem, including charge controllers and PV inverters (if needed).
- Earthing subsystem.
- AC bus, combining all inverters AC outputs.
- Control and communication subsystem, including energy/power meters and internet access.
- Weather sensors.
- 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.

4.5.1.1 Rooftop installation

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

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 sheets 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 A.

Most of rooftops are gable roofs with structural elements as shown on Figure 24.

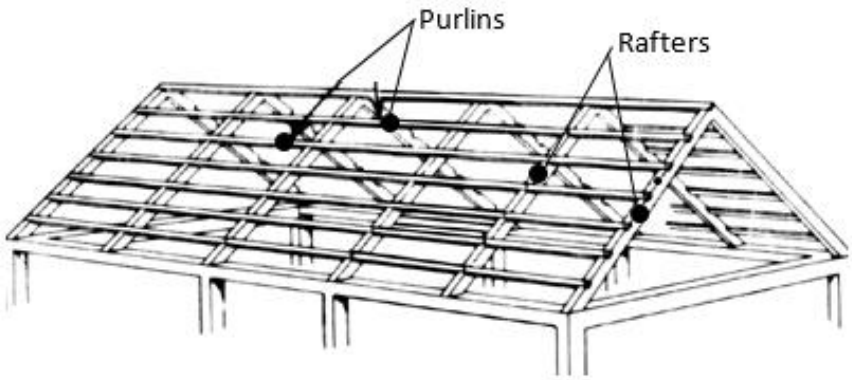

Figure 24. Typical structural elements of a gable roof

On rooftops, the 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 25. Example of flush-mounted structure solution

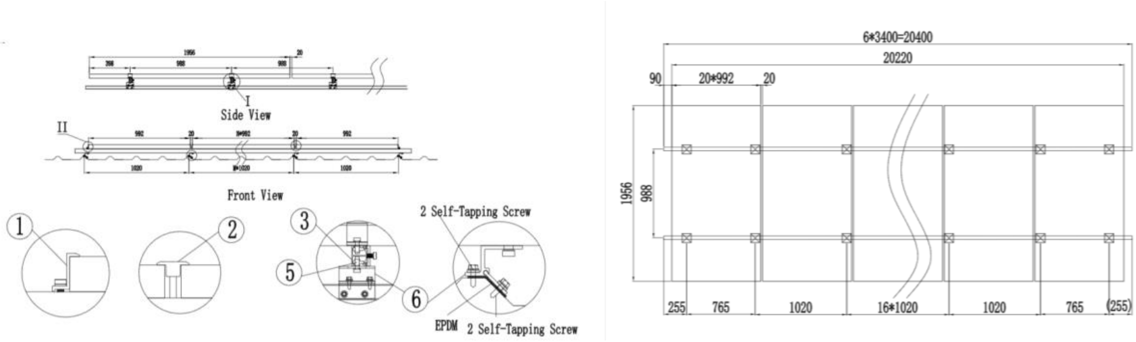

Figure 26. Example of drawing for flush-mounted structure

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 might be 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 27. Example of a 3 m high canopy installation (waterproofed for Etten and Piis Paneu). 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 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.

4.5.2 PV plants locations

The table below presents a summary of all the PV sites regarding Etten and Piis Paneu.

Table 11. Summary of PV sites with capacity to be installed

Label	Island	Institution name	Type installation	Min estimated. PV power (kWp)
E-RT1	Etten	Elementary school	Rooftop - School	38
E-CP1	Etten	Future school	Canopy	30
P-RT1	Piis Paneu	Church	Rooftop – Church	52
P-CP1	Piis Paneu	Government land	Canopy	58
			Total Rooftop	**90**
			Total Canopy	**88**
			Total	**178**

Important note:

All sites where the canopies 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 are provided in Annex A.

4.5.2.1 Etten

Figure below shows the layout of the PV arrays will be constructed in Etten. There will be a rooftop installation and a canopy installation.

