N048-ILF-AD-0007/REV.1

Hybridization of Islands, Thailand

FEASIBILITY STUDY
KOH MAK NOI

07/08/2017

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1 EXECUTIVE SUMMARY

The project site is located in the Andaman Sea in Southern Thailand. The current electricity supply relies mainly on diesel generators, which supply either individual households, small grids or large grids of up to 100 households. The objective of this project is to upgrade the conventional electrical generation system into a modern, renewable-conventional hybrid system. A secure 24 hour electrical supply shall be provided by implementing a hybrid system consisting of diesel generator, photovoltaics (PV) and battery.

1.1 Site Visit

A site visit has been carried out in March 2017. During the site visit, ILF Consulting Engineers (ILF or the Consultant) focused especially on technical aspects such as the locally available generators and grid infrastructure, while GIZ conducted a socio-economic assessment. Moreover, the Consultant reviewed the possible areas for the PV and battery installation in terms of suitability. To determine an energy demand and load profile of the island, the Consultant installed an energy measurement device to record the power output of the generator over the course of 1 month. In addition the infrastructure and logistics were reviewed to ensure a successful project implementation and to identify potential risks and limitations.

1.2 Energy Demand Analysis

Based on the recorded energy data as well as the findings during the site visit, the Consultant analysed the data to determine the current energy demand on the island. Taking further assumptions, such as socio-economic factors and future appliances into account, a future energy demand and load profile has been developed and optimized. The forecast was performed for the period 2018-2027. The estimated future annual amount of gross generated energy by the hybrid power plant has been calculated and amounts to:

- In year 2018 : 351.95 MWh
- In year 2022 : 415.29 MWh
- In year 2027 : 477.43 MWh

Furthermore, the related monthly load profiles were developed. The load profiles formed the basis for system design and were implemented in the system simulation.

1.3 Hybrid System Design and Energetic Simulation

The parameters of the future hybrid system were sized and optimized. The optimized system parameters were simulated to:

- Total capacity diesel generators : 3 x 60 kW (3 x 75 kVA)
- Total installed PV capacity : 270 kW_p
- Total installed battery capacity : 440 kWh

For comparison, a reference scenario, assuming 100% diesel, was also simulated.

Based on the mentioned results, a total renewable fraction of 62% in the first year of operation (2018) could be achieved by implementing the hybrid system. This means, compared to the reference scenario, a significant saving of diesel fuel (65,096 litres in 2018) could be achieved. Moreover, the emission of CO_2 could be reduced significantly by almost 66%.

1.4 Calculation of Levelised Cost of Electricity

The Consultant calculated the future levelised cost of electricity (LCOE) for both, the hybrid system and the reference scenario (100% diesel). Therefore, the capital expenditure (CAPEX) and operational expenditure (OPEX) were estimated. Furthermore, several assumptions such as inflation rate, fuel price escalation, discount rate, and basic financial input parameters were defined and considered in the calculation. It shall be noted that especially the future estimated escalation of fuel price shows the dominant influence on the estimated LCOE. The calculated LCOE for 30 year project lifetimes:

- Reference scenario with 100% Diesel : 0.575 USD/kWh (19.56 THB/kWh)
- Diesel/PV/Battery hybrid system : 0.482 USD/kWh (16.41 THB/kWh)

The results show that the LCOE of Diesel/PV/Battery hybrid system, compared to the calculated reference scenario with 100% Diesel, is significantly reduced by approx. 16%.

In addition to the LCOE calculation, the Consultant also calculated the real annual generation costs for the years 2018, 2022, 2027 and 2047. The calculated real generation costs in the first year of operation (2018) are:

- Reference scenario with 100% Diesel : 0.376 USD/kWh (12.80 THB/kWh)
- Diesel/PV/Battery hybrid system : 0.324 USD/kWh (11.03 THB/kWh)

Compared to the reference scenario, the results of the real annual generation costs in the first year of operation of hybrid system is lower than reference scenario. This confirms the attractiveness of the Diesel/PV/Battery hybrid system.

1.5 Summary results table

Table 1: Summary results of 100% diesel scenario

Reference scenario: 100% Diesel		Unit	2018	2022	2027
System parameters					
Total capacity diesel generators		kW	180 (3x60 kW)		
Number of diesel generators		Unit	3		
Homer simulation output					
Total energy production (demand)		kWh/a	351,955	415,291	477,434
Total diesel consumption		l/a	101,452	117,538	134,912
Specific diesel consumption		l/MWh	288	283	283
Total diesel operating hours		hr/a	9,502	10,455	11,950
Operation hours below 50%		%/a	23	18	13
CO_2 emission		t/a	268	310	356
Financial parameters					
Clusters	**Willingness to pay**		**Current electricity expenses**		
Residential type I	8.81-14.69 USD/month (300-500 THB/month)		14.69-17.63 USD/month (500–600 THB/month)		
Residential type II	2.94-26.44 USD/month (100-900 THB/month)		14.69-28.20 USD/month (500-960 THB/month)		
Residential type III	11.75-17.63 USD/month (400-600 THB/month)		14.69-17.63 USD/month (500-600 THB/month)		
HH+Shop	8.81-60.81 USD/month (300-2,070 THB/month)		11.75-60.81 USD/month (400-2,070 THB/month)		
HH+Shop+Restaurant	No information		17.63 USD/month (600 THB/month)		
HH+Shop+Motorbike/ boat repairing shop	More than 14.69 USD/month (More than 500 THB/month)		14.69-39.66 USD/month (500-1,350 THB/month)		
LCOE	0.575 USD/month (19.56 THB/month)				

Table 2: Summary results of PV/Diesel/Battery hybrid system

PV / Diesel / Battery Hybrid System	Unit	2018	2022	2027
System parameters				
Total capacity diesel generators	kW	180 (3 generators of 60 kW)		
Total PV capacity	kW_p	270		
Total PV inverter	kW_{AC}	240		
Total battery capacity	kWh	440		
Usable total battery capacity (SOC_{min} 10%)	kWh	396		
Battery inverter capacity	kW	90		
Homer simulation output				
Total energy production (demand)	kWh/a	351,955	415,291	477,434
Share Diesel	kWh/a	133,807	180,932	225,041
Share PV and battery	kWh/a	218,147	234,359	252,393
Excess PV energy	kWh/a	153,479	121,960	91,976
Total diesel consumption	l/a	36,355	49,285	60,579
Reduction of diesel consumption (compared to diesel reference scenario)	l/a	65,097	68,253	74,333
Specific diesel consumption	l/MWh	272	272	269
Renewable fraction (PV and battery)	%	62	56	53
Excess PV energy	%	40	32	25
Total diesel operating hours	hr/a	2,767	3,792	4,428
Operation hours below 50%	%/a	1	0.34	0
CO_2 emission	t/a	96	130	160
Reduction of CO_2 emission (compared to diesel reference scenario)	t/a	172	180	196

Financial parameters		
Cluster	**Willingness to pay**	**Current electricity expenses**
Residential type I	8.81-14.69 USD/month (300-500 THB/month)	14.69-17.63 USD/month (500–600 THB/month)
Residential type II	2.94-26.44 USD/month (100-900 THB/month)	14.69-28.20 USD/month (500-960 THB/month)
Residential type III	11.75-17.63 USD/month (400-600 THB/month)	14.69-17.63 USD/month (500-600 THB/month)
HH+Shop	8.81-60.81 USD/month (300-2,070 THB/month)	11.75-60.81 USD/month (400-2,070 THB/month)
HH+Shop+Restaurant	No information	17.63 USD/month (600 THB/month)
HH+Shop+Motorbike/ boat repairing shop	More than 14.69 USD/month (More than 500 THB/month)	14.69-39.66 USD/month (500-1,350 THB/month)
LCOE	0.482 USD/month (16.41 THB/month)	

2 INTRODUCTION

Mak Noi Island is located in Southern Thailand. The current power generation relies mainly on diesel generators, which supply either individual households or small grids of approximately up to 100 households.

The Consultant has produced a technical and financial pre-feasibility study to determine a suitable hybrid system utilising diesel generators, PV and batteries which will provide 24-hour coverage of electricity for 10 years based on forecasted power consumption.

The Consultant conducted a site visit to examine and evaluate the existing system, quality of electricity supply, island's socio-economics and to forecast future demand for the island.

2.1 Project Location and Description

The island is located in the Andaman Sea between Phuket and Krabi as shown in Figure 1. Approximately 1,400 inhabitants are living on Koh Mak Noi in 250 households. The economy of the island relies mainly on rubber production, coconut farming, fishery and motorbike repair shop. Main public buildings of the island are the health centre, school and mosque. No street lighting, traffic lights or other infrastructure electrification has been observed. There are two seasons which are summer season and rainy season.

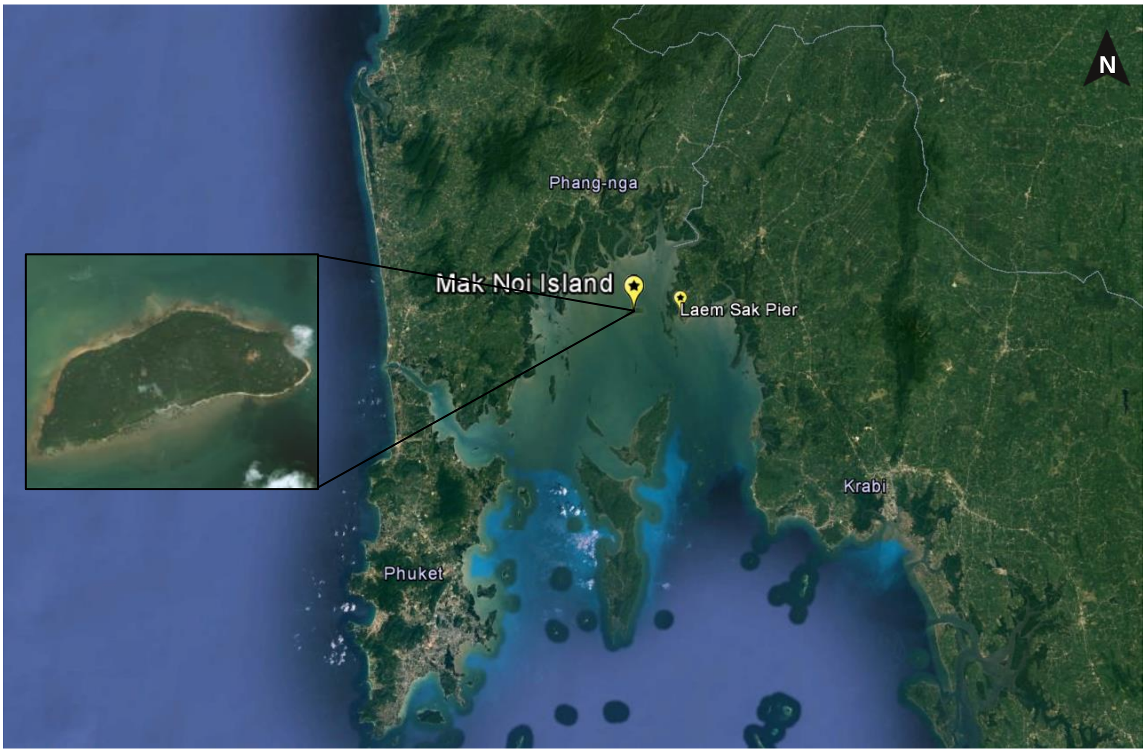


Figure 1: Project location

The current power generation of the island relies mostly on large diesel generators, supplying up to 100 households per a grid transmission line or smaller units powering single households. Additionally, some households are electrified by solar home systems which are PV modules and batteries. One of the grids on the island, has electricity prices based on 2 fixed tariffs which are based on low load consumers (500 THB/month) and high load consumers (600 THB/month).

2.2 Methodology and Background Information

2.2.1 Current Situation on the Island

Currently, Mak Noi Island is mainly electrified by diesel generators, which supply either individual households or small grids of approximately up to 100 households.

The vision and target is to upgrade the very basic, low-tech and manually managed system to a modern grid system providing up to 24 hours electrical supply by implementing a hybrid system consisting of diesel, PV and batteries.

2.2.2 Socio-Economic Background

Most electrical demand originates from residential buildings on the island. To understand the actual condition on the island, to project a load profile and to conduct a load forecast, GIZ conducted and studied the socio-economic situation of the island. A survey of several households, listing electrical appliances, income and other factors have been conducted during the site visit and further used to predict the load forecast.

The results showed that a standard household is equipped with lights, electrical fans, mobile chargers and TV.

The income of the inhabitants covers the wide range from 29.38 USD/month (1,000 THB/month) to 2,644 USD/month (90,000 THB/month). The main income source appears to be from fisheries, rubber plantation and coconut plantation.

2.2.3 Load Measurement, Forecasting and Load Assumptions

To model and deploy a hybrid system, a load profile needs to be generated. No load/energy demand information was available on the island and so the Consultant installed a measurement device to record the power demand for 1 month. As of the number of small grids on the island, it was difficult to record the power demand of all households on the island. Therefore, one of the largest grids in terms of number of connected households was chosen to install the measurement device.

The Consultant analysed the recorded data and determined the load profile of all households on the island. The profile was projected from approx. 4 hours to 24 hours. Taking seasonality effects into account, the profile was estimated over 12 months and further expanded into a profile for a 10 year period.

Typically a load forecast is carried out to cover a period of 10 years. Such period is then used for the simulation and design of the system, ensuring sufficient reserves and sizing of the system.

To simulate the load profile and expand it from 4 hours to a 24-hour load profile, the socio-economic data on the island and the experience of the Consultant were applied.

2.2.4 Hybrid System Simulation

The simulation was carried out using HOMER Pro 3.9.1 software ("HOMER"). The target of the simulation was twofold:

1. To simulate various technical viable scenarios to determine the optimum size of each involved technology and simulate the sensitivity of the results by re-analysing the system
2. To financially optimize the system to obtain the best LCOE for each scenario.

Hourly load profile of year 2018-2027 served as input-data as shown in Chapter 4.7.4. Results of the solar PVsyst simulation and financial parameters as observed in the market with standard market prices completed the inputs. As a summary, simulation inputs consisted of:

- Load profile over the period (hourly resolution)
- Selected technologies and their technical parameters
- Weather data set
- Fuel consumption curves of the generators
- Battery technologies and parameters
- Costs of each system component
- Financial parameters of each technology such as CAPEX, OPEX, replacement costs and lifetime.

The overall target of the simulation was to achieve a system that:

- Has a high renewable energy share
- Ensures reliable and sustainable energy supply
- Is optimized technically and economically according to the LCOE
- Provides sustainable electricity over 24 hours and 7 days a week
- Is capable and sized sufficiently for at least 10 years

To achieve this aim, two possible scenarios were simulated and the corresponding LCOE was calculated as

- Reference scenario with 100% diesel
- Diesel/PV/Battery hybrid system

2.2.5 30-year project lifetime consideration

Currently, the PEA plan to build a 33 KV submarine cable connecting the island to the mainland. The lifetime of the submarine cable is considered as 30 years and therefore the consultant assess the hybrid systems lifetime to the same 30 year period.

3 SITE VISIT

During the site visit of Mak Noi Island, the Consultant focused on several aspects to develop a hybrid system. In particular the current situation of socio-economic factors, grid infrastructure, electrical generation, and possible areas for the solar PV and battery installation were evaluated and reviewed. The load over the course of 1 month was also measured with a 1 minute resolution to determine a load profile of the island. Beyond the technical aspects, the Consultant has reviewed the infrastructure and logistics to ensure the system can be transported to site and the required resources such as diesel can be made available. Furthermore the Consultant has studied the socio-economics of the island to ensure major impacts on electrical load forecasting have been identified and can be addressed accordingly.

3.1 Socio-economic of Mak Noi Island

A socio-economic survey was conducted by GIZ during the site visit.

3.1.1 Education

Koh Mak Noi School is the only school on the island. It was established in 2005 and provides education from Kindergarten to grade 9. There are approx. 250 students and 21 teachers. For higher education, the students have to leave the island to study on the mainland. There are 6 classroom buildings and at the time of the site assessment, the school was constructing a new classroom building.

3.1.2 Occupation, Local business and Economic Situation

The main sources of income are from fisheries, rubber plantations and coconut plantations. Some inhabitants are technicians/mechanics that operate motorbike repair shops and boat building/fixing businesses. Around 30 technicians were trained by a university to maintain Solar Home Systems, they can diagnose and repair the systems. There are also shops and a couple of grocery stores mostly selling daily products and gasoline for the motorcycles.

The income of the population is widely spread ranging from approx. 29.38 USD/month (1,000 THB/month) to over 2,644 USD/month (90,000 THB/month), averaging around 220.33 USD/month (7,500 THB/month) in mode average.

3.1.3 Typical Appliances

The survey results show that typical household appliances are light bulbs, TVs, mobile phones and electric fans. Some households also have washing machines, radios, rice cookers, blenders, speakers and electric irons. The motorbike repair shops and boat building/fixing have certain power tools (e.g. drills, saws, sanding tools etc.), welding machine and compressor.

Besides the residential households, there are several public buildings such as the health centre, school and the mosque. These buildings have more appliances installed (additional light bulb, fans, TVs as well as computers, etc.)

3.1.4 Community Spirit

In general the people are well connected and know each other as they are mainly descendants from a few families. The close relatives generally live together in one premise, which are in some cases a cluster of 3-4 houses. There are no established community cooperatives, groups or social entities. As a remark, the water supply used to be operated under a community committee, but it didn't work well and now Mr. Abdullah is taking care of the water supply.

Between the electricity operators and the households, there are some small conflicts. On the operator side, there are issues on delayed payments (up to a month) and secretly using washing machines and irons without paying more, which may cause brownouts. Some people also blame it on the operator (or on other users using iron/washing machines) that their appliances broke down because of low electricity quality.

3.1.5 Local Resources

There are 2 large ponds collecting rain water which are the main water resources on the island.

Currently a lot of locals are operating and maintaining their own diesel generators, which means they have a certain technical know-how which the Project can build upon. Most houses are also constructed by the locals who may provide support in construction work of the Project.

3.2 Existing Grid Infrastructure

There are currently 5 major grids supplying approx. 250 households. Each of these grids is connected to one of the 5 generators described in Chapter 3.3. Figure 2 shows 5 major grids on the island from the largest to smallest grids in terms of number of connected households, which are the light blue, grey, brown, green and dark blue respectively. It has to be noted that these grids were built by the locals.

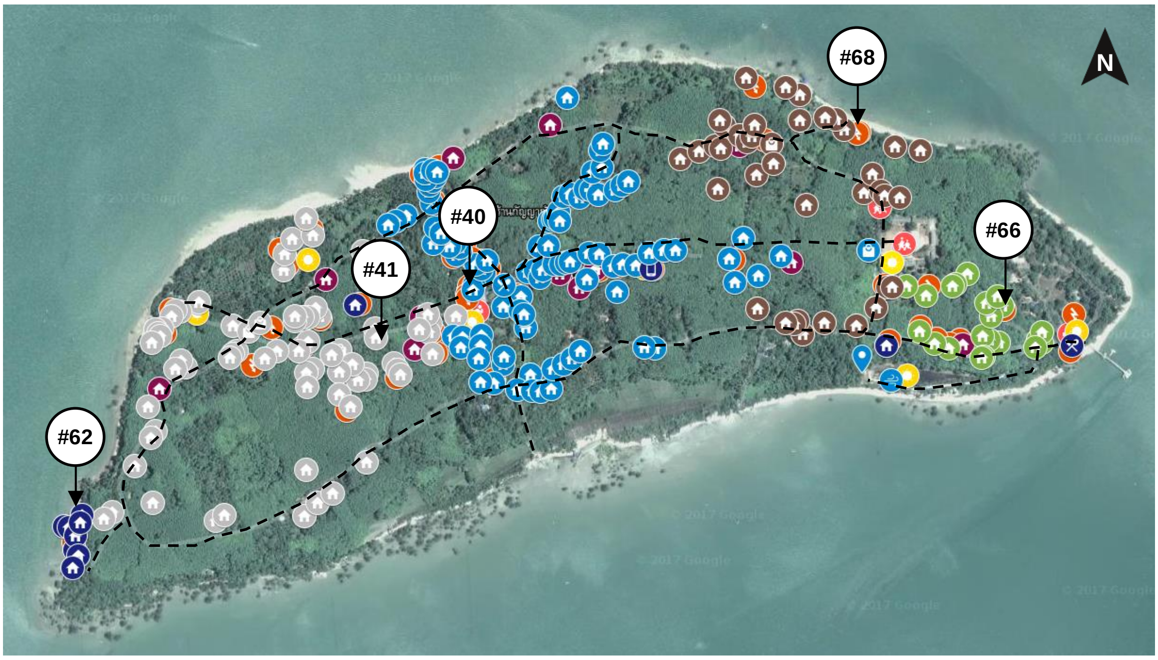


Figure 2: Existing central grid transmission line

The Consultant assessed each of these grids and summarized in Table 3.

Table 3: Overview of existing grid infrastructure

Item	Light blue	Grey	Brown	Green	Dark blue
Frequency	50 Hz				
Voltage level	220 V				
Length	Varied				
Cable specification	▪ THW-A 25 sq.mm TIS 2541 ▪ THW-A 16 sq.mm TIS 2541 ▪ THW-A 10 sq.mm TIS 2541 ▪ VAF 2x2.5 sq.mm TIS 2553	▪ THW-A 25 sq.mm TIS 2541 ▪ VAF 2x2.5 sq.mm TIS 2553	▪ THW-A 16 sq.mm TIS 2541 ▪ VAF 2x2.5 sq.mm TIS 2553	▪ THW-A 10 sq.mm TIS 2541 ▪ VAF 2x2.5 sq.mm TIS 2553	▪ VAF 2x1.5 sq.mm TIS 2531
Electricity source	Generator #40	Generator #41	Generator #68	Generator #66	Generator #62
Owner	Mr. Abdullah	Mr. Abdullah	Mr. Shade	Mr. Weerachai	Mr. Usop
No. of connected households	~105	~75	~40	~20	~10

3.3 Existing Diesel Generator

Approximately 50 generators were observed during the site visit, which are either used to power single household or supply group of households via separate grids (5 major grids as described in Chapter 3.2. Due to the time constraint during the site visit, only those 5 generators were evaluated. The detailed information of each generator is described in the site visit report (N048-ILF-AD-0003_Site Visit Report_Mak Noi).

Figure 3: 5 generators on the island forming major grids

3.4 Existing Photovoltaics systems

There are PV systems and solar home systems observed during the site visit. The detailed information of each system is described in the site visit report (N048-ILF-AD-0003_Site Visit Report_Mak Noi).

Figure 4: Examples of solar home systems on the island

Figure 5: Examples of PV systems on the island

Furthermore, there is a PV/Wind/Battery hybrid system supplying the electricity for water pumping as shown in Figure 6. The detailed information is described in the site visit report (N048-ILF-AD-0003_Site Visit Report_Mak Noi).

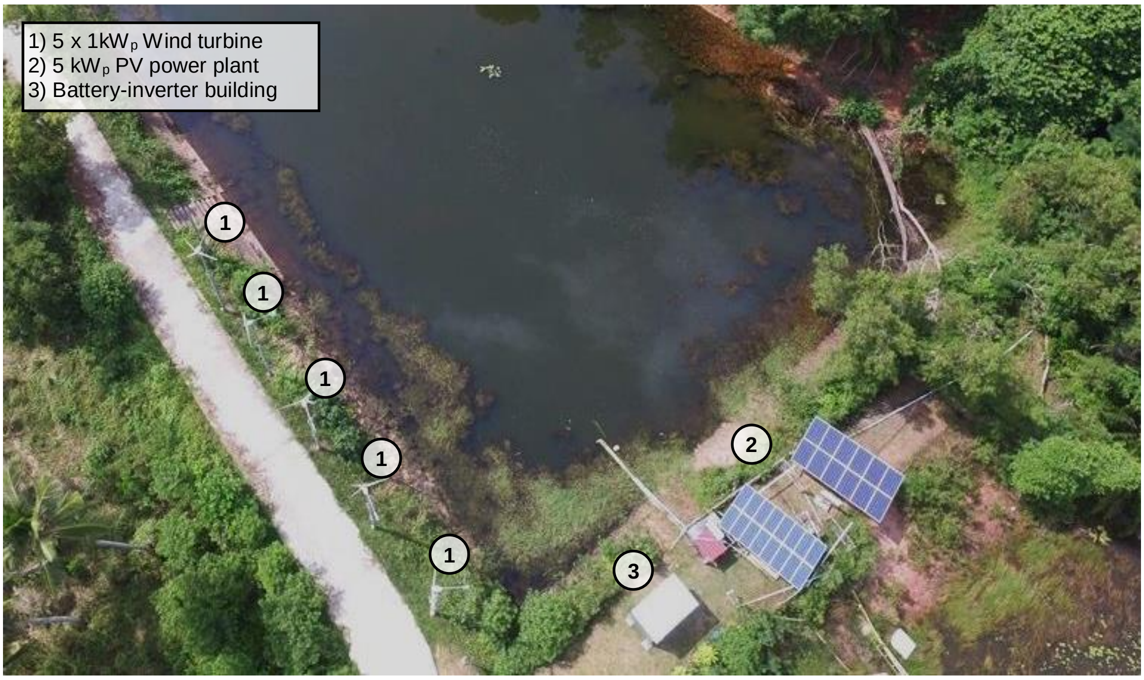


Figure 6: PV/Wind/Battery hybrid system

3.5 Areas for PV Hybrid System Installation

According to the site visit report, there are 2 preferred areas, Area 1 and 2 as shown in Figure 7, to install the PV power plant of the hybrid system which are selected in Chapter 5.2.2. However, the designed PV power plant in this study requires more space than the 2 preferred areas from the site visit report. Therefore, Area 3 shall be considered. It has to be noted that this land is owned by the police. According to information from Mr. Abdullah, the area has not been used since a very long time. This opportunity can be discussed with the owner and the SAO. The trees within boundaries can be cut if necessary.

Figure 7: Overview of possible areas of the hybrid system installation

Two preferred locations have been identified to install the generator and battery housing. The first location, is located near the pond approximately 700 m away from Area 1. The second location, Area 1 & Area 2, is shown in Figure 7. Additionally the consultant proposes another location to install the generators and batteries, located in Area 3.

Figure 8: Possible area for new power house with the abandoned building

The advantages and disadvantages of each location is summarised in Table 4

Table 4: Pros and cons of the 2 locations for the generators and batteries installation

Area	Pros	Cons
Near the pond	▪ Far from the residential area (low noise pollution)	▪ Far from PV power plant resulting in transformers are required in order to connect between this building, i.e. generators/batteries, and PV power plant
Within Area 1 and Area 2	▪ There might be no land issue.	▪ Not enough space ▪ Close to the residential households resulting in noise pollution
Within Area 3	▪ Far from the residential area (low noise pollution)	▪ Currently owned by local Police. Potential issue with leasing land or unable to be used.

3.6 Transport and Logistics

The transportation on the island relies heavily on motorbikes. Most of the roads are made of concrete. The transport of larger hybrid system components can be performed because there is a pier on the island as shown in Figure 9.

During the site visit, an excavator and a pickup truck was observed on the island. This means, it’s possible to transport heavy-duty vehicles from mainland to the island.

Furthermore, the Consultant was informed by the locals that in the past, there was a huge flat boat conveying a pile of sand, 10-wheel truck, 6-wheel truck and excavator to the island. Another example of transportation for heavy equipment is Mr. Abdullah’s generator and the tripod winches to lift the generator from the boat.

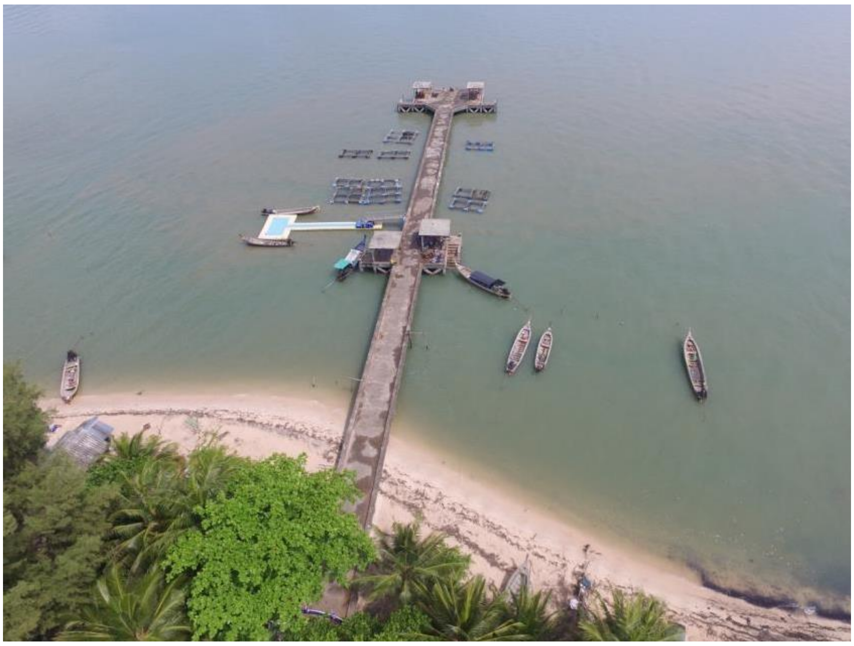


Figure 9: Koh Mak Noi pier

4 ENERGY DEMAND ANALYSIS

An energy demand analysis presents the current and future estimation of energy demand on Mak Noi Island. The current energy demand of Mak Noi Island is analysed. The results of the current energy demand analysis shall be used as a basis to develop future load profiles of Mak Noi Island.

4.1 Load Measurement

Since there was no any data logger or recorded energy data prior to the site visit, the Consultant installed two load measurement devices (Eco Sense 3) on Mak Noi Island on 6th March 2017 to measure the energy consumption of the connected generator loads until 8th April 2017. The devices measure relevant grid parameters like voltage, current, active and reactive power and frequency for each phase separately.

One of the measurement devices was connected to the largest grid supplying 102 households. This grid is electrified by Generator #40 (40kW diesel generator). Another one was connected to the second largest grid supplying 71 households which is electrified by Generator #41 (40kW diesel generator).

The main data input for the study comprises of daily power consumption recorded on-site and the GIZ Survey. The main data, information and inputs have been used as a basis for energy demand and load profile analysis for Mak Noi Island. The main inputs and data are presented in Table 5.

Table 5: Main input data for energy demand and load profile analysis

Data	Content	Source
Daily Power Consumption	Daily power consumption of a 2x40-kW generator providing the electricity for 173 households, 1 minute recording interval	Measurement on-site
Socio-economic survey	Detailed information of each household: ▪ Type of consumer ▪ Current electrical appliances ▪ Monthly income ▪ Current source of the electricity ▪ Current electricity expenses ▪ Ability to pay for the electricity from the hybrid system in the future ▪ Future electrical appliances	Survey prepared by GIZ

4.2 Current Energy Demand and Load Profile Analysis

4.2.1 Measurement Data

At the time of measurement, the power is supplied by the decentralized generators to the end-users. The power consumption measurement is conducted at the generator, where after the energy demand and load profile have been analysed.

The generators generally are switched on during 18:30-22:30, therefore the measurement data presents only behaviours of the locals during such duration only. Moreover, the measured power comprises of many appliances and many types of connected households. To clearly analyse in a later stage, according to information received from GIZ, the households on Mak Noi Island can be categorized into 6 clusters based on current appliances and socio-economics as presented in the following table.

Table 6: Household clusters on Mak Noi Island

Cluster	Appliances
Residential type I	Basic appliances (Lighting, fan, phone)
Residential type II	Basic appliances and TV
Residential type III	Basic appliances, TV and either blender, rice cooker, washing machine or iron
HH+Shop	Basic appliances, TV and either blender, rice cooker, washing machine, iron, speaker or pump (more amount than residential type III)
HH+Shop+ Restaurant	Basic appliances, TV, washing machine, coconut shredder, rice cooker and blender
HH+Shop+Motorbike/ boat repair shop	Basic appliances, TV, washing machine, welding machine and compressor

The measurement devices measured the data of 173 households, however, GIZ Survey has completed only 62 household samples due to time constraints. Table 7 summarizes the figures of each household cluster.

Table 7: Number of households in each cluster of the measured grids

Household Cluster	Total household samples (GIZ Survey)	Total households of #40 and #41 (extrapolated)
Residential type I	5	17
Residential type II	28	96
Residential type III	13	44
HH+Shop	8	8
HH+Shop+Restaurant	4	4
HH+Shop+Motorbike/boat repair	4	4
Total	**62**	**173**

4.2.2 Load Profile Analysis of Measured Data

The measured data was qualitatively analysed. The data recorded on 24th March 2017 was excluded from the analysis because the generators were switched off during 19:00-20:30. The reason was that there was heavy rain during that period and Mr. Abdullah was afraid that lightning might damage the electrical components in his grids, specifically automatic voltage regulator (AVR). Since the above day is not a typical day, the data recorded on 24th March shall be excluded from the analysis.

In addition, the Consultant understands that the power generator usually switches on randomly during 18:30-19:00, and presumes that the power consumption behaviour is similar in regular day basis. Therefore, the filtered measurement data has been shifted the starting time to be 18:30 for the load profile analysis in order to avoid the averaging overlapping time and leading to under- or overestimation.

It should be noted that the Consultant considers daylight saving time programmed in the measuring device influencing the readings during 26th March - 8st April 2017, when the recorded time has been delayed for an hour. Therefore, the starting recording time of time saving period was adjusted to be at 18:30 for the load profile analysis.

Since the measured grids are quite large, particularly the longest distance from the generators to the households is approx. 850 m. To further analyse the consumer load profile, the Consultant estimated and took distribution line loss of 1.6% into consideration. The average daily load profile of 173 residential households is shown in the following graph.

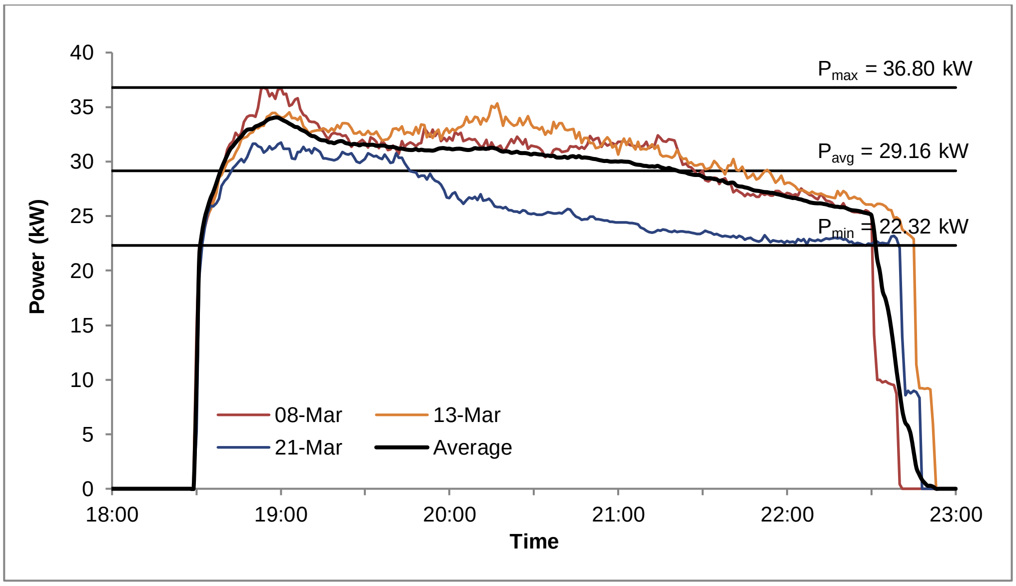


Figure 10: Average daily consumer load profile

The results of current energy demand of measurement data are presented in the following table.

Table 8: Results of current energy demand of measurement data

Item	Value
Residential type I	17 households
Residential type II	96 households
Residential type III	44 households
HH+Shop	8 households
HH+Shop+Restaurant	4 households
HH+Shop+Motorbike/Boat repair	4 households
Total average daily generation of diesel generators (#40 and #41)	124.75 kWh/d
Estimated distribution loss	1.6%
Total average daily energy demand (exclusive distribution loss)	122.75 kWh/d
Average power	29.16 kW
Maximum power	36.80 kW
Minimum power[1]	22.32 kW
Average operation duration	4.21 hrs

Each group is further considered to be broken down into the individual devices powering it. To assess the devices used, time of use and period of use the Consultant assess the measured load to the recordings found in the socio-economic survey.

According to GIZ Survey, basic appliances, TV, washing machine, iron and pump were switched on during the measurement period. The average quantities[2] of basic appliances and TV of each cluster were estimated and presented in the following table.

Table 9: Estimated quantity of basic appliances and TV according to GIZ Survey

Appliance	Residential			Residential + Other		
	type I	type II	type III	HH+Shop	HH+Shop+ Restaurant	HH+Shop+ Motorbike/ Boat repair
Lighting (20W)	3.33	3.53	5.11	8	9	5.5
3-level fan (50W)	1	1.4	1.72	2.33	2	1.33
Phone (7.5W)	2	2	2	2	2	2
TV	0	1.1	1	1.7	1	1

[1] This minimum power is considered during the operating period (not in the beginning/end of the operation)

[2] The average quantities are calculated from number of appliances in each cluster according to GIZ Survey

Appliance	Residential			Residential + Other		
	type I	type II	type III	HH+Shop	HH+Shop+ Restaurant	HH+Shop+ Motorbike/ Boat repair
(72W)						

Apart from the basic appliances and TV in Table 9, washing machine, iron and pump were switched on during the measurement period. Since GIZ Survey did not cover all of 173 households, the Consultant extrapolated these appliances as presented below:

- 61 washing machines (8kg), assuming approx. average power of 100W
- 17 irons, assuming approx. average power of 230W
- 3 pumps, assuming approx. average power of 150W

Interpreting the on-site measurement data, the following appliances are estimated to be in operation at the same time and categorized in various clusters, as presented in Table 10, and it was assumed that similar behaviour applied in the evening time. This combination shows a good fit with the on-site measurement.

Table 10: Behaviour assumptions of each appliance during the measurement period

Time	18:30	19:00	19:30	20:00	20:30	21:00	21:30	22:00
Light	80%	80%	80%	85%	85%	80%	70%	70%
Fan[1]	85%	85%	85%	85%	85%	85%	75%	70%
Phone	80%							
TV	80%	80%	80%	85%	80%	80%	80%	70%
Washing machine	40%	30%	30%	0%	0%	0%	0%	0%
Iron	40%	30%	0%	0%	0%	0%	0%	0%
Pump	0%	80%	0%	0%	0%	0%	0%	0%

The load profiles of each cluster based on basic appliances and TV in Table 9 for 1 household are presented in the following figure.

[1] The fan is assumed to be switched on at level 2, i.e. 35W power consumption

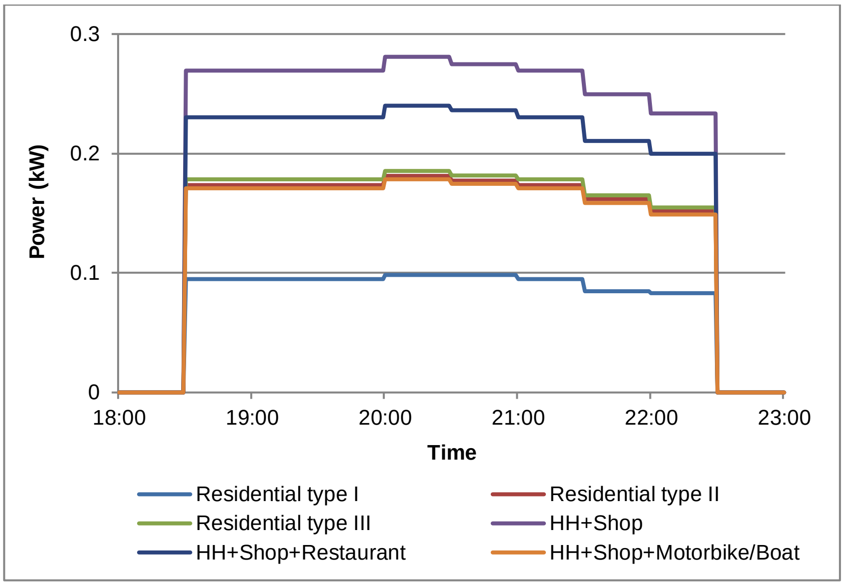


Figure 11: Estimated load profiles based on basic appliances and TV of each cluster

The results of estimated daily energy demand of each cluster are summarized in Table 11. The estimated total daily energy demand of approx. 121.96 kWh/d is in-line with the actual energy demand of the measurement data in Table 8, i.e. 122.76 kWh/d. This combination shows good fit with the measurement data. Therefore, the Consultant shall use the basis and findings described above for further analysis in this study.

Table 11: Estimated daily energy demand

Type	Average daily energy demand per unit	Qty.	Total average daily energy demand
Residential type **I**	0.37 kWh/d	17	6.29 kWh/d
Residential type **II**	0.69 kWh/d	96	66.24 kWh/d
Residential type **III**	0.70 kWh/d	44	30.80 kWh/d
HH+Shop	1.06 kWh/d	8	8.48 kWh/d
HH+Shop+Restaurant	0.90 kWh/d	4	3.60 kWh/d
HH+Shop+Motorbike/boat repair	0.67 kWh/d	4	2.68 kWh/d
Washing machine	0.05 kWh/d	61	3.05 kWh/d
Iron	0.08 kWh/d	17	1.36 kWh/d
Pump	0.06 kWh/d	3	0.18 kWh/d
		Total	**122.68** kWh/d

4.3 Load Profile Estimation of Mak Noi Island

The total number of households on Mak Noi Island is 250 households. Based on information received from GIZ on 31[th] May 2017, GIZ estimated the number of following households, shown below:

- 12 HH+Shop
- 4 HH+Shop+Restaurant
- 5 HH+Shop+Motorbike/Boat Repair

Therefore, the total number of residential households (residential type I, II and III) shall be 229 households. The Consultant anticipated the propotion of households based on GIZ Survey. The propotion and extrapolated number of households are presented in the following table.

Table 12: Residential households recorded of GIZ Survey

Residential households	No. (from GIZ Survey)	Percentage	All households on the island (extrapolated)
Residential type I	6	9.09%	21
Residential type II	38	57.58%	132
Residential type III	22	33.33%	76
Total	**66**		**229**

As a result, the total number of households in each cluster are summarized in the followin table.

Table 13: Total number of households in each cluster

Residential households	Total number
Residential type I	21
Residential type II	132
Residential type III	76
HH+Shop	12
HH+Shop+Restaurant	4
HH+Shop+Motobike/boat repair shop	5
Total	**250**

In addition, the quantities of the additional appliances switched on during the measurement period, i.e. washing machine, iron and pump, are also extrapolated based on GIZ Survey sample i.e. 87 samples, to 250 households. The estimated figures of each appliances are presented in Table 15.

The number of households in each cluster in Table 13 and number of appliances in Table 15. are used as a basis for energy demand extrapolation and load profile development for the whole island in a later chapter.

Based on the combination of on-site measurment results, GIZ Survery, and assumptions made by the Consultant, the estimated load profile of Mak Noi Island is shown as Figure 12.