Figure 28. Top view of PV arrays in Etten

Table 12. Summary of PV capacity in Etten

Label	Type installation	Azimuths	Min estimated PV power (kWp)
E-RT1	Rooftop - School	-8° / 172°	38
E-CP1	Canopy	-101° /79 °	30
		Total:	68

On the roof of the E-RT1 there is a 4 m high antenna which can cast shadows on the PV field, and a standalone solar system. There is also a flag-holding pole in the plot of land. These antennas wil be replaced by the school to avoid shades.

Figure 29. Antenna and standalone solar system on the roof of the school (left), pole in the plot of land (right)

4.5.2.2 Piis Paneu

The figure below shows the layouts of PV arrays that will be constructed in Piis Paneu. There will be a rooftop installation and a canopy installation.

Figure 30. Top view of PV arrays in Piis Paneu

Table 13. Summary of PV capacity in Piis Paneu

Label	Type installation	Azimuths	Min estimated PV power (kWp)
P-RT1	Rooftop - Church	-115°/65 °	52
P-CP1	Canopy	-115°/65 °	58
		Total	110

4.5.3 Solar Basic Unit (SBU)

The Consultant recommends the deployment of standardized electrical designs between different mini-grids based on a modular and component standardization approach, conceptualized through the Solar Basic Unit (SBU). The Solar Basic Unit is the building block of the design of the generation side (PV panel configuration and charge controller) for each of the PV generators and it can be connected in parallel with as many others SBUs as required to meet the required PV capacity to be installed in each site. Its main benefits are the ease of replication, the standardization of components, ease of transportation of components, ensuring quality and facilitating the operation and maintenance of the plants.

A detailed SBU will be sized in the technical aspects.

4.5.4 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 to avoid vandalism, while keeping the inverter well ventilated. The inverter must not be exposed to direct sunlight or rainwater.

Figure 31. Example of a metallic cage that protects outdoor inverters from theft. Additional protections against water should be considered also

4.5.5 Battery technology

The battery technology selectec for the project is Li-ion LFP.

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**.

4.5.6 Battery inverter

The battery inverter will have the following features.

- Output voltage: 240 V – 60 Hz split phase.
- Must be bidirectional.
- Must be grid-forming.
- Must be able to provide the specific features of functional requirements section.

Detailed specifications will be provided in the technical specifications.

4.5.7 Technical room

The technical buildings shall be divided into 3 main rooms.

- Battery room.
    - Battery and Air Conditioning unit.
- Technical room.
    - Battery inverters.
    - Charge controllers.
    - DC Board.
    - AC Board.
- Office.
    - Office desk for the operator.
    - Monitoring platform.

The building must be elevated by 60 cm 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. The detail drawings regarding the technical rooms will be added in Annex B

4.5.7.1 Etten

The first option to consider is to place the technical room just next to the existing school (**E-RT1**). The required area of the technical room will be approximately 40 m^2. There is sufficient space to allow access to the adjoining buildings as well as to locate the diesel generator. However, the trenches from the PV field to the technical room will be longer, increasing a bit the cost and the voltage drop.

Figure 32. Option 1: available area next to the school for the technical room

Figure 33. Option 1 - available area next to the school for the technical room

The second option would be to locate the technical room just below the canopy E-CP1. However, there will be a future school (currently under construction) right underneath, and therefore it is not possible to locate the technical room under the canopy. As a solution, the technical room can be placed right next to the ECP1 canopy (i.e, between ECP1 and ERT1 as shown in the figure below). The required area of the technical room would be approximately 40 m^2. The location of the genset would be placed outdoors, just behind the technical room (as can be seen in red in the figure below).