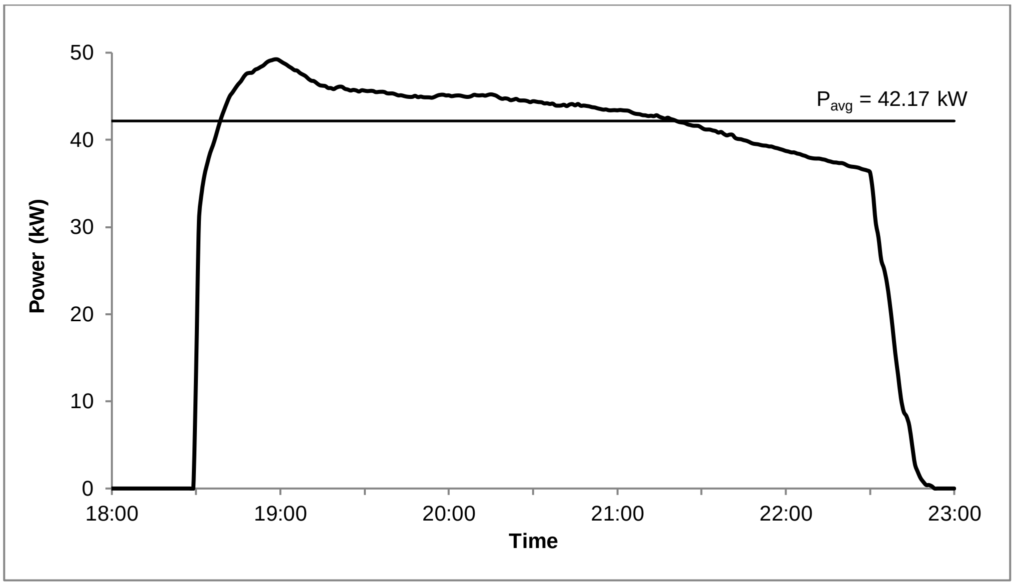


Figure 12: Load profile of Mak Noi Island during the measurement period

The estimated energy demand and power consumption are presented in Table 14.

Table 14: Estimated energy demand and power consumption

Item	Value
Average power	42.17 kW
Total average daily energy demand	177.53 kWh/d
Average operation duration	4.21 hrs

4.4 24-hour Load Profile of Mak Noi Island Anticipation

To derive a suitable and plausible future 24-hour load profile local behaviour was observed and matched with the Consultants experiences. The assumptions and methodology are described in following section.

4.4.1 Anticipated 24-hours Residential Load Profile

The Consultant appraises the behaviours and characteristics of local people living on Mak Noi Island based on field interview with the locals carried out by GIZ during the site visit as well as the information taken from the GIZ Survey. This information is crucial inputs to anticipate the 24-hour load profile of Mak Noi Island.

The working hours of fishermen are dependent on the types of fisheries, which are shrimp and fish fisheries. Most fishermen on the island do shrimp fishery, approximately 70%, and only 30% of fishermen do fish fishery.

- For shrimp fishery, they regularly leave the island in early morning around 6:00, and comeback for having lunch at home and relax around an hour or one and a half hours before the afternoon round. They generally then come back in the late evening around 16:00-17:00. Regarding low tidal days, the shrimp fishermen will shift leaving time and arrival time for 1-2 hours, which low tidal days are approximately 10 days a month.

- For fish fishery, they regularly leave the island in late evening, around 16:00-17:00, and they come back to the island around late morning of the next day.

The appliances are switched on as much as possible during the daytime in households equipped with Solar Home Systems (SHS) as long as sunlight can produce electricity. This can be interpreted that the local people will tend to utilize more electricity, if there is supply.

The assumptions for a regular 24-hour load profile have been made according to the acquired information, perceiving an electricity-supply for 24 hours, as presented below:

- Some men go to work on the mainland while women and children stay home during the daytime this forms the assumed base load from their energy consumption;
- Students leave in the morning and come back home in the late afternoon. Demand for electricity prior to leaving their homes and after returning home is expected to increase.
- Shrimp fishermen returning home at noon time will increase electrical demand. Fishermen return to work in early afternoon and they will return home again in the late afternoon.
- Tendency to utilize more if electricity is able to be supplied;
- Low tidal influences are not considered under the typical load profile estimation. However, the sensitivity analysis shall address this to cover low tidal influence.

It is expected that the increased supply of electricity will be met by demand for power, as well as demand for new appliances. According to the GIZ Survey and experience of the Consultant this could include appliances, such as washing machine, iron, pump, rice cooker, speaker, coconut shredder, welding machine, compressor, blender, fridge and computer. The Consultant assumes the characteristics and sizes of these new appliances to anticipate the 24-hour load profile of Mak Noi Island in the following table.

Table 15: Estimated quantities of additional appliances

Residential households	No. (from GIZ Survey)	Percentage (87 sample)	Number of appliances (extrapolated)
8-kg washing machine (100W)	30	34.48%	86
Iron (230W)	9	10.34%	26
Pump (150W)	2	2.30%	6
1.8-l rice cooker (650W)	3	3.45%	9

Residential households	No. (from GIZ Survey)	Percentage (87 sample)	Number of appliances (extrapolated)
Speaker (30W)	3	3.45%	9
Coconut shredder (300W)	2	2.30%	6
1.5-l blender (500W)	1	1.15%	3
80-100 litre fridge (176.66 kWh/year)	Since there is no fridge information, the amount shall be based on the assumption in Table 19 (Y1)		
Computer (laptop, 50W)	Since there is no computer information, the amount shall be based on the assumption in Table 19 (Y1)		
Computer (desktop, 300W)	Since there is no computer information, the amount shall be based on the assumption in Table 19 (Y1)		

It shall be noted that motorbike and boat repairing are the on-going activities on the island. Considering motorbike and boat repairing activities, the Consultant understands that one generator is dedicated for this particular activity. Moreover, there is no detailed information regarding motorbike and boat repairing power tools provided in GIZ Survey. Only welding machine (assuming 1kW) and compressor (assuming 1kW) were observed during a site visit.

Based on the above assumptions, the Consultant assumes the following behaviours for anticipated 24-hour residential cluster load profile of Mak Noi Island.

- TVs will be partly switched on in early morning and during the day, especially when fishermen come back home at noon for lunch and rest. Moreover, TVs will be mainly turned on in the afternoon (students are back home after school) and night time;
- Light bulbs are expected to turn on by 15% during the daytime. During the site visit, the light switches were observed in household, and the light bulbs were installed inside and outside a household. Therefore, the lighting is assumed to be switched on by 60-85% when it is necessary during the night-time;
- Compact fans are mainly utilized for the whole night. Considering daytime, the high operation rate of compact fan is expected when fishermen come back home at noon and early afternoon, however, it is assumed to be on partly during the rest of the day time;
- Washing machines are expected to be in operation in late morning and in the evening;
- Rice cookers are assumed to be utilized in early morning and in the evening;
- Blenders are assumed to be utilized from time to time in the morning and in the afternoon;
- Pumps are assumed to be utilized from time to time in the morning and in the evening;

- Computers will be expected to be mainly switched on in the evening but partly in the morning as well. During the end-of-semester period, however, computer could be in use during daytime as kids will be staying at home.
- Refrigerators will expected to be switched on all day
- At least 1 mobile phone charger will expected to be utilized all day in each household

In addition, the specific usages of each appliance are summarized in Appendix 1.

Consequently, the 24-hour load profiles of each cluster of 1 household are presented in the following figure. It has to be noted that the number of some appliances such as washing machine and iron belonged to each cluster is unknown, therefore the appliances of residential type I, II, III and HH+Shop are based on Table 9. However, 1 rice cooker, 1 blender and 1 coconut shredder are assumed to be included in HH+Shop+Restaurant. Also, 1 welding machine, 1 compressor, power tools are assumed to be included in HH+Shop+Motorbike/boat repairing shop.

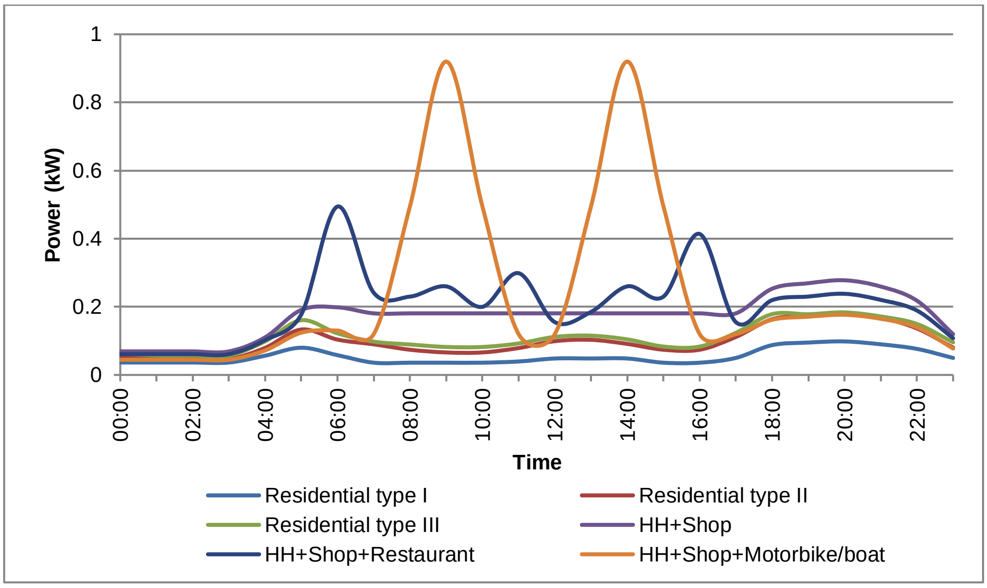


Figure 13: 24-hour load profiles of each cluster of 1 household

Based on the assumptions above, the load profiles of each additional appliances are shown in the following figure.

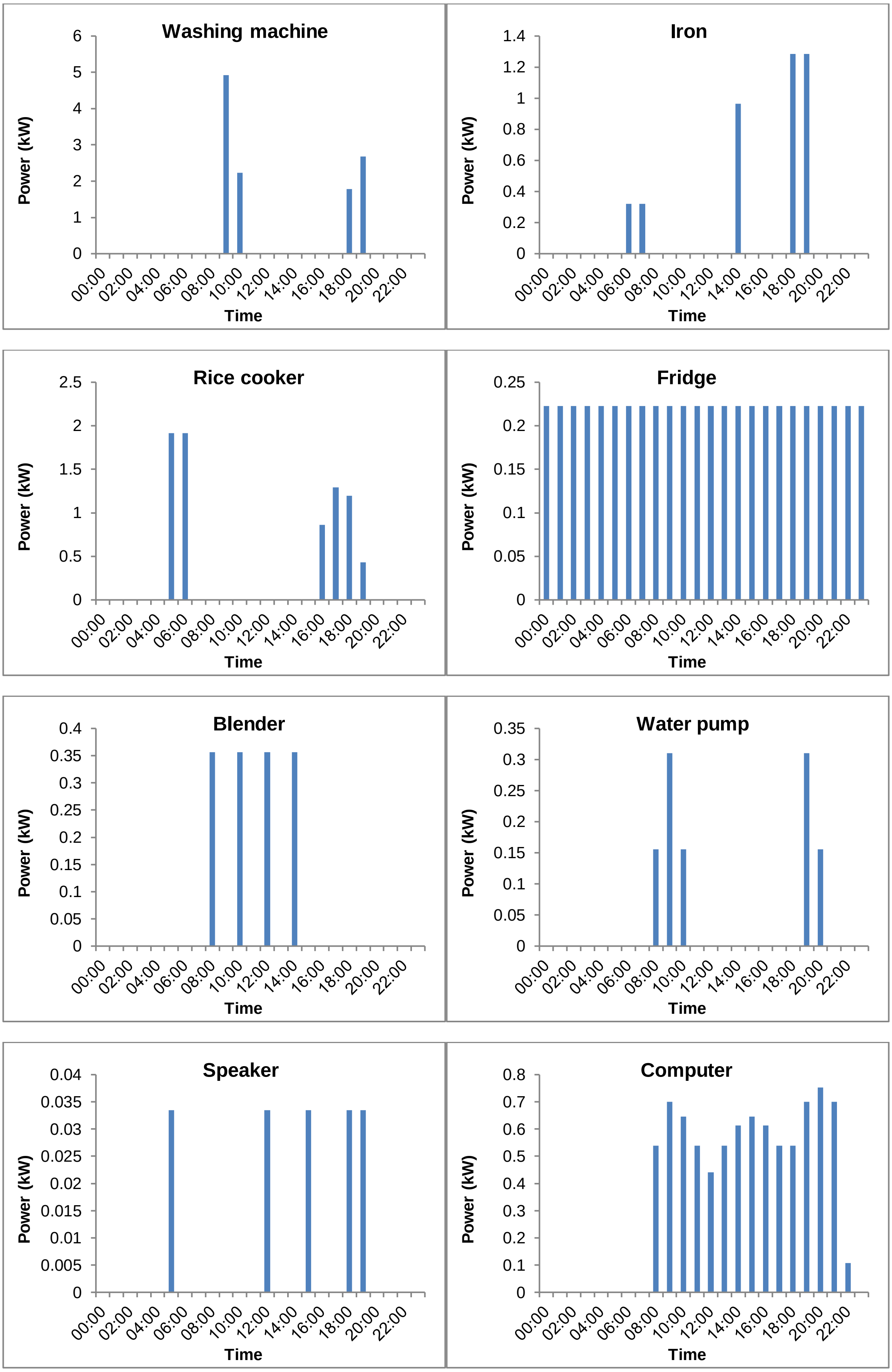


Figure 14: Anticipated load profiles for additional appliances

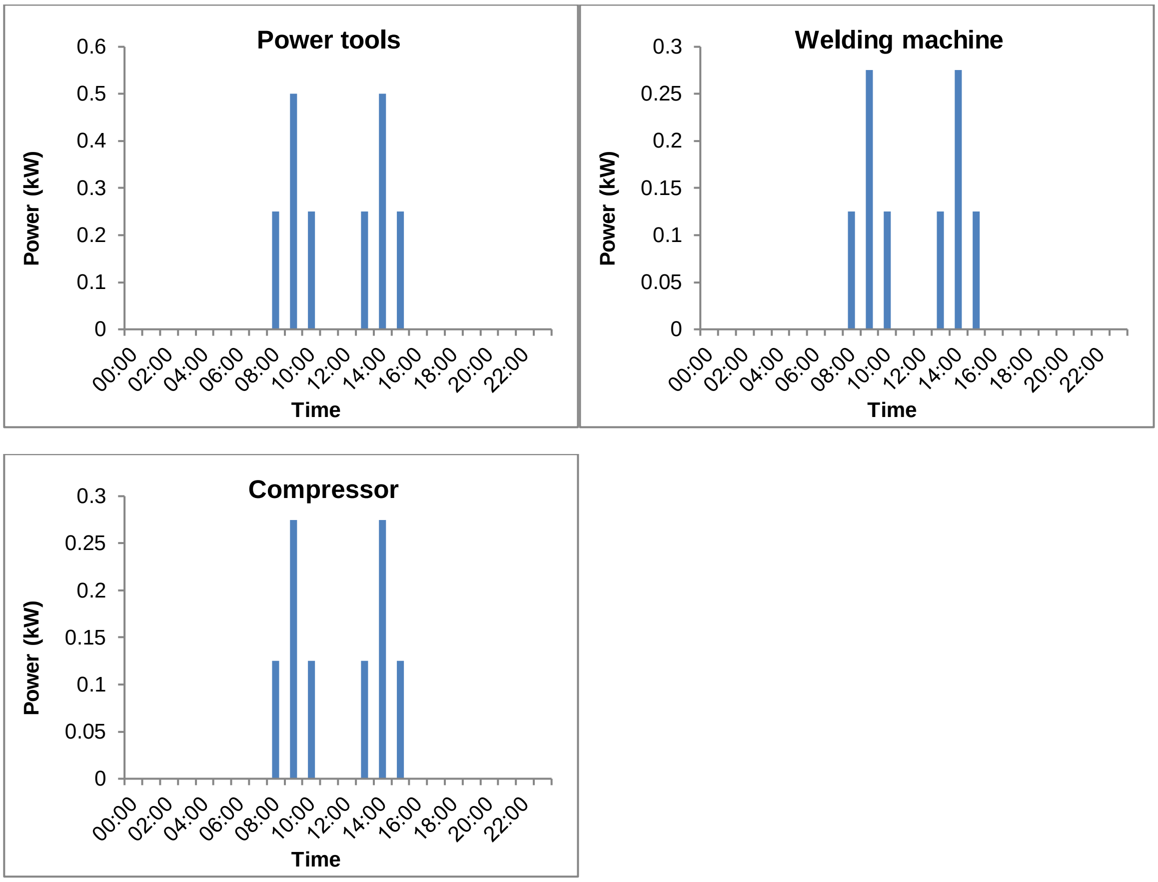


Figure 15: Anticipated load profiles for additional appliances (HH+Shop+Motorbike/Boat)

The 24-hour load profile of all residential clusters together with all additional appliances for the month of March is presented in Figure 16.

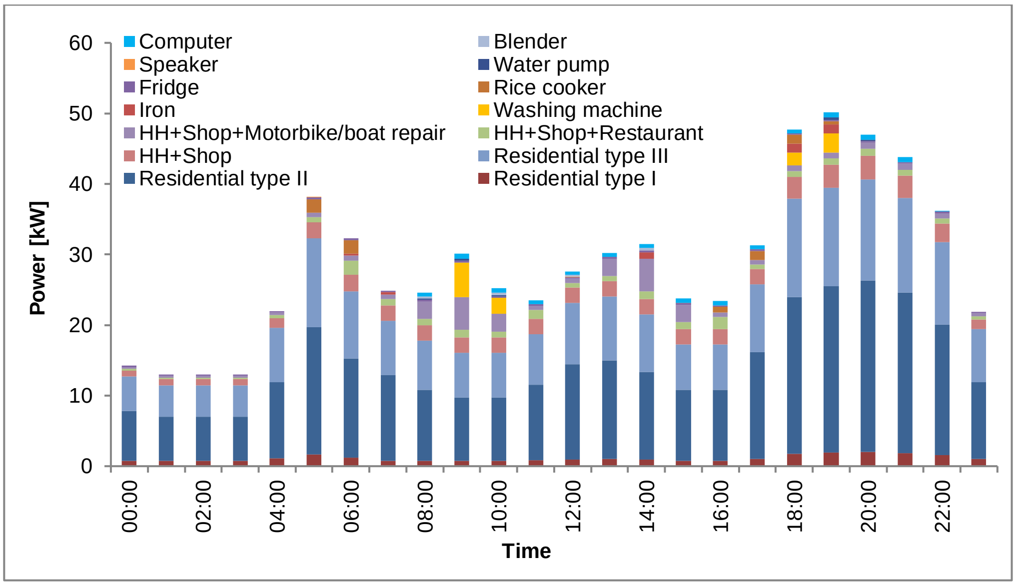


Figure 16: Anticipated 24-hour load profile for all residential clusters of Mak Noi Island

Based on the 24-hour load profile for all residential clusters with additional appliances above, the estimated daily energy demand and power for 24-hour scenario results in the typical month of March are presented in Table 16.

Table 16: Estimated 24-hour energy demand and power of all residential households

Item	Value
Maximum power	50.2 kW
Minimum power	13.01 kW
Average power	28.70 kW
Total average daily energy demand for 24-hour electricity	688.58 kWh/d
Average daily energy demand for 24-hour electricity (per 1 household)	2.75 kWh/d

The seasonality influences will be taken into account and described in more detail in the following sections.

4.4.2 Anticipated 24-hours Non-residential Load Profile

Besides residential area on Mak Noi Island, there are several other clusters on the island, which are listed as the following:

- School
- Mosque
- Health Centre
- Street Lights
- Battery Storage Room

The current appliances and their anticipated behaviour will be described and used as a basis to anticipate a 24-hour load profile for each cluster.

School

As the on-site measurement did not apply to the school, the Consultant assumes the most likely behaviour on summer semester as a basis, based on the available information and assessment of the Consultant.

According to GIZ Survey, the school has totally 250 students. However, teacher amounts are not specified in the survey but additional information of school teachers has been provided which is 21 teachers. During the site visit, the Consultant observed that there was a teacher's building construction on-going.

The current school's appliances are listed below. However, the power of some appliances is not indicated in the GIZ Survey and no information was received during the site visit. The power consumption of these devices will be assumed and are written with the quantities of the devices below:

- 143 Light Bulbs (20 W)
- 37 TV (80 W)
- 48 Fans (50 W)
- 23 Computers (300 W)
- 1 Speaker (50 W)
- 3 Printers (20 W)
- 1 Network (50 W)

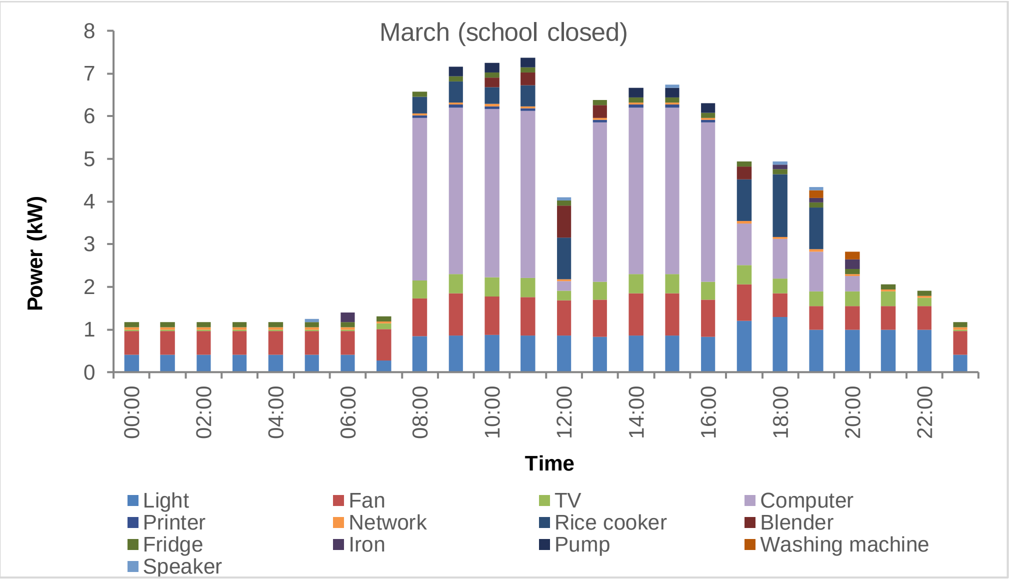
Moreover, there is a new school building under construction and might be operated in next year. The number of future appliances are estimated in Table 20.

During school hours it is assumed that appliances used for education (Fans, computers, network system, lighting, TV and the water pump) are switched on for classes between 08:00-11:00 and 12:00-16:00, where 11:00-12:00 is the lunch break.

As teaching staff resides at the school. It is assumed that they will use TV, lighting and fans at night time. The refrigerator is assumed to be switched on 24 hours every day.

The specific usages of each appliance are also summarized in Appendix 1.

Based on the above assumptions, 24-hour load profile of school is simulated, as presented in Figure 17.



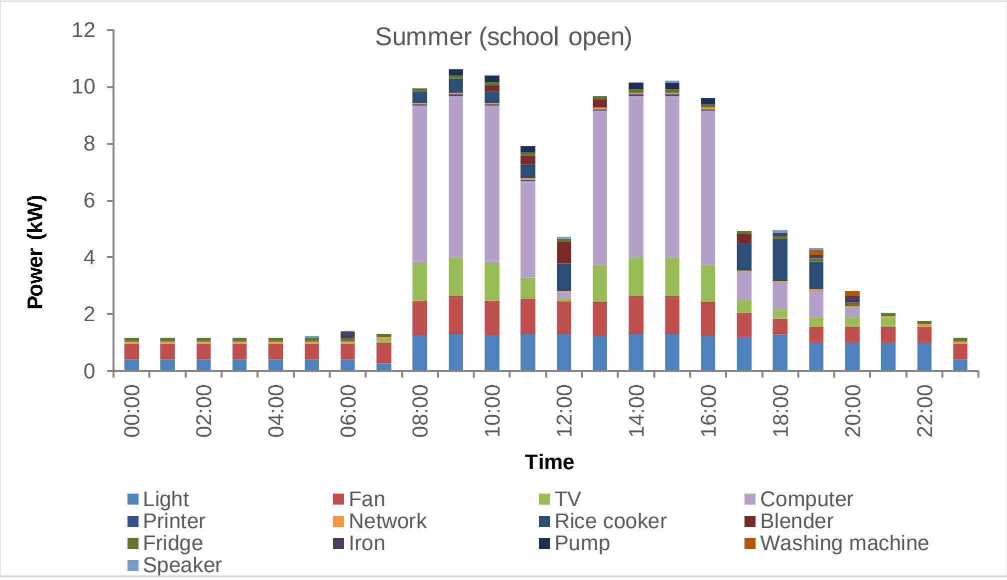


Figure 17: Anticipated 24-hour load profile for school of Mak Noi Island in March

The school vacation and seasonality influences will be taken into account and described more detail in the following chapter.

The Consultant estimates that the school in March (school closed) and during summer semester (school opened) requires approx. 90.48 kWh/d and 115.11 kWh/d respectively.

Mosque

As the measurement data did not apply to the mosque, the Consultant assumes the most likely behaviour in March as a basis, based on the available information and assessment of the Consultant.

Based on GIZ Survey, the quantity of appliances is provided but wattage information of each appliance is not provided, they shall be assumed shown below. The current mosque's appliances are listed below:

- 25 Light Bulbs (40 W)
- 5 Fans (50 W)
- 1 Speaker (50 W)

According to the information provided by GIZ on 15th May 2017, the averaging praying times on Mak Noi Island are provided and it is assumed that appliances will be utilized during praying times only, as listed below:

- Fajr (early morning, before sunrise) 04:30-05:00
- Dhuhr (mid-day) 12:00-12:45
- Asr (afternoon) 15:15-15:45
- Maghrib (after sunset) 18:15-18:30

- Isha'a (night time) 19:00-19:30

Each prayer time is estimated around 15-30 minutes. Additionally, people usually stay at the mosque after Maghrib till Isha'a.

The specific usages of each appliance are summarized in Appendix 1.

Based on the above assumptions, 24-hour load profile of mosque in March is simulated, as presented in Figure 18.

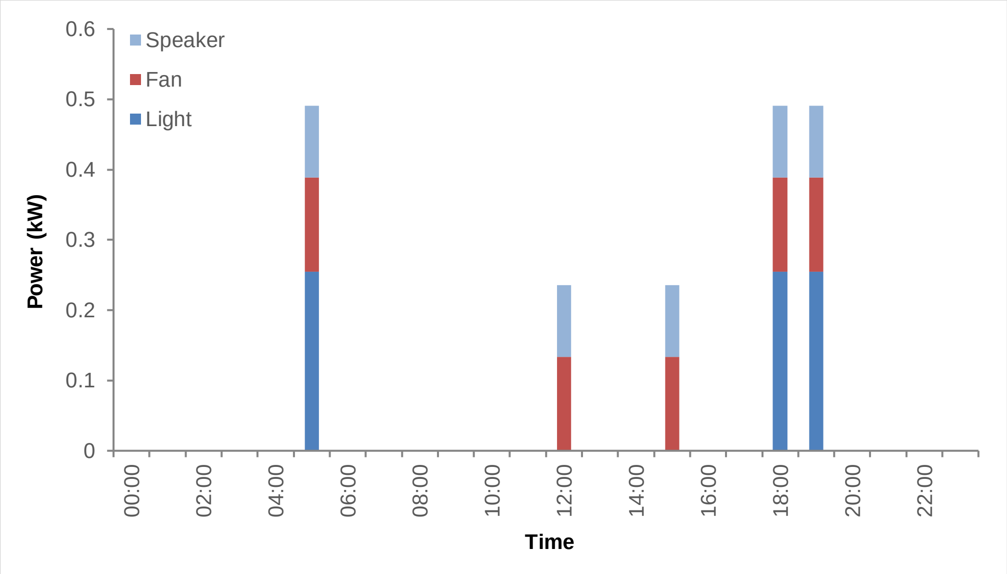


Figure 18: Anticipated 24-hour load profile for mosque of Mak Noi Island in March

The Ramadan period and seasonality influences will be taken into account and described more detail in the following chapter.

The Consultant estimates that the mosque requires energy approximately 1.94 kWh/d in March.

Health Centre

As the measurement data did not apply to the health centre, the Consultant assumes the most likely scenario based on the available information and assessment of the Consultant.

Based on information received during the site visit, three doctors are stationed at the health centre. The 24-hour load profile of health centre is estimated considering existing appliances recorded in GIZ Survey.

Based on GIZ Survey, the health centre's quantity of appliances and power of some appliances are provided. Any devices where power consumption data was not collected will be assumed. The current health centre's appliances are listed below:

- 18 Light Bulbs (19 W)

- 3 TV (80 W)
- 4 Fans (50 W)
- 1 Fridge (80-200 L) approx. required average energy of 176.66 kWh/year[1] for 24/7 usage
- 2 Computers (300 W)
- 2 Electric scale (6 W), and
- 2 Printers (120 W).

The specific usages of each appliance are summarized in Appendix 1.

Based on the above assumptions, 24-hour load profile of health centre in March is simulated, as presented in the following figure.

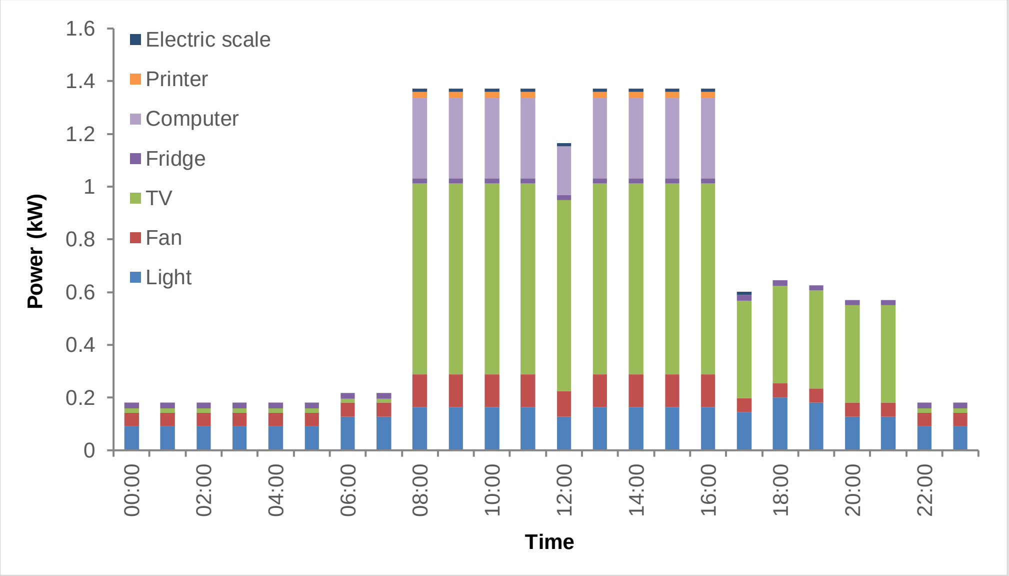


Figure 19: Anticipated 24-hour load profile for health centre of Mak Noi Island in March

The seasonality influences will be taken into account and described more detail in the following chapter.

The Consultant estimates that the health centre requires approximately 17.27 kWh/d in March.

Street Lighting

The Consultant assumes that simple necessary infrastructure will be developed to facilitate villagers, which are street lights. The street lights are expected to be installed after completion of hybridization system installation. The quantity and power of light bulbs are assumed:

---

[1] This average energy demand is derived from EGAT energy consumption survey data.

- 200 Light Bulbs (24 W).

The street lights are expected to be in operation only in the night time (18:00-06:00).

Based on the above assumptions, 24-hour load profile of street light in March is simulated, as presented in Figure 20.

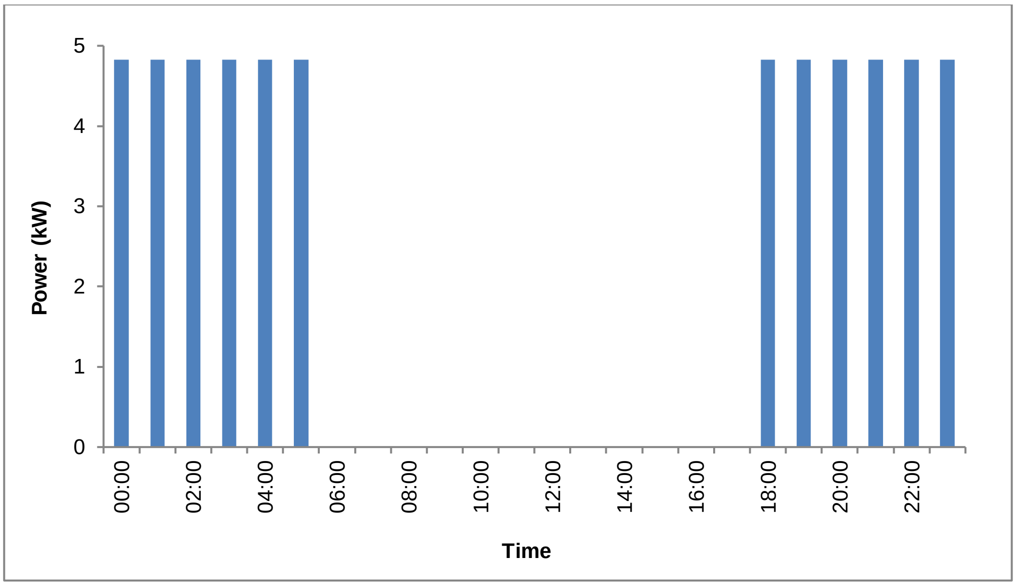


Figure 20: Anticipated 24-hour load profile for street lights of Mak Noi Island in March

The Consultant estimates that the street light requires approximately 57.89 kWh/d in March.

Battery Storage Room

Based on the area requirement for battery storage and PV-inverter, the room shall be approx. 15 sq. meter and requires an 18,000 BTU air conditioner for sufficient cooling. The air-conditioner load profile is specific to the surrounding climates conditions, which is complex to model accurately and requires a much higher resolution of 1 min for load profiling. As of this an average consumption per hour is assumed, in which day time cooling demand will be higher compared to the night time, shown in Figure 21. The average demand is approximately 3,400 kWh/year. Additionally the system is sufficiently designed to account for the in-rush current associated with the starting of the compressor. A pre-fabricated containerised solution is viable, a detailed investigation into the logistics to deliver such a solution is necessary at the next stage of the project. Both containerised and non-containerised solutions occupy the same space and require the same air-conditioning capacity.

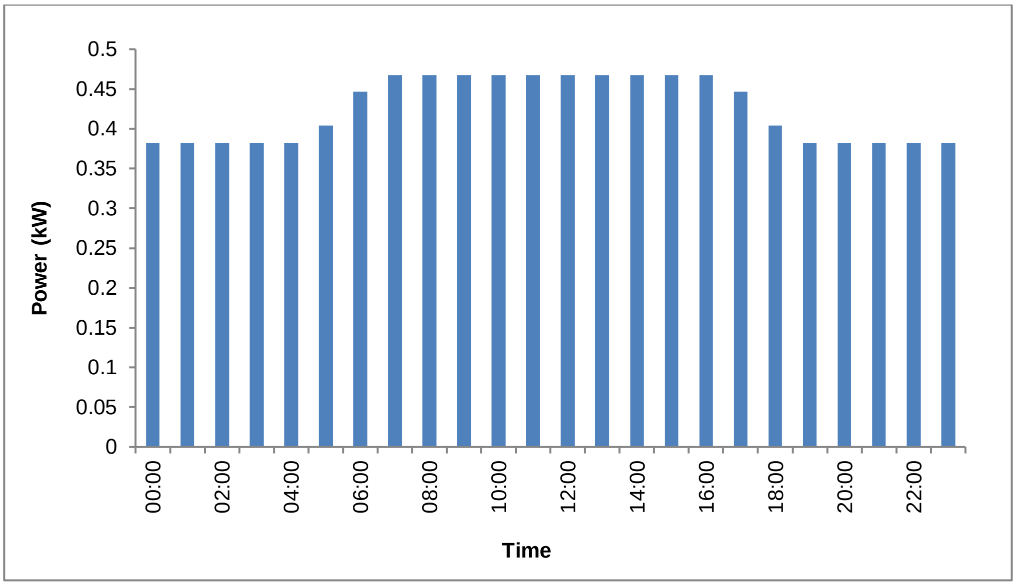


Figure 21: Anticipated load profile for A/C in battery storage room

4.4.3 Anticipated 24-hour Load Profile of the Mak Noi Island

The anticipated 24-hour load profile of Mak Noi Island is estimated based on the combination of the load profile of all clusters as presented in the earlier sections. The anticipated 24-hour load profile of Mak Noi Island is presented in Figure 22.

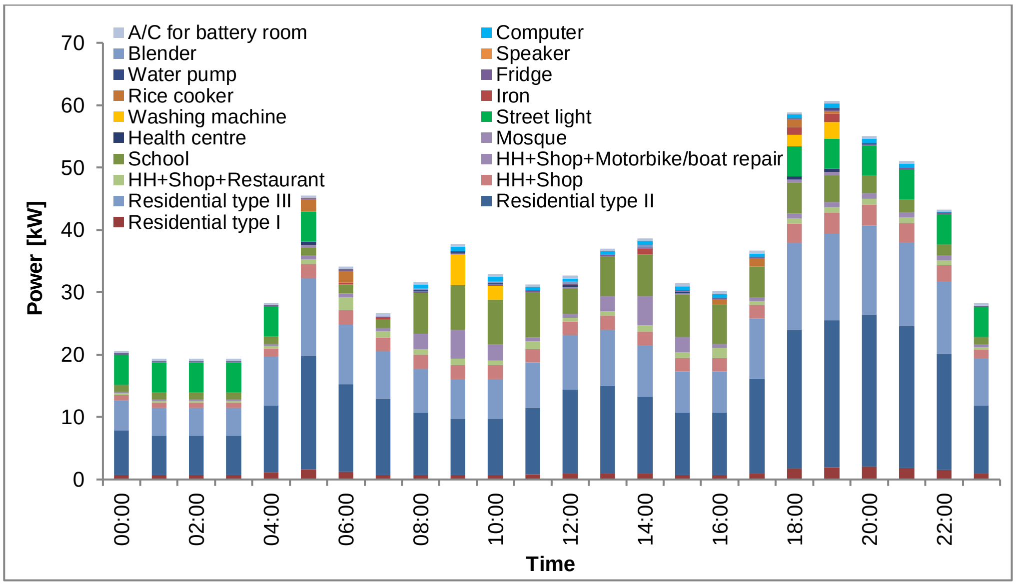


Figure 22: Anticipated 24-hour load profile of Mak Noi Island in March

The energy demand of Mak Noi Island incorporated all associated clusters is presented in the following table.

Table 17: Estimated energy demand of Mak Noi Island incorporated all clusters

Item	Value
Residential clusters including additional appliances	688.58 kWh/d
School	90.48 kWh/d
Mosque	1.94 kWh/d
Health centre	17.27 kWh/d
Street light	57.89 kWh/d
Air conditioner for battery storage room	10.2 kWh/d
Total	**866.36 kWh/d**

4.5 Influences of the Seasonality on Energy Demand

To develop the energy demand and load profiles over the 12 months, the Consultant takes the seasonality effect into consideration.

According to the Thai Meteorological Department (TMD) weather data, the weather on the island can be divided into 3 seasons as follows:

1. Summer season : Jan, Feb, Mar, Apr, Nov, Dec
2. Rainy season : May, Jun, Jul, Aug
3. Monsoon season : Sep, Oct

The season on the island has influence on the locals' behaviour directly as assumptions below:

In rainy season,

1. The temperature will be lower than in the summer. Fans will therefore switch on at level 1 instead of level 2 in the summer season, (the power consumption of the fan at level 1 is approx. 20W). The power consumption of the fridge in the rainy season is also less than in the summer season.
2. The daylight hours will be less than the summer season and the number of cloudy and dark days will increase. The number of light bulbs switching on during the daytime by approx. 20%.
3. Due to the turbulent waves, the fishermen cannot go out for the fishing, which could lead to approx. 10% more TVs being switched on during rainy season in comparison to summer season as mentioned in Chapter 0.

In monsoon season,

1. The effect is similar to rainy season but increased. The number of fans switching on at the same time will be reduced by approx. 20% less than in the rainy season. The number of light bulbs switching on during the daytime will be

increased by approx. 15%. The number of TVs switching on during the normal fishing time will be increased 10% more than in the rainy season.

Furthermore, the school also has the seasonality effect from the end-of-semester period which is in Mar, Apr, May and Oct. Therefore, the power consumption of the school will be less during the end of semester as the following assumptions:

1. The power consumption of the appliances related to the classroom during the end of semester, which are fans, light bulbs, computers and TVs, will be significantly reduced.
2. The season on the island described above also has influence on the school's load profile.

Since most of the locals are Muslims, Ramadan period[1] also has influence on the locals' behaviour as follows:

1. For the breakfast, the locals must finish breakfast before the sunrise, therefore, they have to wake up very early in the morning. The energy demand of light bulbs, fans, rice cookers and TVs shall be shifted to the early morning.
2. For the dinner, they must have dinner after the sunset. The energy demand of the appliances shall be shifted to the late evening.

4.6 Peak Load Analysis

Based on the measurement data, the daily peak loads during the measurement period were analyzed. Subject of the analysis is the specific P90 power which covers 90% of the annual measured peaks. In other words, 90% of the total amount of measured values are below or equal to the P90 value. The results are outlined in Table 18.

Table 18: Measured daily peak load and P90

Period	P90	Highest measured peak
6th March 2017 to 8th April 2017	32.90 kW	36.80 kW

The distribution of daily peak load is showed in Figure 23. It should be noted that the outliers are excluded from the peak load analysis.

[1] Ramadan period depends on Islamic calendar which is changed every year. The developed load profiles in this study are considered Ramadan period in July only.

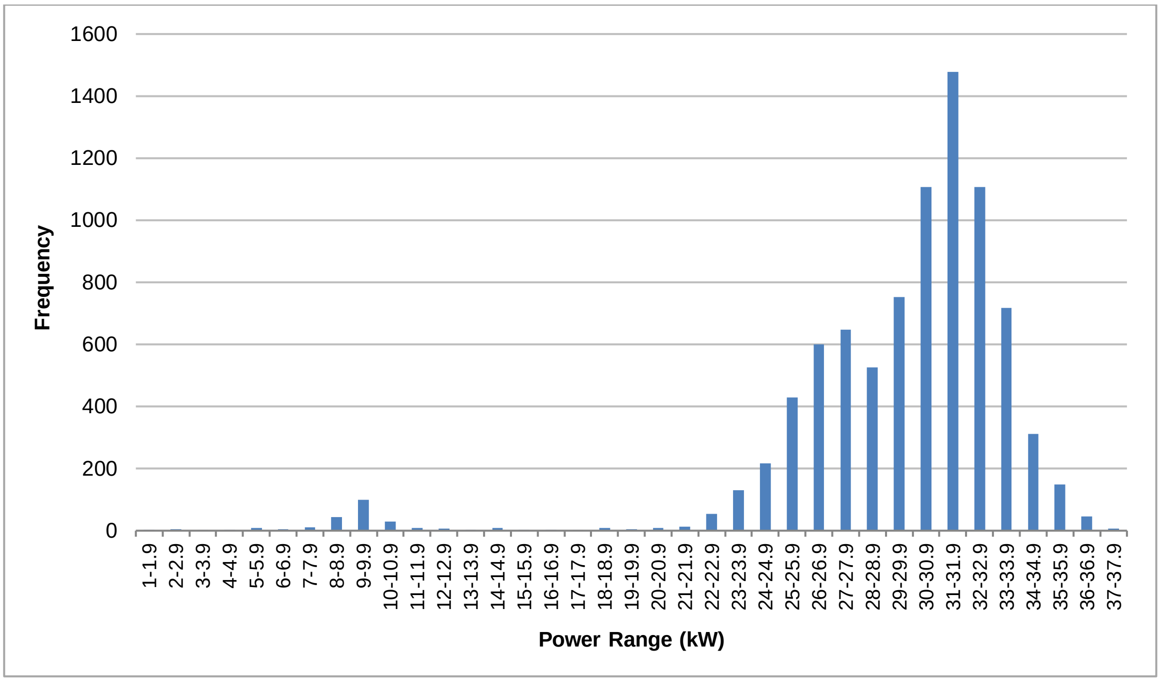


Figure 23: Distribution of measured daily peak load

As the total energy daily consumption is scaled up based on the measurement data. Therefore, P90 of Mak Noi Island is estimated to increase by the same proportion as the average power. The P90 is approximately 42.73 kW.

4.7 Forecast Future Energy Demand and Load Profile

4.7.1 General Assumptions

The Consultant estimated the future energy demands and developed the corresponding future load profiles based on the assumptions for energy demand forecast and additional appliances as shown in Table 19. The assumptions can be divided into 3 parts which are:

1. Residential household growth
2. Specific appliance growth (quantity growth)
3. Power consumption growth

It has to be noted that all of the growth assumptions are cumulative calculation.