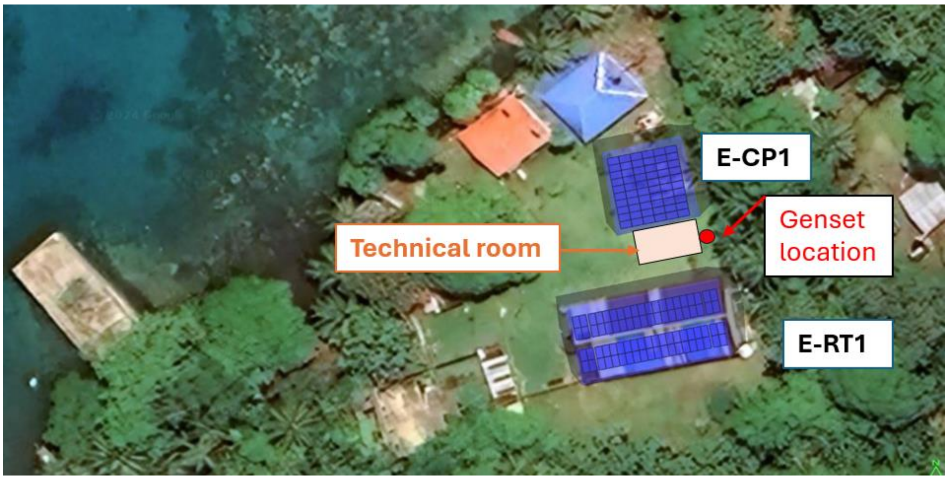

Figure 34. Option 2: Satellite view of the space available for technical room in Etten

Figure 35. Option 2: available area under the canopy for the technical room

After having analyzed the two options, **option 2 is considered the most favorable**. It minimizes the trenching distance (and therefore less voltage drop losses) as well as the associated economic cost compared to option 1.

4.5.7.2 Piis Paneu

The most favorable option for locating the technical building is to place it under the canopy **P-CP1**. This option has more than enough space for the technical room and is far enough away from the coastline (115 feet away), to avoid king tides, waves and coastal erosion risks.

Figure 36. Satellite view of the spaces available for technical room and storage in Piis Paneu

Figure 37. Picture view of the government land (canopy place) for technical room and storage in Piis Paneu

4.5.8 Back-up generator

The back-up generator should be placed outdoors of the technical building, simply behind or next to the technical building.

The backup generator should have the following main features.

- Must be soundproof (silent generator).
- Must be adapted for marine environment.

More details will be provided in the technical specifications.

4.5.9 Standardization of components

The standardization of components between the PV generation sites facilitates the operation and maintenance of the system as a whole and reduces considerably the need for spare parts as inventories are compatible for all mini-grids. Standardization with projects of Satowan, Fefen, 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 standardized as much as possible.

4.5.10 Functional requirements

The distribution network should be in low voltage (LV), therefore, the voltage level of the distribution line should be 240V L-L and 120V L-N 60Hz.

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

1. Hybrid mode.
    a. The BESS acts 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 controlled by the battery inverter. In case of failure of communication between the PV inverters and the battery inverters, 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.

4.5.11 User interface, communication & control

The **mini-grids 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, ambient temperature, module temperature, 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: Operators should be able to control some basic features of the plant remotely, including change settings to optimise the system performance.

4.6 Distribution network

4.6.1 Underground vs overhead

For the on-going projects on the state of Chuuk, CPUC recommends underground distribution networks for the following reasons:

a) it minimizes the risk of falling overhead poles due to nearby vegetation;
b) it makes it more resilient to strong typhoons. (in Weno, the whole grid had to be rebuilt after Maysak typhoon);
c) it reduces the trimming of trees.

Using underground installations, the resiliency of the electrical infrastructure is improved and therefore will maximize its longevity. This is more specifically done by:

- installing buried conductors;
- using distribution pillars to connect the main distribution lines to the service lateral.

Figure 38 provides an example of a typical underground cable installation. In situations requiring crossing a river or creek, the distribution network can be adapted with the most appropriate solution according to the situation (conduits or overhead jump) to allow crossing the river or creek.

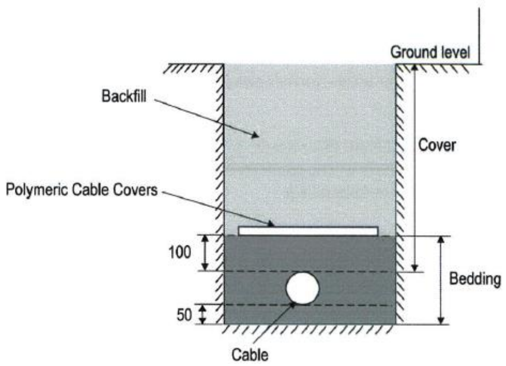

Figure 38. Example of underground cable trench cross-section and figure of a creek (right)

4.6.1.1 Piis Paneu

For Piis Paneu, the soil conditions (see 4.4.5) are similar to the lower parts only of the other islands in Chuuk lagoon (Udot, Fefen, etc): this is a flat, atoll island with coral-based ground. It should not present any other specific constraints during installation. The UXO risk is defined as small, as this island is deemed to not have been occupied by the Japanese forces during the second World War. Safety measures must be taken to manage this low risk. Considering the advantages listed above, an underground distribution network will be installed.

4.6.1.1 Etten

The situation in Etten is different from the other islands in Chuuk. Indeed, a 1-foot depth concrete slab has been built all over the island by the Japanese during second world war, which can make the underground installation more difficult.

Over the island, the concrete slab is generally located 1-foot below the ground level (see Figure 39). Underneath the concrete slab, there can be found the remains of metallic elements and a true risk of UXO (see paragraph below).

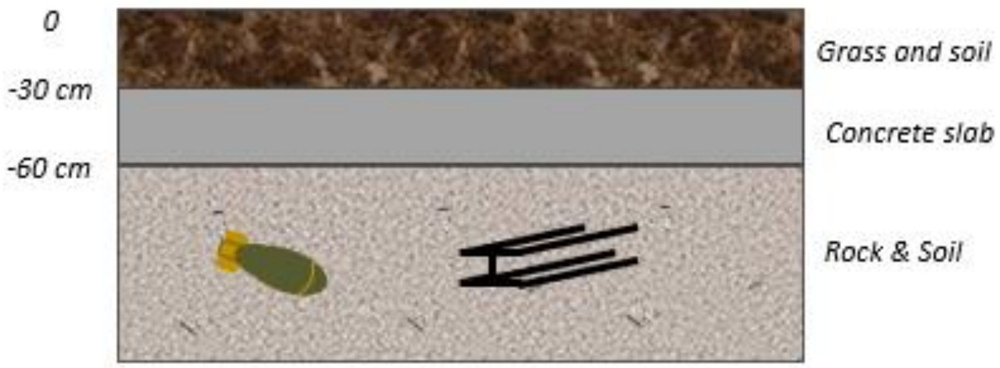

Figure 39 : Soil composition for Etten island, with metals and potential risk of UXO

When it comes to installing an underground network where a concrete slab is present, there are 2 options that can be considered:

a) Horizontal Directional Drilling (HDD).
b) mechanical Trenching

Table 14 shows a comparison of these 2 technologies and gives the specifies of Etten's Island.

Depending on the available machinery on site, the mechanical trenching can be either by jack-hammer and excavator or with a mechanical trencher.

Table 14: Comparison between horizontal directional drilling and mechanical trenching