Table 19: Assumptions for energy demand forecast

Item	Growth description	Y1-Y5	Y6-Y10
Residential household growth			
Residential type I (will buy new TV)	Decreasing 1 household/year	-1 household/a	
Residential type II	% of type **II** in previous year + residential type **I** (buy new TV)	1.5% p.a.	
Residential type III	% of type **III** in previous year	1.5% p.a.	
HH+Shop	Steady (no growth)	0	
HH+Shop+Restaurant	Steady (no growth)		
HH+Shop+Motorbike/boat repair shop	Steady (no growth)		
Specific appliance growth (quantity growth)			
Washing machine	% of total households	2.5% p.a.	1% p.a.
Iron	% of total households	1%	
Rice cooker	% of total households	4% p.a.	2.5% p.a.
Fridge	% of total households	4% p.a.	3% p.a.
Pump	% of total households	1% p.a.	
Speaker	% of total households	1% p.a.	
Blender	% of total households	1.5% p.a.	1% p.a.
Laptop	% of total households	2.5% p.a.	2% p.a.
Desktop computer	% of total households	1% p.a.	0.5% p.a.
Power consumption growth			
Fan power consumption	% of total residential households' fan power consumption	4% p.a.	2% p.a.
School	% of power consumption	3% p.a.	
Health centre	% of power consumption	2% p.a.	
Mosque	% of power consumption	2% p.a.	
Street lights	% of power consumption	0.5% p.a.	

Furthermore, Table 20 below shows the assumptions for future appliances during year 1-5 for school, health centre and mosque made by GIZ to estimate the future demand and to developing the corresponding load profiles.

Table 20: Future appliances assumptions for energy demand forecast during year 1-5 for School, Health centre and Mosque

Item	No. of future appliances		
	School	Health centre	Mosque
Lighting	40	2	5
Radio	3	0	0
Fan	10	1	2
Phone	10	1	0
TV	5	0	1
Rice Cooker	3	0	0
Blender	3	0	0
Computer	5	0	0
Speaker	5	0	1
Fridge	6	3	1
Iron	2	1	0
Pump/Motors	2	0	0
Washing Machine	3	1	0

4.7.2 2018, 2022 and 2027 Results

Figure 24 shows the estimated values for the future energy demand. The values were estimated based on the assumptions which have been defined in Chapter 4.7.1.

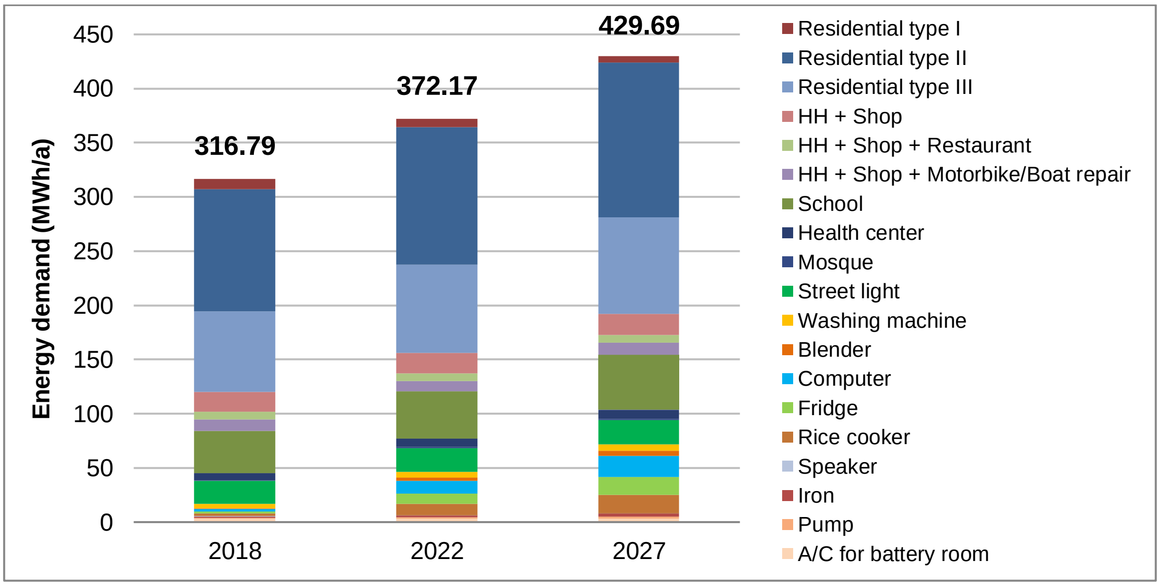


Figure 24: Future estimation of energy demand

To implement the grid transmission line covered all households, taking distribution losses of 10% into account, the future energy generation delivered by the hybrid power plant is summarized in Table 21.

Table 21: Future estimated amount of generated energy by hybrid power plant

Data	2018	2022	2027
Gross generation of hybrid power plant	351.95	415.29	477.43

4.7.3 Results of Peak Load Forecast

The Consultant takes the following daily peak load forecasts for the next ten years into account. As it could be seen in Figure 25, the future load profiles were estimated based on monthly average values. To simulate more realistic values, the random variability inputs[1] of day-to-day ≈ 5% and a time step ≈ 5% were assumed in HOMER simulation. The hourly load demand will be automatically generated by HOMER.

Based thereon, the resulting peak powers are listed in Table 22.

Table 22: Summary peak load forecast

Data	Average power (P_{avg})[2]	Peak power (P_{max})	P_{max}/P_{avg}	Peak power (used in HOMER simulation)
2017[3]	29.59	37.39	1.26	-
2018	63.10	79.74		80.29
2022	75.18	95.01		94.74
2027	86.65	109.50		108.92

4.7.4 Developed Load Profiles in 2018, 2022 and 2027

The developed future load profiles are shown in Figure 25. The load profiles were implemented in the HOMER simulation considering the random variability as mentioned above.

[1] These values are to add randomness to the load profile to make it more realistic, however, the total energy and average power are not modified.

[2] This average power is considered only in March, 18:00-22:00.

[3] The data in 2017 is from measured data of 173 households in March.

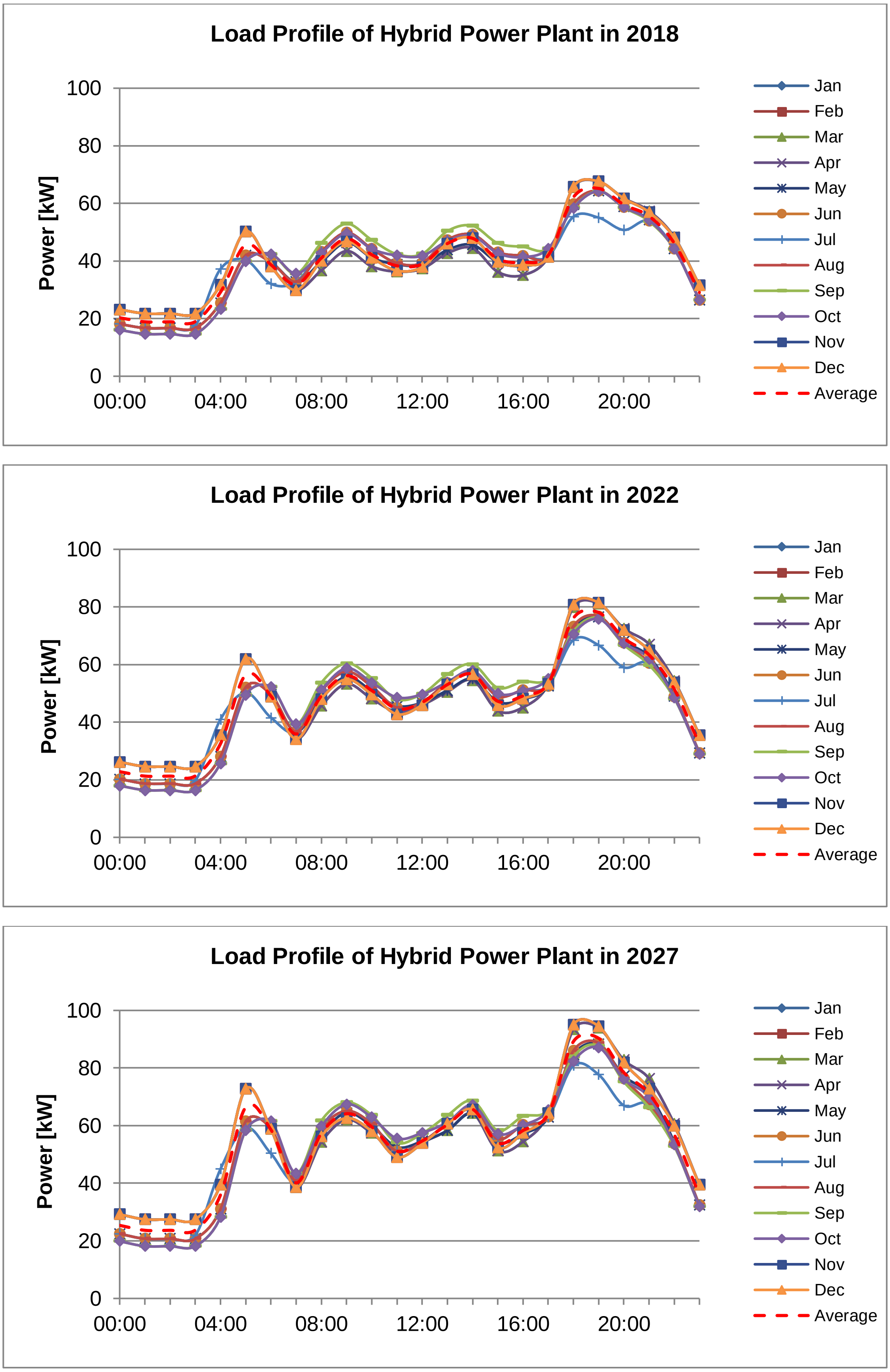


Figure 25: Developed load profiles in 2018, 2022 and 2027

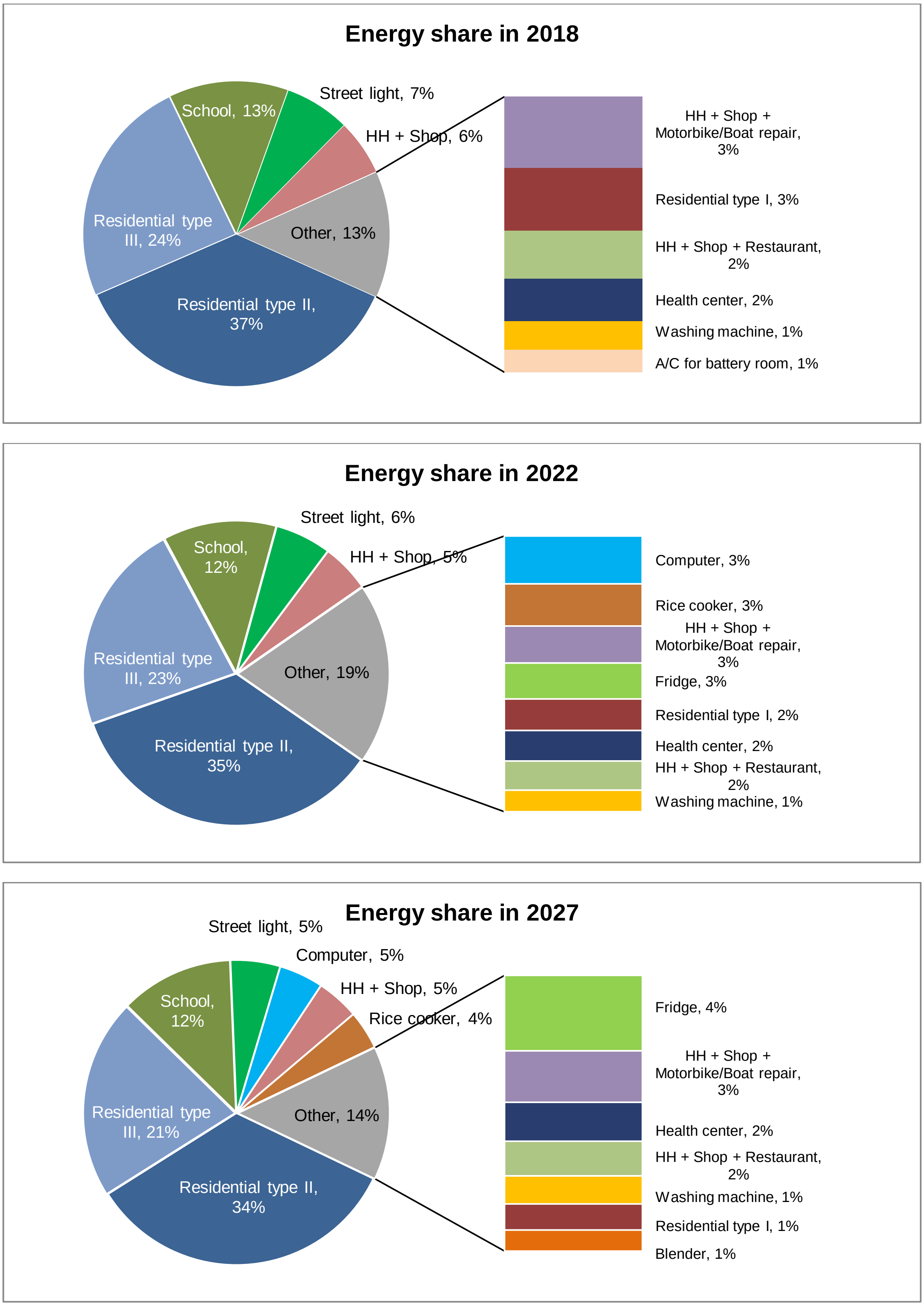


Figure 26: Energy share in 2018, 2022 and 2027 (only the values above 1% are shown)

5 HYBRID SYSTEM DESIGN AND ENERGETIC SIMULATION

5.1 Sizing and Simulation Tools

To size, simulate and optimize the hybrid system of Mak Noi Island, the HOMER Pro® version 3.9.1 was used. HOMER (Hybrid Optimization Model for Multiple Energy Resources) is a commonly used simulation software to design renewable hybrid micro grids for on- and off-grid application. Also, the software will evaluate and optimize the technical and economic feasibility of a large number of technology options. For a more flexible and powerful economic optimization and financial calculation, the Consultant used an in-house developed Microsoft-Excel-based calculation tool.

5.2 System Architecture and Methodology of Operation

Figure 27 shows the schematic system architecture of future hybrid system of Mak Noi Island. The hybrid system consists mainly of the following components:

- Diesel generators
- PV power plant including string inverters
- Battery storage system including grid forming battery inverters and hybrid system controller

The detailed arrangement of the components and its specific capacities are shown in the Single Line Diagram (SLD) in Appendix 5 and are further discussed in the following chapters.

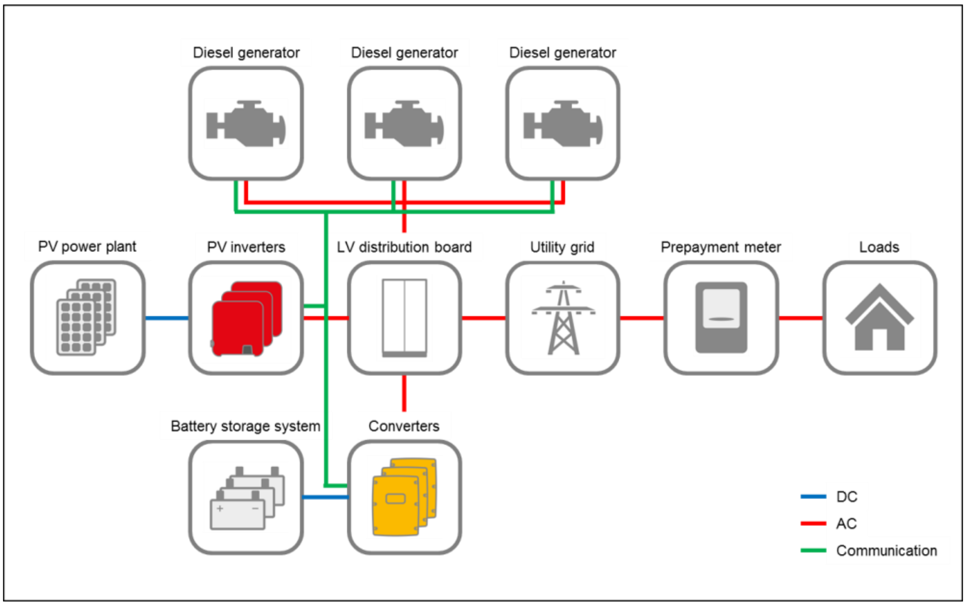


Figure 27: System architecture hybrid system the Island

Figure 28 illustrates the principle of operation of the hybrid system of the island. During the day the output power of PV system covers the whole load and generates sufficient surplus energy to fully recharge the battery (SOC_{max} = 100%).

During the evening peak hours (~18:00-23:00), the diesel generators are forced to run, and the generator, when technical possible, runs at its rated capacity (load factor ~80%) as shown in Figure 37. This also generates surplus energy to charge the battery up to the defined SOC. Furthermore, whenever the energy feeding from the PV system or the battery is not sufficient to cover the load, the diesel generators will be activated running at its rated capacity to cover the remaining load and create surplus energy to charge the battery.

This methodology is called Cycle Charging ("CC"). The benefit of CC operation method is to reduce the operating hours of diesel generators at low load factor (below 50%) significantly, as the generator is always running at its rated capacity. With CC, the shared generated energy by the diesel generator will increase and total renewable fraction consequently is lower.

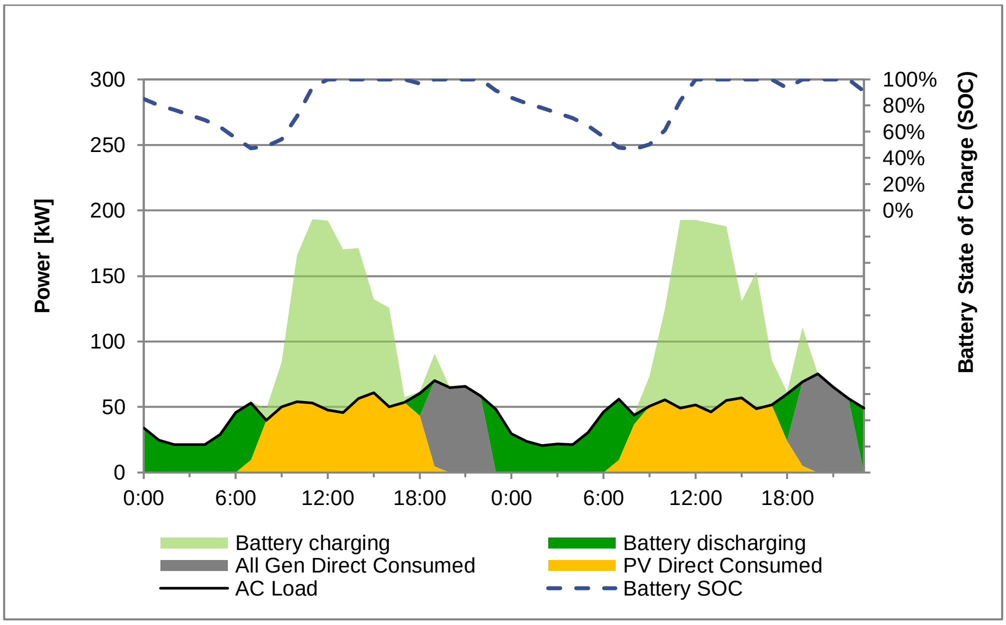


Figure 28: Operating methodology hybrid system

An alternative to CC approach is called "Load Following" (LF). This means, a generator produces only sufficient power to serve the load and does not charge a battery. As a result, the LF operation method provides a higher renewable fraction (lower demand of conventional fuel), which it is a benefit of this operation method. However, the operating hours of diesel generator at low load factor (below 40%), e.g. bad sunlight day, would be higher.

The Consultant has simulated both scenarios and recommends the operation methodology "Cycle Charging" for Mak Noi Island to achieve the lowest Levelised Cost of Electricity ("LCOE"). Moreover, higher generator operating duration at low load factor would be higher under LF operating method, which this could shorten the generator life time. It notes that the renewable fraction of both CC and LF are about equal.

To control of the hybrid system, there are two common types of communication systems:

1. The heart of the hybrid system is the battery inverter together with the hybrid system controller. The battery inverter is the grid forming unit, providing frequency and voltage. The hybrid system controller communicates in a separate network (see Figure 27) and is generally responsible for the balance between the load and the hybrid system components and shall ensure grid stability even in critical situations. The controller communication is based on pre-defined and component specific set-points. For instance, the controller would switch on the diesel generators to provide the required power, once the PV system and battery outputs are no longer sufficient to supply the current energy demand.

2. Another way of communication between battery and PV system is the so-called "frequency droop control". This means, the battery inverters uses only the frequency as a communication medium to control the output power of the PV inverters. This solution avoids additional communication cables between battery inverter and PV inverter making the hybrid system controller, which it is less complex in terms of communication units. However, the frequency droop control is usually used within smaller and less complex systems (PV system capacity below 300 kW_p) and is therefore not recommended for Mak Noi Island.

5.2.1 Diesel Generator

The main objectives of sizing the diesel generator are:

- to select the right size which will be sufficient to provide the required power during the average peak load hours in the evening,
- to limit the number of operating hours

Figure 29 shows the specific consumption curves for various diesel generators. The diesel generator operates ideally above 50% of its rated capacity, to reduce the specific diesel consumption per generated megawatt-hour. Frequent undercutting of this threshold value may impair the diesel generator and lead to higher maintenance effort and consequently to a limitation of its average operation lifetime. Therefore the aim during simulation and sizing was to increase the operating hours above 50% and to operate the diesel generator in an optimal range of above 50% as well.