Category	A) Horizontal Directional Drilling	B) Mechanical Trenching	Etten Specificities
1. Surface Disruption	Minimal surface disruption, especially with guided boring	Significant disruption with open trenches. More UXO risks	Not a densely urbanized island No need for costly reconstruction of ground infrastructure UXO risks
2. Terrain Suitability	Suitable for various terrains, including hilly or uneven surfaces	Ideal for flat or gently sloping terrain	Etten has a flat terrain No big obstacles
3. Installation Speed	Speed depends on soil conditions, distances and curves	Generally faster for straight paths	Straight paths can be prioritized during design thanks to low density of inhabitants
4. Complexity	Technology more complex, need to specifically know the drilling paths	Easy technology, access all the way of the trench	Isolated island, need for easy installations methods and small & lightweight equipment (for logistics) Need to install a pillar box every ~ 100m
5. Environmental Impact	Reduced environmental impact, as it minimizes surface disruption and soil disturbance	May cause more disturbance to ecosystems	Disturbance on the nearby trees UXO risks
6. Cost	Investments cost is higher, whereas labour effort is lower	Smaller investment cost, but requires more labor	CPUC already bought excavators that can be used. There would only be a need for an automative trencher. Labor cost might not be critical for the project.

As per the above table and CPUC's requirements for longevity of the installation, the Consultant recommends that the distribution network is designed as being underground and with mechanical trenching. The proposed trench profile section is the following:

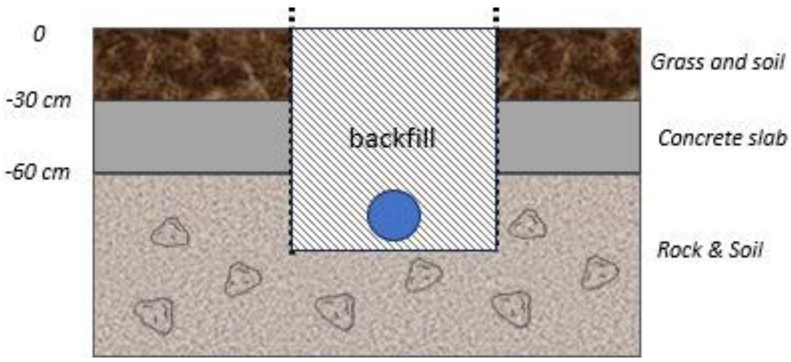

Figure 40 : Profile section for underground distribution in Etten.

Notes on UXO risk

There is a potential presence of Unexploded Ordnance (UXO) on both Etten and Piis islands, as well as the other islands in Chuuk. The risk exists whether the distribution network is underground or overhead. In the case of an underground network, the excavation of trenches at a depth of approximately 45-60 cm poses a risk of encountering UXO. Similarly, for overhead lines, the construction of foundations for poles at a depth of around 2 meters also introduces the risk of UXO. While the surface area to be cleared may be extensive for the underground network, the underlying risk remains for both solutions. It is advisable to conduct a more comprehensive investigation with experts in demining field, to assess and determine the appropriate clearing activities for both islands.

4.6.2 Typology of the distribution network

The distribution networks for Etten and Piis are designed to be like the ones that will be constructed on the other islands in Chuuk (Udot, Satowan, Fefen). The underground low voltage (LV) distribution network is divided into the following.

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

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

4.6.3 Earthing and protections

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

4.6.4 Cables

The conductors shall be 600 volt triplex placed in PVC conduits. All conductors of the same circuit and, where used, the grounded conductor and all equipment grounding conductors shall be installed in the same conduit. Insulated conductors and cables installed in these conduits in underground installations shall be listed for use in wet locations and shall comply with NEC article 310.10. The conduit 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):

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

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

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

4.6.5 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 with instructions according to NEC relevant standards.

The distribution pillars used shall:

- 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 41. Example of a pillar box. Source: Transnet

4.7 Electrical single line diagram

A reference electrical single line diagram will be provided in the technical specifications.

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 12 public streetlights are planned for Etten and 15 public streetlights for Piis Paneu. Locations have been selected by CPUC based on local needs by community.

Figure 42. Public streetlights planned for Etten Island. Source: CPUC

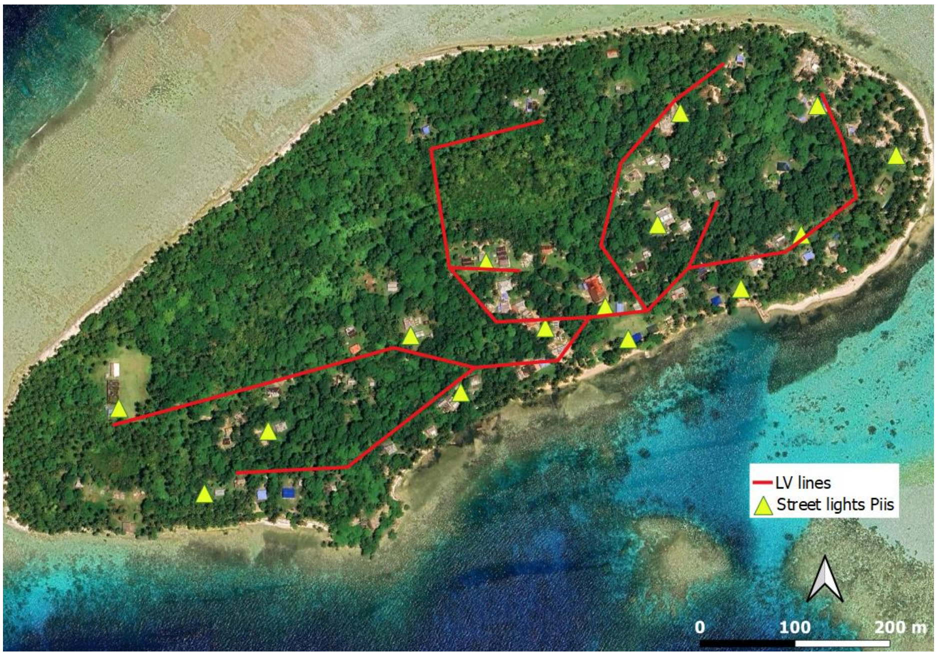

Figure 43. Public streetlights planned for Piis Paneu island. Source: CPUC

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 or treated wooden poles 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

The project scope includes everything related to the end-users connection.

- Service lateral.
- Externally mounted meter box.
- Internally mounted distribution board.
- Internal house wiring (lighting, cables, sockets, …).
- Earthing.
- Basic appliances (Led light, sockets, …).

4.9.1 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.

4.9.2 Externally mounted meterbox

Meterboxes must include the following equipment, at a minimum:

- A UV resistant enclosure, rated IP65 for ingress protection, with transparent face
- A meter with 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;
  - compatible with SUPRIMA system, used by CPUC.
- All necessary protections equipment according to standards
- Safety signage

The meterbox installations must satisfy the following minimum requirements:

- mounted in a structurally sound fashion, which may include installation of a mounting pole if a suitable location is not available at the customer premises;
- be shaded from direct sunlight;
- be at a location agreed with the customer;
- satisfy the relevant standards.

4.9.3 Internally mounted distribution board

A distribution board should be placed inside each customer's premises, or externally pole mounted where no solid internal structures are available (e.g. thatched house) in a location agreed in consultation with householder.

- Distribution boards horizontal surface mount polycarbonate enclosure with DIN-rail, earth and neutral bars including link.
- Residual current circuit breakers with overload protection (RCBO) as well as overload circuit breakers need to be included.

4.9.4 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.

All residential end-users will be provided with the same equipment:

- 3 x 6W LED lighting fixtures, 2 internal and 1 external;
- 3 x switches (1x per lighting fixture);
- 2 x sockets;
- 1 x Distribution board;
- required cabling, trunking, and grounding system.

The installation and maintenance of these systems should be done by the operator to guarantee the respective standards are followed.

4.9.5 Earthing

Customer connections must be provided with earthing in accordance with the relevant standards.

4.9.6 Appliances

It is recommended that CPUC gets involved in some way in the supply or control of appliances, to avoid the use of inadequate appliances.

4.10 Access to internet on site

For Etten, the antenna will be upgraded by the end of 2024, so the 3G/4G will be reliable.

However, for Piis-Paneu, a satellite connection will be needed, before the telecom tower upgrade in 2025-2026.