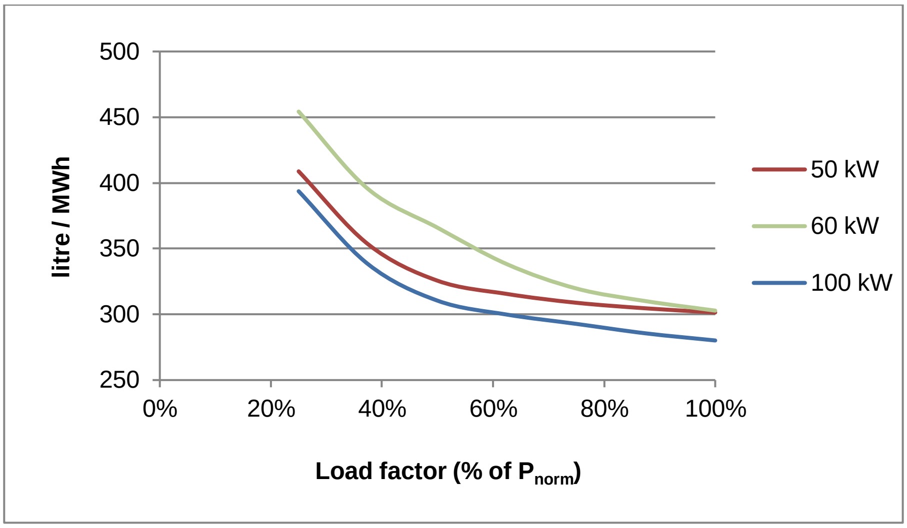


Figure 29: Specific consumption curve for different size of diesel generator[1]

The optimized diesel generator capacity, for the case of the island has been identified to be 60 kW (75 kVA) considering a power factor of 0.80. In the first year of operation, one generator should almost be sufficient to serve the load during the average peak load hours in the evening. In case the output power will be no longer sufficient, the second generator will be switched on and they share the load. In the later years, the load will increasingly require the second generator. It has to be noted that the third generator represents a backup, in case of a failure or maintenance demand.

Currently, the diesel generators were controlled manually by the locals. In the future hybrid system, an automatic mode will be implemented to ensure the required grid stability.

The main characteristics are summarized in Table 23. Most of the parameters were implemented and considered in the HOMER simulation. But it needs to be mentioned, that it is not possible to define the power factor or the overload capacity in HOMER itself.

Table 23: Main characteristics of diesel generators

Parameter	Value
Number of generators	3
Application class (according to ISO-8528-1)	Prime Power (PRP)
Operation strategy	Load sharing (if necessary during peak load hours)
Generator size	60 kW (75 kVA)
Power factor (cosφ)	0.8
Minimum load ratio	30%
Possible (short-term) overload capacity	10%

[1] Source: Generac diesel generator datasheet

Parameter	Value
Lifetime (operating hours) before general revision or replacement	20,000 hrs
CO_2 emission (diesel fuel)	2.64 kg/l

5.2.2 PV/Battery Sizing Optimization

The size of the PV power plant was optimized according to the following criteria:

- The output power during an average day with average solar irradiation must be enough to cover the daytime load and further to create sufficient surplus energy to fully recharge the batteries
- PV system excess energy should not exceed 40%

For the battery, the Consultant considered Li-ion technology and took no further technology such as lead-acid based battery into consideration. The capacity of the Li-ion based battery was optimized according to the following criteria:

- The amount of energy is usually necessary to cover the load during the night and early morning hours,
- In combination with the daily direct consumption of PV energy, the hybrid system shall achieve an annual renewable fraction of more than 60% considering the future estimated energy demand in 2018, and
- The hours of the battery operating at SOC more than 20% shall be increased to extend the battery’s lifetime

To achieve the above criteria the range of PV capacity, 250-300 kWp, and battery capacity, 420-450 kWh, has been simulated by HOMER to show the sensitivity of the LCOE compared to installed capacity. Figure 30 shows the LCOE of the hybrid system in various sizing’s of PV/Battery capacity compared with the lowest LCOE scenarios, the optimum LCOE value for PV/Battery is 270 kWp / 420 kWh.

While a financial optimum appears at these levels, there are technical issues surrounding a battery capacity of 420 kWh which become increasingly apparent from year 10 onwards. The issue is that the battery bank becomes increasingly unable to serve the morning load, before the PV can provide sufficient power. As of this the generator is required to start and the frequency of the start-stop operation of the generators increases as shown in Figure 31. To avoid any damage from start-stop operation of the generators the Consultant recommends to increase the battery bank capacity by 20 kWh. The LCOE varies only slightly from the optimum while mitigating any damage that could be incurred from stop-start operation. Therefore, the Consultant recommends PV/Battery capacity of 270 kWp / 440 kWh to be installed.

However, at year 10 a design review should be triggered to assess the actual trends in load profile, to expand the system size and to maintain the lowest LCOE while at safe and stable operation. Nevertheless, the Consultant would recommend to upgrade the PV to 300 kWp in year 10 because this can reduce the frequency of the start-stop operation of the generators.

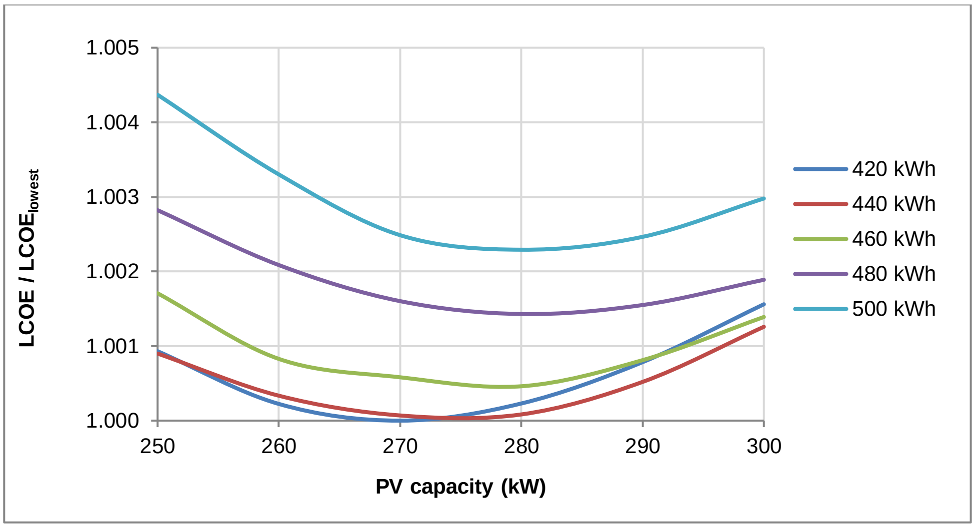


Figure 30: LCOE / $LCOE_{lowest}$ of various sizing of the PV/Battery capacity

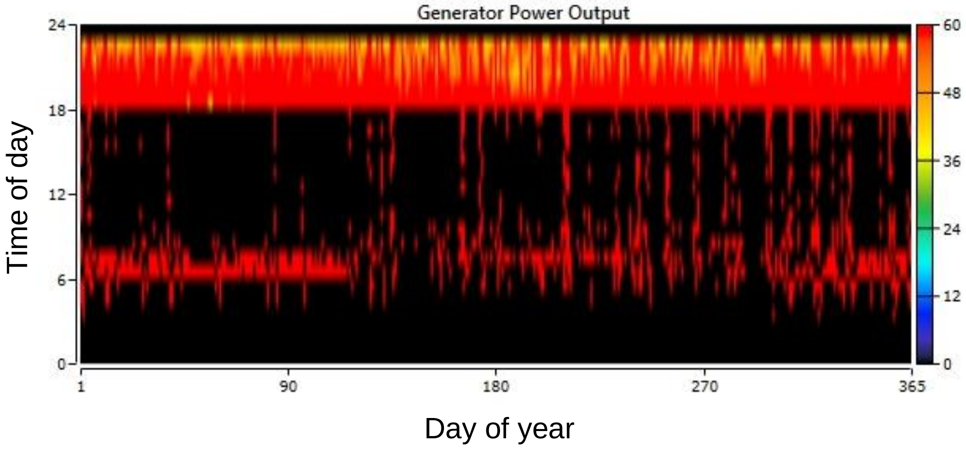


Figure 31: Generator#1 operating hours in year 10 with PV/Battery of 270 kW / 420 kWh system (source: HOMER simulation)

Table 24 summarizes the main parameters of the PV power plant. As described in chapter 3.5, Area 1 and Area 2 do not met the required area of the designed PV power plant, i.e. 270kW. Area 3 only, shall be selected to install PV power plant.

Figure 32 shows an overview of the designed PV power plant. Power station building for batteries and diesel generators is also included in the figure. Alternatively, power station building could be constructed nearby the pond area as described in Chapter 3.5. If there is no area constraint or ample area, however, the Consultant would recommend to construct the power station building nearby the PV power plant to minimize the costs for connecting this building to PV power plant.

More information are stated in Appendix 5 (Single line diagram of the hybrid system) and Appendix 6 (PV power plant layout).

Table 24: Main characteristics of PV power plant

Parameter	Value
Total PV capacity (DC, STC)	270 kW
Total inverter capacity (AC)	4x60 kW
DC/AC ratio	1.13
Power factor (cosφ)	0.8

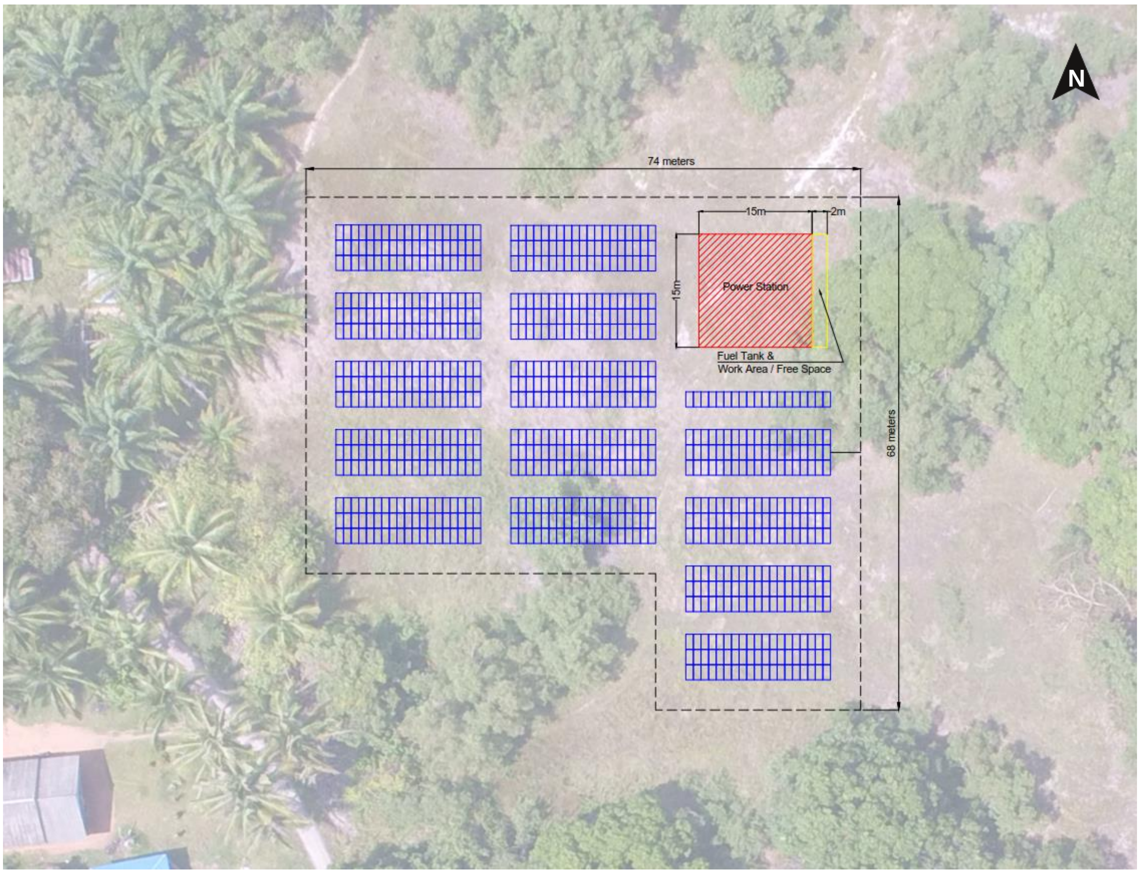


Figure 32: PV power plant layout (see Appendix 6)

Table 25 summarizes the main parameters of the battery storage system

Table 25: Main characteristics of battery storage system

Parameter	Value
Technology	Li-ion
Total battery capacity	440 kWh

Battery inverter capacity	90 kW
Roundtrip efficiency	~90%
Maximum C-Rate (charge/discharge)	1.0C / 1.0C
Maximum DOD (SOC_{min})	90% (10%)
Estimated shelf lifetime (according to manufacturer information)	30 years (Performance Warranty 10 years and Product Warranty 5 years)
Number of cycles @ DOD 100% EOL 70%	~6,000 cycles
Room conditions for battery storage	▪ An air-condition system must be installed in the battery storage room to prolong the battery lifetime ▪ Battery storages shall be housed in specially made cabinet rated for salt mist protection.

5.2.3 Prepayment Energy Meter

The Consultant proposes the usage of prepayment energy meter on the island due to its benefits for the customers and electricity suppliers. A prepayment meter is a special type of energy meter that can be installed in domestic properties. With a prepayment, or 'pay as you go' tariff, customers pay for their energy before they consume. Users can monitor their usage unit of electricity and also control their usage against their budget.

The payment method is flexible for users. The supplier will receive payment regularly. There is no need to send a person to check on energy meter and to collect the payment from users. This also prevents human error from meter reading.

<u>Prepayment process</u>

Each household is encouraged to register at the electricity supplier spot; the electricity supplier shall install prepayment energy meters for each household. Meters shall be installed visibly to avoid any fraud, i.e. bypass. The electricity supplier shall install a central recharging unit to top-up and provide an energy credit. A user can then use an electricity until a warning signal appears at the energy meter to buy more energy credit.

<u>System Setup</u>

The Consultant recommends to install a prepayment energy meter in outdoor area because this will avoid bypassing the meter. With regard to the safety, a fuse, residual-current device (RCD), surge arrestor, shall comprise a high level of safety and installation quality according to international installation standards.

<u>System Main Functions</u>

- Anti-tampering functions against reverse connection, magnetic and meter/terminal cover open detection

- Emergency credit management
- Two-way communication
- Internal relay for load control
- Max demand management
- Event recording including programming, reverse connection, power failure and tampering
- Import and export active / reactive energy measurement optional
- LCD display item configurable
- Backup battery for energy display when powered off

5.2.4 Transmission Line Recommendations for the Hybrid System

To implement the hybrid system covered all households on the island, grid transmission line shall also be investigated in this study. Since the island is large, approx. 2.5 sq.km, and the locals living spread out around the island, the current low voltage transmission line is not feasible for the hybrid system. A high voltage transmission line with 3 phases is therefore technically recommended to minimize the voltage drop in the line. Consequently, 22kV transmission line shall be considered. The poles shall be made of concrete.

It has to be noted that the 33kV submarine cable planned by PEA might be built and connected the island to the mainland in the future. Therefore, 33KV transmission line might be implemented instead of 22kV, however, the transmission costs will be increased for 33kV system. A close communication with PEA is recommended.

5.3 Other Inputs used in HOMER simulation

It shall be noted that the specifications for the inputs for HOMER simulation are presented in Appendix 2.

5.3.1 Meteorological Data

For the calculation of the expected annual PV yield, the Consultant used the weather data set of Meteonorm 7. The data is shown in the following graph. It shows the monthly average values of global horizontal irradiation (GHI), diffuse irradiation (DHI), ambient temperature.

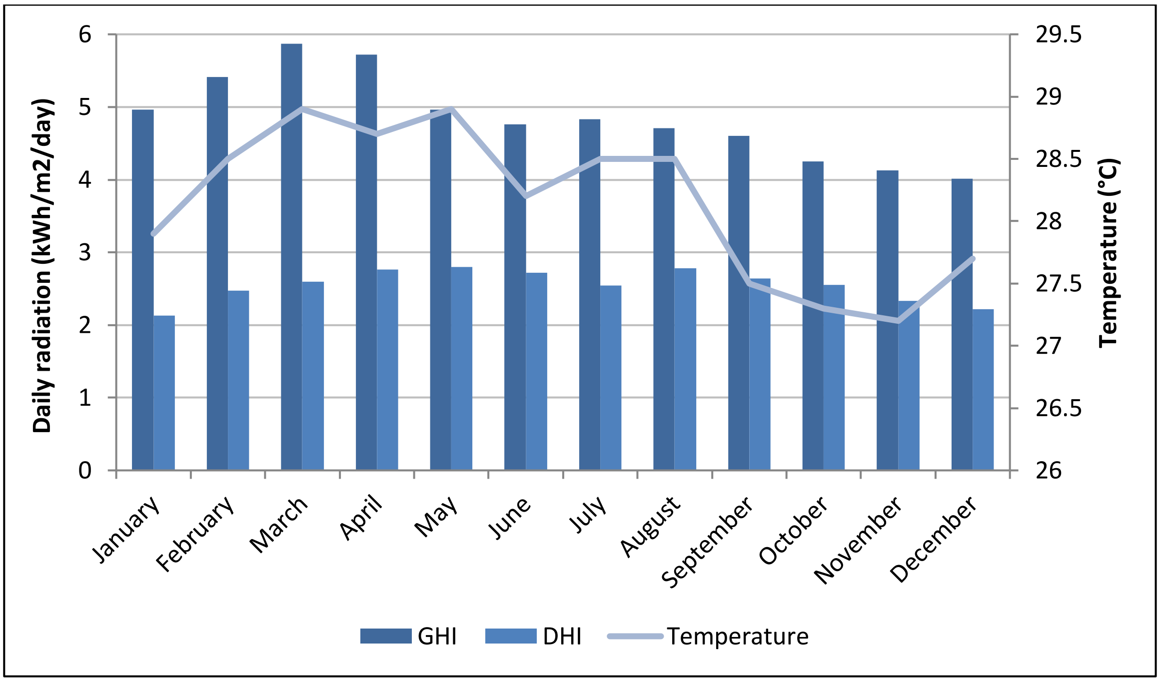


Figure 33: Meteorological data for HOMER and PVSyst simulation

5.3.2 Load Profiles

The load profiles used in HOMER are according to Chapter 4.7.4.

5.4 Interpretation of Simulation Results

The following chapter presents the energetic results of the HOMER simulation. To compare the result with the conventional power generation, a 100% diesel generator scenario was simulated. Therefore, two scenarios were simulated considering in total three different load profiles (2018, 2022 and 2027).

5.4.1 Simulation Summary: Reference Scenario with 100% Diesel

Table 26: Summary of simulation results reference scenario with 100% Diesel

Reference scenario: 100% Diesel	Unit	2018	2022	2027
System Parameters				
Total capacity diesel generators	kW	180 (3x60 kW)		
Number of diesel generators	Unit	3		
Homer simulation output				
Total energy production (demand)	kWh/a	351,955	415,291	477,434
Total diesel consumption	l/a	101,452	117,538	134,912
Specific diesel consumption	l/MWh	288	283	283
Total diesel operating hours	hr/a	9,502	10,455	11,950
Operation hours below 50%	%/a	23	18	13
CO_2 emission	t/a	268	310	356

5.4.2 Simulation Summary: PV/Diesel/Battery hybrid system

The main energetic simulation results of the Diesel/PV/Battery hybrid system are summarized in Table 27. In first year of operation (2018), a renewable of 62% could be achieved. Due to the increasing load over several years, this value will be reduced to approximately 53% in the next ten years (2027). Compared to the 100% Diesel reference scenario in Table 26, the diesel consumption as well as the diesel operating hours can be reduced. Moreover, due to the limitation of diesel operating hours below 50%, the specific consumption of the diesel generators in the hybrid system is acceptable. Harmful annual CO_2 emission could be also reduced.

Table 27: Summary of simulation results Diesel/PV/Battery hybrid system

PV / Diesel / Battery Hybrid System	Unit	2018	2022	2027
System Parameters				
Total capacity diesel generators	kW	180 (3x60 kW)		
Number of diesel generators	Unit	3		
Total PV capacity	kW_p	270		
Total battery capacity	kWh	440		
Usable total battery capacity (SOC_{min} 10%)	kWh	396		
Battery inverter capacity	kW	90		
Homer simulation output				
Total energy production (demand)	kWh/a	351,955	415,291	477,434
Share Diesel	kWh/a	133,807	180,932	225,041
Share PV and battery	kWh/a	218,147	234,359	252,393
Excess PV energy	kWh/a	153,479	121,960	91,976
Total diesel consumption	l/a	36,355	49,285	60,579
Reduction of diesel consumption (compared to diesel reference scenario)	l/a	65,097	68,253	74,333
Specific diesel consumption	l/MWh	272	272	269
Renewable fraction (PV and battery)	%	62	56	53
Excess PV energy	%	40	32	25
Total diesel operating hours	hr/a	2,767	3,792	4,428
Operation hours below 50%	%/a	1	0.34	0
CO_2 emission	t/a	96	130	160
Reduction of CO_2 emission (compared to diesel reference scenario)	t/a	172	180	196

5.4.3 Energy Distribution 2018-2047

Figure 34 shows the energy distribution curve over the whole project lifetime. Due to the increasing energy demand from 2018-2027 and considering an annual PV degradation of 0.5%, the renewable share is decreasing compared to the total energy production. After 2027, the annual energy demand was estimated as constant and the renewable share is reduced annually by 0.3% in average. However, there is an increase on renewable share on 2025, 2032, 2039 and 2046 because of the replacement of the battery storage.

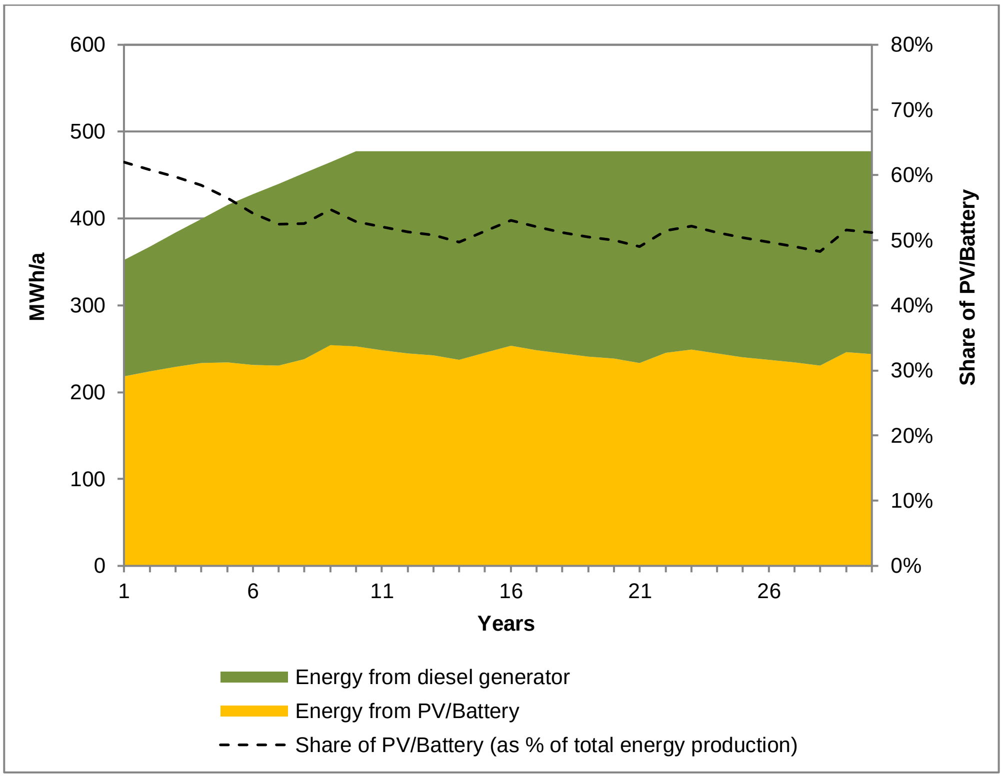


Figure 34: Energy generation and distribution curve 2018-2047

5.4.4 Energy Generation and Consumption Curve for a Typical Week 2018, 2022 and 2027

Figure 35 shows the energy generation and consumption curve for a typical week in 2018, 2022 and 2027. Furthermore, the related curve of battery's SOC is shown in the upper part of each figure.

During a "perfect" day (see in Figure 35: day 3, 4, 5, 6 and 7), the daily energy demand is covered by the PV power plant. The created surplus energy charges the battery during the daytime. The diesel generators generate the required energy during the peak load hours in the evening. In the night and the early morning hours, the battery is discharging.

During a "bad" day (see in Figure 35: day 1 and 2) with less solar irradiation, the produced energy from the PV power plant is not sufficient to serve the daily load and to recharge the battery. Therefore whenever required, the diesel generators are forced to run and to generate the missing energy. The operation hours during the "bad" days lead to the amount of operating hours in the early morning time, which could practically not be avoided.

Due to the increased energy demand in year 2027 (see in Figure 35: typical week 2027), the battery is no longer able to store enough energy during the day and to cover the whole load during the night or the early morning hours. As a result, the diesel generators are forced to generate the missing energy. As stated previously, at this point a design review is necessary to consider expansion of the renewable systems capacity.

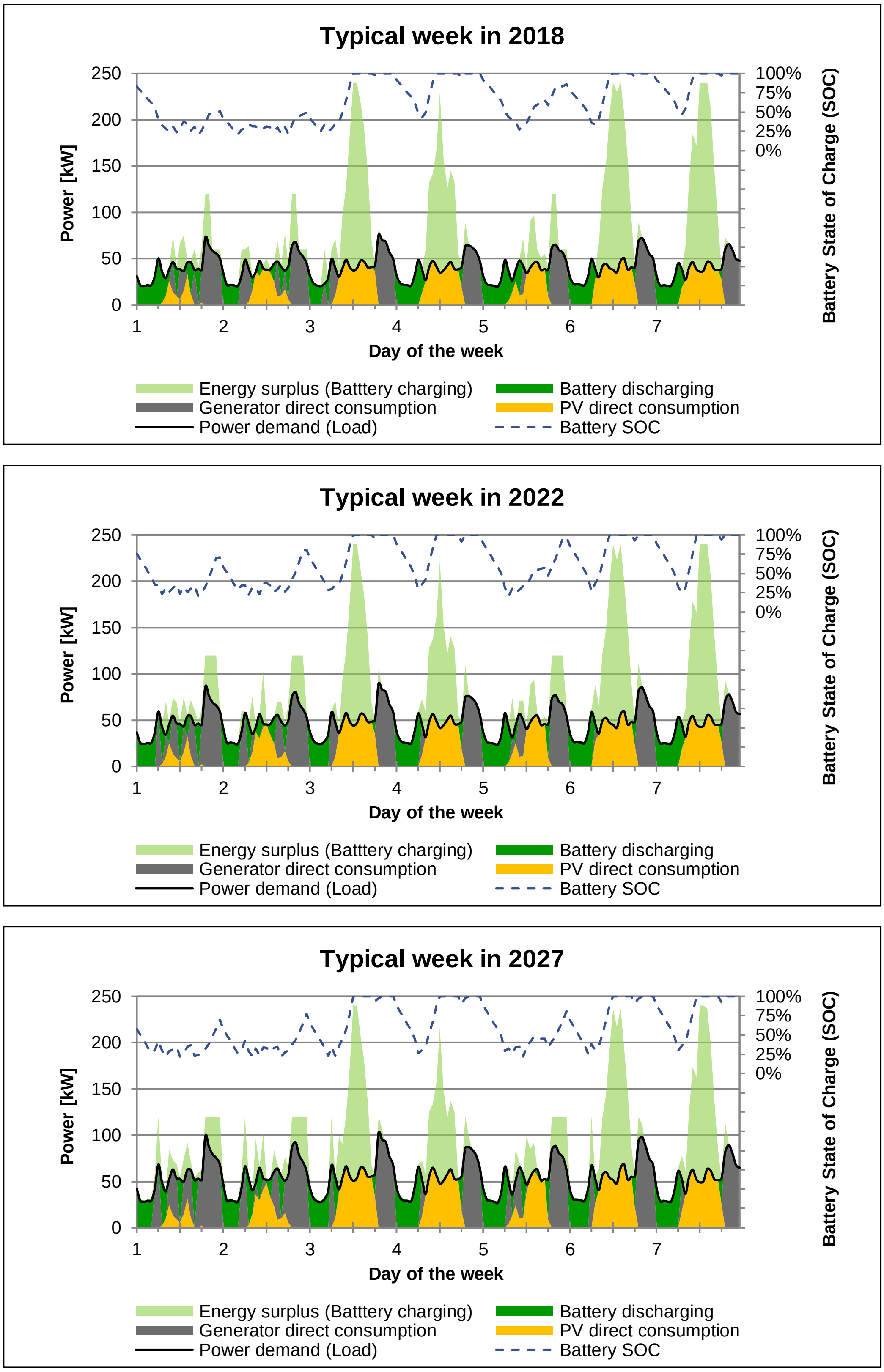
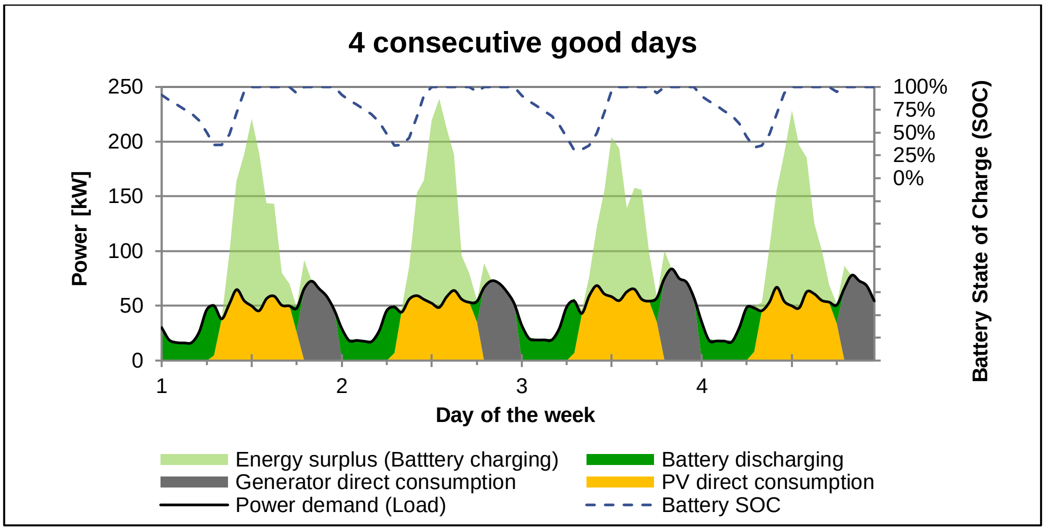


Figure 35: Energy generation and consumption curve for a typical week in 2018, 2022 and 2027



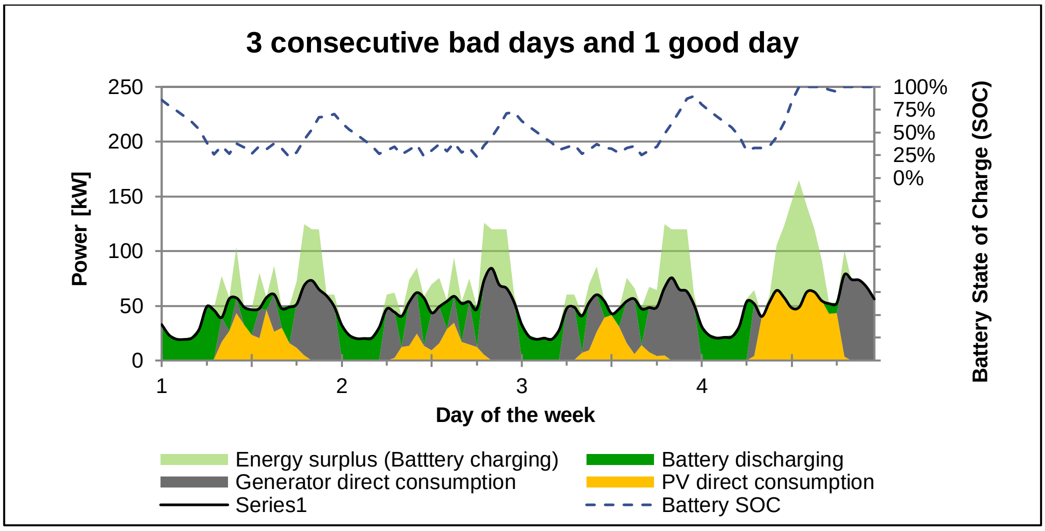


Figure 36: Energy generation and consumption curve for consecutive good days and bad days

5.4.5 Load Factor Curve 2018, 2022 and 2027

Figure 37 shows the number of operating hours running at different load factors (% of its rated capacity). The graphs show clearly that the majority of operating hours are running at full capacity (100%) with operation at low load factors kept to a minimum. The advantage for the operation methodology of CC is described in more detail in Chapter 5.2, the operating hours at low load factor (below 50%) are significantly reduced. The specific figures are summarized in the following table.

Table 28: Summary of generator operating hours below 50%

Parameter	Number of hours operating below 50%		
	2018	2022	2027
Operating hours	8 hours	6 hours	0 hour
Percentage	0.77%	0.34%	0%

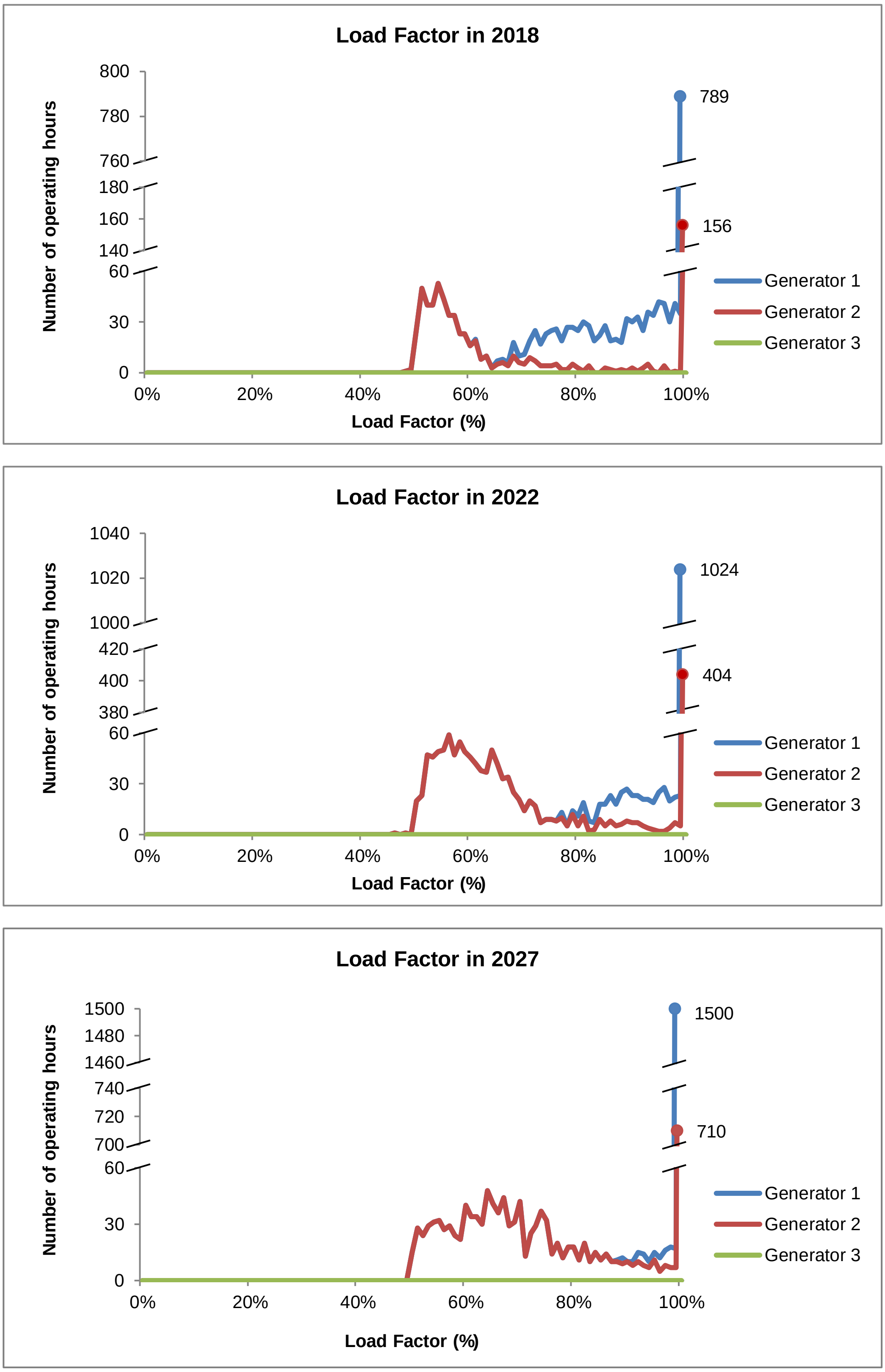


Figure 37: Load factor curve generators in 2018, 2022 and 2027

6 CALCULATION OF LEVELISED COST OF ELECTRICITY

This chapter presents the calculation of the Levelised Cost of Electricity ("LCOE") for each investigated scenario. The two scenarios are:

- Reference scenario with 100% diesel
- Diesel/PV/Battery hybrid system

The initial investment costs and the required costs for operation as well as maintenance were estimated for each system on a pre-feasibility level and may have a typical error-margin in solar-PV of -15% to +20%. The cost estimation presents the input for the subsequent LCOE calculation.

6.1 Calculation Formula

The calculation of the LCOE is based on the following formula:

$$LCOE = \frac{\sum_{n=1}^{N} \frac{I_n + F_n + O\&M_n}{(1+d)^n}}{\sum_{n=1}^{N} \frac{Q_n}{(1+d)^n}}$$

- I_n Investment or Capital Expenditure in year n
- F_n Financing costs
- $O\&M_n$ Operating & Maintenance costs or Operating Expenditure in year n
- Q_n Net electricity production in year n
- d Discount rate of 6 %
- n Analysis period of 30 years has been taken into consideration

6.2 Main inputs and assumptions

The most relevant inputs and assumptions which are used for the LCOE calculation are presented in this section.

6.2.1 Economic Project Lifetime

The Consultant considers an economic project lifetime of 30 years. The calculation starts in year 2018 and ends in 2047.

6.2.2 Exchange Rate

All prices are stated in Thai Baht (THB) or in United States Dollar (USD). The considered exchange rate in the study was taken on 8th June 2017: 34.04 THB/USD (source: www.bot.or.th).

6.2.3 Inflation Rate

The inflation rate is assumed to be 2.0%, which is the mean of Thailand inflation rate of the last 10 years (source: https://tradingeconomics.com/thailand/inflation-cpi).

6.2.4 Diesel Escalation Rate

The Consultant used an initial price and annual growth rates to calculate the impact of the diesel fuel price on the LCOE. The diesel price in Thailand was approximately 0.72 USD/litre (24.59 THB/litre) based on price structure of petroleum product dated 8th June 2017 provided by Energy Policy and Planning Office (EPPO). The price consists of the refinery price plus handling, marketing, tax as well as oil fund costs. The refinery price was 0.42 USD/litre (14.41 THB/litre) and presents the basis for the future escalation. The costs for handling, marketing, tax and oil fund were approximately 0.30 USD/litre (10.18 THB/litre) and were assumed as constant, subject to inflation (source: www.eppo.go.th). During the site visit, the Consultant was informed by the locals with respect to the diesel delivery cost of approx. 0.0059 USD/litre (0.2 THB/litre).

To define the annual growth rate, forecasts of the crude oil price (COP) were applied. In the last ten years the correlation coefficient of diesel and crude oil (petroleum) price was 0.927, indicating that the diesel price strongly depends on COP and the application of COP forecasts to project diesel prices is valid (source: www.indexmundi.com).

World Bank, Economic Intelligence Unit (EIU) and International Monetary Fund (IMF) projected crude oil prices in 2017. World Bank forecasted a COP annual growth of approximately 2.9% within the next 10 years, and EIU predicted a COP annual growth of approximately 3.3% within the next 5 years. However, IMF forecasted no growth of COP till year 2022. The following table provides a brief overview of projected COP annual growth rates and projection periods.

Table 29: Overview of crude oil forecasts

Institute	Project annual growth	Projection period
World Bank	2.9%	2017-2030
EIU	3.3%	2017-2021
IMF	0%	2017-2022

Based on these forecasts, COP annual growth rate of IMF was considered too optimistic, therefore, it has not been applied to the calculation. The Consultant hence conservatively applies the average COP annual growth rate of World Bank and EIU for the financial calculation, with an annual diesel price escalation of 3.1%.

6.2.5 Discount Rate

The discount factor was assumed to be 6.0%.

6.2.6 Project financing

The Consultant received the information from GIZ that the project shall be 100% equity.

6.2.7 Degradation Rates

The annual degradation rate for PV was assumed 1.8% for year 1 and 0.5% per year afterwards, which presents common values warranted degradation rates for polycrystalline-based PV modules.

6.3 Capital and Operating Expenditure

6.3.1 Capital Expenditure

The investment costs also known as Capital Expenditure (CAPEX) were estimated on a feasibility level. The prices are based on a combination of the Consultant's experience from previous projects and budgetary offers from several product manufacturers.

Table 30 summarizes the estimated CAPEX costs for the 2 scenarios. The detailed estimated costs for each system component could be found in the following sections.

Table 30: Summary of total initial CAPEX for different scenarios

Scenario	Parameter	Value
100% diesel	Initial CAPEX Diesel	45,000 USD
	Initial CAPEX Other	447,100 USD
	Total CAPEX	**492,100 USD**
Diesel/PV/Battery hybrid system	Initial CAPEX Diesel	45,000 USD
	Initial CAPEX PV	351,000 USD
	Initial CAPEX Battery	316,800 USD
	Initial CAPEX Other	447,100 USD
	Total CAPEX hybrid	**1,159,900 USD**

6.3.1.1 CAPEX Diesel Generator

The estimated investment costs of 250 USD/kW for the new diesel generators include all required mechanical and control equipment, as well as installation costs. The transportation costs are also included. Additionally, the estimated CAPEX is based on the adaptation of the existing house. Thus, no additional civil costs were assumed.

Table 31: CAPEX diesel generators

Component	Parameter	Value
Diesel generator	Installed Capacity	180 kW (3x60kW)
	Initial CAPEX per unit	250 USD/kW
	Initial CAPEX	45,000 USD

6.3.1.2 CAPEX PV System

The calculated initial investment costs for PV are approximately 1,300 USD/kW and includes for the main components such as PV modules, string inverters, combiner boxes, DC and AC cabling, transformer station and mounting structure. In addition, installation and delivery costs are included.

Table 32: CAPEX PV system

Component	Parameter	Value
PV system	Installed Capacity	270 kW
	Initial CAPEX per unit	1,300 USD/kW
	Initial CAPEX	351,000 USD

6.3.1.3 CAPEX Battery Storage System

The estimated CAPEX for the battery storage system costs approximately 700 USD/kW. The pre-fabricated containerized solution is based on Li-ion technology contains mainly in battery racks, battery converter, control system, distribution board and air-conditioning. The battery storage prices varies between 400-950 USD/kWh which are based on budgetary offers from several manufacturers. The Consultant selected the budgetary offer of a European manufacturer, which has strong cooperation with the global leading manufacturing of solar inverters.

Table 33: CAPEX battery storage system

Component	Parameter	Value
Battery storage system	Installed Capacity	440 kWh
	Initial CAPEX per unit	720 USD/kWh
	Initial CAPEX	316,800 USD

6.3.1.4 Other CAPEX (Transmission line, prepayment energy meter, powerhouse, land cost)

Since the grid transmission line shall be upgraded to high voltage system for the whole island as mentioned in Chapter 5.2.4. The Consultant considers the prepayment energy meter into the estimation.

For optimal lifetime of batteries and operation of battery inverter/chargers an air-conditioning system must be installed in the battery storage room located in powerhouse. The room shall be well insulated, to avoid the heat and the battery lifetime could be prolonged. The foundation shall be designed for battery weight, additional reinforcement could be expected. For the diesel's powerhouse, an air conditioner system is not required, and additional reinforcement may not be required.

Land costs have not be included in the system CAPEX as the Consultant understands land might be made available for the project.

Table 34: CAPEX (transmission line, prepayment energy meter, powerhouse, land cost)

Scenario	Component	Value
100% Diesel	New transmission line	386,000 USD
	Street Lights	6,000 USD
	Prepayment energy meter	37,500 USD
	Powerhouse building for diesel generator	17,600 USD
	Total other CAPEX	**447,100 USD**
Diesel/PV/Battery hybrid system	New transmission line	386,000 USD
	Street Lights	6,000 USD
	Prepayment energy meter	37,500 USD
	Powerhouse building for hybrid system	17,600 USD
	Total other CAPEX	**447,100 USD**

6.3.2 Operation Expenditures

The costs for operation, maintenance and replacement (Operation Expenditures, "OPEX") were estimated on a feasibility level. Same as for the CAPEX prices, OPEX are based on a combination of the Consultant's experience from previous projects and budgetary offers from several product manufacturers.

6.3.2.1 OPEX Diesel Generator

Table 35 summarizes the estimated OPEX costs for the diesel generators regarding the reference scenario with 100% diesel. In comparison to the hybrid system scenario, the diesel generators operate continuously over the entire year which leads to a higher maintenance effort and significantly increase of necessary replacement intervals.

Table 35: OPEX diesel generators (Reference scenario: 100% Diesel)

Component	Parameter	Value
Diesel generator	Replacement costs (30% of initial CAPEX)	75 USD/kW
	Replacement year (according to HOMER simulation results)	3, 5, 7, 10, 11, 12, 14, 16, 17, 19, 21, 23(2 replacements), 26, 28 and 30(2 replacements)
	O&M costs (labour, maintenance, etc.)	0.11 USD/kWh
	Fuel cost	Refer to section 6.2.4

Table 36 summarizes the estimated OPEX costs for the diesel generators of diesel/PV/hybrid system. Based on the manufacturer's information, an operational lifetime of 20,000 hours has been assumed. After reaching this value, a general revision or replacement needs to be done.

Table 36: OPEX diesel generators (Diesel/PV/battery hybrid system)

Component	Parameter	Value
Diesel generator	Replacement costs (30% of initial CAPEX)	75 USD/kW
	Replacement year (according to HOMER simulation results)	9, 14, 17 and 24(2 replacements)
	O&M costs (labour, maintenance, etc.)	0.11 USD/kWh
	Fuel cost	Refer to section 6.2.4

6.3.2.2 OPEX PV System

Table 37 summarizes the estimated OPEX costs for the PV system. DC/AC ratio is approximately 1.13. The PV installed capacity is 270 kW_p, thus string inverter capacity is 240 kW.

Table 37: OPEX PV system

Component	Parameter	Value
PV System	Replacement costs string inverters	120 USD/kW
	Number of inverter replacements over project lifetime	1
	Resulting inverter replacement costs linear over project lifetime	1,200 USD/a
	General O&M costs	20 USD/kW_p/a
	Resulting general O&M costs linear over project lifetime	5,400 USD/a

6.3.2.3 OPEX Battery Storage System

Reaching the battery's end of lifetime (State of Health below 70%), the battery cells (battery racks) must be replaced. Within the financial calculation, the Consultant considers a reinvestment of the battery as shown in Table 38. The price for the reinvestment based on the future price forecast for Li-on cells estimated within a study by Bloomberg New Energy Finance Institute. In general, Li-on batteries are almost maintenance free. Nevertheless an annual general inspection of the battery storage system by certified staff is highly recommended.

Table 38: OPEX battery storage system

Component	Parameter	Value
Battery storage system	Replacement costs battery cells and battery inverter(s) in year 2033 (based on future estimated Li-ion cell price in year 2030 according Bloomberg New Energy Finance: ~250 $US/kWh)	110,000 USD
	Replacement year (according to HOMER simulation results)	8[1], 15, 22 and 29
	General O&M costs (annual inspections)	5,386 USD/a

6.3.2.4 Other OPEX (Transmission line, prepayment energy meter, powerhouse)

We assume the OPEX of transmission line, prepayment energy meter and powerhouse of approx. 1,500 USD/a.

[1] The battery replacement cost in 8th year of operation is assumed to be 360 USD/kWh (50% of battery CAPEX)

6.4 Financial Calculation Results

6.4.1 LCOE Calculation

LCOE defines the total costs to build and operate the system over its total lifetime 30 years (as per calculation in Chapter 6.1). It includes generation costs and all additional costs such as:

- CAPEX
- OPEX
- Financing costs
- Replacement costs
- Fuel costs

Based on the energetic simulation results, the financial assumptions and estimated CAPEX as well as OPEX costs, the calculated LCOE for each scenario are summarized in Table 40. Detail of the calculation is shown in appendix 3.

To compare with the current electricity price, the current electricity price per kWh was estimated. Based on information received by the locals, each household currently pays about 500 and 600 THB per month based on their energy demand for electricity supplied by the Generator#40 and Generator#41, operated by Mr. Abdullah, during 18:00-22:00 as presented in Table 39. To roughly estimate the number of high load consumer of these grids, the extrapolated number of washing machine according to chapter 4.2.2 shall be considered. Consequently, the number of low load and high load consumers are 112 households and 61 households respectively. According to Table 8, the average daily energy demand is approx. 122.75 kWh/d. Consequently, the electricity price per kWh is around 0.74 USD/kWh (25.15 THB/month).

Table 39: Electricity prices of the grids electrified by Generator #40 and #41

Consumer	THB/month	Number of households	Typical loads
Low load	500	112	Light and TV
High load	600	61	Light, TV and washing machine

The calculated future LCOE for the reference scenario with 100% Diesel is 0.575 USD/kWh (19.56 THB/kWh). The calculated LCOE of the PV/Diesel/Battery hybrid system is approximately 0.482 USD/kWh (16.41 THB/kWh). In comparison with the LCOE's reference scenario, the LCOE of hybrid system is lower by approximately 16%.

Table 40: Estimated LCOE

Parameter	LCOE [USD/kWh]	LCOE [THB/kWh]	Reduction (reference scenario: 100% diesel)
Reference scenario: 100% Diesel	0.575	19.56	Reference
PV/Diesel/Battery hybrid system	0.482	16.41	-16.14%

As already mentioned, the LCOE presents the costs for the whole system over the whole project lifetime. Besides the pure generation costs, LCOE includes all additional costs such as CAPEX for equipment, OPEX, replacement costs and financing costs. The LCOE is typically defined as one single number, representing all costs for the system over the total project lifetime. The way to calculate the considered input parameters of the calculated pure annual generation costs are different. As a result, actual pure generation costs of a specific year cannot be compared to the LCOE. The LCOE is used to compare various generation types over the total lifetime.

6.4.2 Real Generation Costs Calculation

However, the Consultant calculated in parallel to the LCOE the future real annual generation costs on the basis of first approximation, applying linear depreciation of the initial CAPEX for the system-specific components over the project lifetime. The calculation of the real generation costs considers therefore:

- Linear depreciation of initial CAPEX:
  - 30 years depreciation for the PV and the battery storage system (incl. BMS, battery inverter, etc.)
  - Computational calculation based on cycling of the batteries and end of life capacity at 70%
  - 20,000 operating hours for the diesel generators
- OPEX
- Financing costs
- Replacement costs
- Fuel costs

The real generation costs per kWh for the Diesel/PV/Battery hybrid system are calculated in 2018, 2022, 2027 and 2047 as shown in Figure 38. The real generation costs for the Diesel/PV/Battery hybrid system amounts 0.32 USD/kWh (10.89 THB/kWh) in the 1st year of operation (2018). Compared to the 100% diesel reference scenario which are 0.38 USD/kWh (12.94 THB/kWh), the real generation cost of hybrid system is already lower in the 1st year of operation.

Moreover, due to the increasing fuel price and low costs for the renewable energy sources (PV and battery), the deviation significantly increases over the whole project lifetime. The real generation costs for the whole project lifetime in each scenario are presented in Appendix 4.

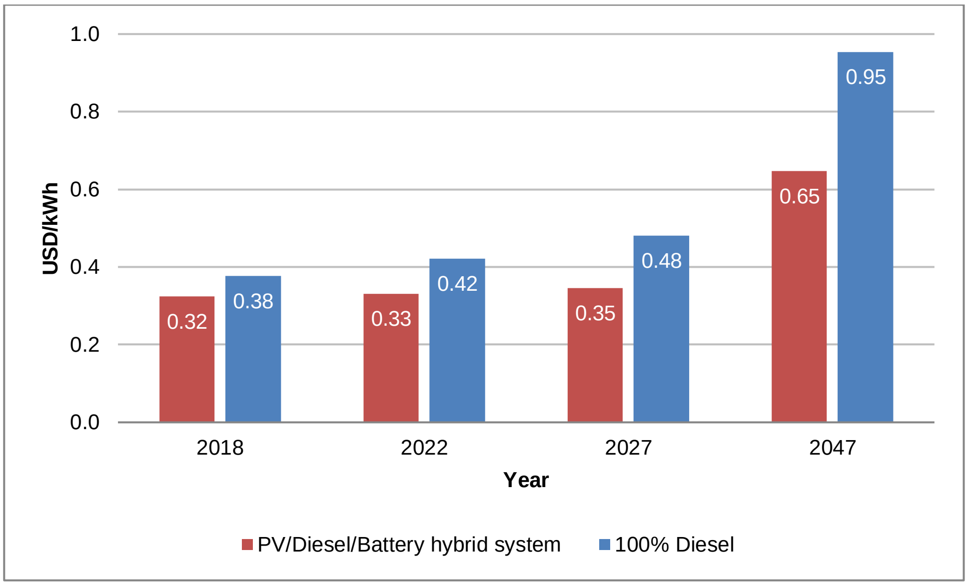


Figure 38: Estimated annual real generation costs in 2018, 2022, 2027 and 2047

The results show that the generation costs of the hybrid system are lower than that of conventional diesel generation provide an attractive economic solution compared to diesel powered generation.

According to the estimated 24-hour residential load profile, including additional appliances in Chapter 4.4.1, the average energy demand per month of each residential household type including additional appliances in 2018 are presented in Table 41.

Table 41: Average energy demand per month of each residential households in 2018

Cluster	Average energy demand (kWh/month)
Residential type I	37.71
Residential type II	71.22
Residential type III	81.58
HH+Shop	125.57
HH+Shop+Restaurant	149.56
HH+Shop+Motorbike/boat repair shop	177.43
Rice cooker	15.46
Fridge	15.08
Washing machine	3.80
Computer	21.85
Iron	4.54

Blender	10.83
Water pump	4.14
Speaker	0.46

In this example, the Consultant selects a real generation cost in 2018, i.e. 0.32 USD/kWh (10.89 THB/kWh), to show the costs or generation for different residential households and appliances as presented in Table 42. Ability to pay and current electricity expenses according to the GIZ Survey are also shown in the table. It can be seen that, for example, if HH+Shop want to buy a rice cooker, fridge, washing machine, computer and iron, the electricity generation cost will be 60.29 USD/month (2,052.27 THB/month)

Table 42: Electricity generation costs, willingness to pay and current electricity expenses

Cluster	Willingness to pay	Current electricity expenses
Residential type I	8.81-14.69 USD/month (300-500 THB/month)	14.69-17.63 USD/month (500–600 THB/month)
Residential type II	2.94-29.38 USD/month (100-1,000 THB/month)	14.69-28.20 USD/month (500-960 THB/month)
Residential type III	11.75-29.38 USD/month (400-1,000 THB/month)	14.69-17.63 USD/month (500-600 THB/month)
HH+Shop	8.81-60.81 USD/month (300-2,070 THB/month)	11.75-60.81 USD/month (400-2,070 THB/month)
HH+Shop+Restaurant	No information	17.63 USD/month (600 THB/month)
HH+Shop+Motorbike/ boat repair shop	More than 14.69 USD/month (More than 500 THB/month)	14.69-39.66 USD/month (500-1,350 THB/month)
Generation costs according to 1st year of operation (2018)		
Residential type I[1]	12.20 USD/month (415.29 THB/month)	
Residential type II[11]	23.05 USD/month (784.62 THB/month)	
Residential type III[11]	26.40 USD/month (898.66 THB/month)	
HH+Shop[11]	40.64 USD/month (1,383.39 THB/month)	
HH+Shop+Restaurant[11]	48.40 USD/month (1,647.54 THB/month)	
HH+Shop+Motorbike/boat repair shop[11]	57.42 USD/month (1,954.58 THB/month)	
Rice cooker	5.00 USD/month (170.20 THB/month)	
Fridge	4.88 USD/month (166.12 THB/month)	
Washing machine	1.23 USD/month (41.87 THB/month)	
Computer	7.07 USD/month (240.66 THB/month)	
Iron	1.47 USD/month (50.04 THB/month)	
Blender	3.51 USD/month (119.48 THB/month)	

[1] Only for basic appliances (light, fan, mobile phone charger and TV) according to the Table 9

Water pump	1.34 USD/month (45.61 THB/month)
Speaker	0.15 USD/month (5.11 THB/month)

6.4.3 Sensitivity Analysis

Sensitivity analysis demonstrates how uncertainty in the output of the system or model be apportioned to different levels of uncertainty in its inputs to increase a higher understanding of the relationship between input and output variables in a system or model. In general, a variable is considered sensitive, if a change of 1% implies a variation of higher or lower than 1% of the assessed value.

According to meeting between GIZ and the Consultant on 20th July 2017, GIZ and the Consultant agreed to carry out sensitivity analysis of the following parameters:

- CAPEX (±30%)
- Energy (±30%), and
- Fuel Price (±10%).

The result is demonstrated in proportion of $LCOE/LCOE_{estimated}$. The $LCOE_{estimated}$ values are referred to LCOE values of each period presented in Table 40.

Figure 39 presents the results of the sensitivity analysis on $LCOE/LCOE_{estimated}$ for the variation of parameters, i.e. fuel price, energy demand and CAPEX.

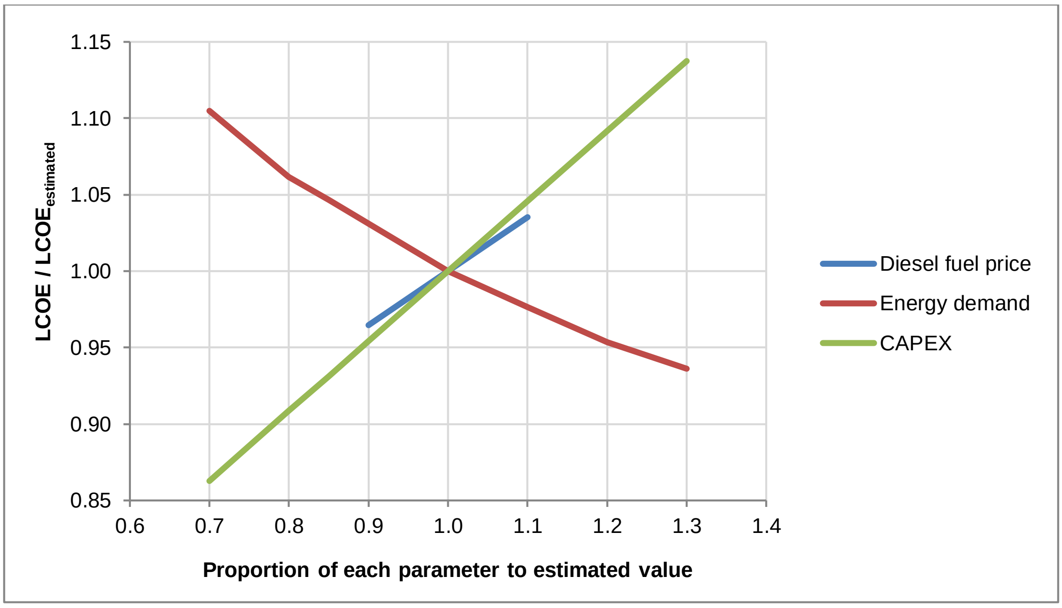


Figure 39: Sensitivity analysis results

Analysis of the results from the sensitivity analysis demonstrates the variation of the different variables impacting the results of the $LCOE/LCOE_{estimated}$ (ranked from the most to the least impact):

- ± 30% variation in CAPEX leads to a ± 13.73% variation in LCOE

- + 30% variation in energy demand leads to a – 6.38% variation in LCOE.
  – 30% variation in energy demand leads to a + 10.49% variation in LCOE.
- ± 10% variation in fuel price leads to a ± 3.53% variation in LCOE

It is shown that the hybrid system is most sensitive to CAPEX, with demand and fuel consumption following.

7 APPENDICES

Appendix 1: Appliance usage assumptions of each Cluster

Residential type I, type II and type III in March

Appliance	Behaviour (as % of total appliances are running at the same time)	
Residential type I		
Light bulb	00:00-04:30 : 0% 04:30-06:30 : 60% 06:30-18:00 : 15% 18:00-22:30 : 60%-85%	22:30-23:00 : 50% 23:00-23:30 : 25% 23:30-00:00 : 15%
Fan	00:00-05:00 : 70% 05:00-06:30 : 80% 06:30-11:30 : 40% 11:30-12:00 : 60%	12:00-15:00 : 75% 15:00-17:00 : 40% 17:00-18:30 : 80% 18:30-00:00 : 70%-85%
Mobile charger	80% all day	
Residential type II		
Light bulb	00:00-04:30 : 0% 04:30-06:30 : 60% 06:30-18:00 : 15% 18:00-22:30 : 60%-85%	22:30-23:00 : 50% 23:00-23:30 : 25% 23:30-00:00 : 15%
Fan	00:00-05:00 : 70% 05:00-06:30 : 80% 06:30-11:30 : 40% 11:30-12:00 : 60%	12:00-15:00 : 75% 15:00-17:00 : 40% 17:00-18:30 : 80% 18:30-00:00 : 70%-85%
Mobile charger	80% all day	
TV	00:00-00:30 : 15% 00:30-04:30 : 0% 04:30-05:00 : 30% 05:00-06:30 : 50% 06:30-08:00 : 60% 08:00-12:00 : 30%-40%	12:00-14:00 : 50%-60% 14:00-17:00 : 40% 17:00-22:30 : 70%-85% 22:30-23:00 : 50%-60% 23:00-00:00 : 25%
Residential type III		
Light bulb	00:00-04:30 : 0% 04:30-06:30 : 60% 06:30-18:00 : 15% 18:00-22:30 : 60%-85%	22:30-23:00 : 50% 23:00-23:30 : 25% 23:30-00:00 : 15%
Fan	00:00-05:00 : 70% 05:00-06:30 : 80% 06:30-11:30 : 40% 11:30-12:00 : 60%	12:00-15:00 : 75% 15:00-17:00 : 40% 17:00-18:30 : 80% 18:30-00:00 : 70%-85%
Mobile charger	80% all day	
TV	00:00-00:30 : 15% 00:30-04:30 : 0% 04:30-05:00 : 30% 05:00-06:30 : 50% 06:30-08:00 : 60% 08:00-12:00 : 30%-40%	12:00-14:00 : 50%-60% 14:00-17:00 : 40% 17:00-22:30 : 70%-85% 22:30-23:00 : 50%-60% 23:00-00:00 : 25%

HH + Shop and HH + Shop + Restaurant in March

Appliance	Behaviour (as % of total appliances are running at the same time)	
HH + Shop		
Light bulb	00:00-04:30 : 0% 04:30-05:30 : 40% 05:30-06:30 : 60% 06:30-18:00 : 25%-35%	18:00-22:30 : 60%-85% 22:30-23:00 : 45% 23:00-23:30 : 25% 23:30-00:00 : 15%
Fan	00:00-05:00 : 70% 05:00-06:30 : 80%	06:30-18:30 : 60% 18:30-00:00 : 70%-85%
Mobile charger	80% all day	
TV	00:00-04:30 : 0% 04:30-06:30 : 15%-35% 06:30-18:30 : 60%-65% 18:30-22:30 : 70%-85%	22:30-23:00 : 50%-60% 23:00-23:30 : 30% 23:30-00:00 : 10%
HH + Shop + Restaurant		
Light bulb	00:00-04:30 : 0% 04:30-05:30 : 40% 05:30-06:30 : 60% 06:30-18:00 : 25%-35%	18:00-22:30 : 60%-85% 22:30-23:00 : 45% 23:00-23:30 : 25% 23:30-00:00 : 15%
Fan	00:00-05:00 : 70% 05:00-06:30 : 80%	06:30-18:30 : 60% 18:30-00:00 : 70%-85%
Mobile charger	80% all day	
TV	00:00-04:30 : 0% 04:30-06:30 : 15%-35% 06:30-18:30 : 60%-65% 18:30-22:00 : 70%-85%	22:30-23:00 : 50%-60% 23:00-23:30 : 30% 23:30-00:00 : 10%
Coconut blender	00:00-08:00 : 0% 08:00-11:00 : 10%-40% 11:00-13:30 : 0%	13:30-16:00 : 20%-40% 16:00-00:00 : 0%
Rice cooker	00:00-06:00 : 0% 06:00-07:30 : 15%-30% 07:30-11:00 : 0% 11:00-12:00 : 10%-15%	12:00-16:00 : 0% 16:00-17:00 : 20%-25% 17:00-00:00 : 0%
Blender	00:00-06:00 : 0% 06:00-07:30 : 10%-20% 07:30-11:00 : 0% 11:00-12:00 : 15%-20%	12:00-16:00 : 0% 16:00-17:00 : 15%-20% 17:00-00:00 : 0%

HH + Shop + Motorbike/boat repair and specific appliances for the households in March

Appliance	Behaviour (as % of total appliances are running at the same time)	
HH + Shop + Motorbike/boat repair		
Light bulb	00:00-04:30 : 0% 04:30-05:30 : 40% 05:30-06:30 : 60% 06:30-18:00 : 25%-35%	18:00-22:30 : 60%-85% 22:30-23:00 : 45% 23:00-23:30 : 25% 23:30-00:00 : 15%
Fan	00:00-05:00 : 70% 05:00-06:30 : 80%	06:30-18:30 : 60% 18:30-00:00 : 70%-85%
Mobile charger	80% all day	
TV	00:00-04:30 : 0% 04:30-06:30 : 15%-35% 06:30-18:30 : 60%-65% 18:30-22:30 : 70%-85%	22:30-23:00 : 50%-60% 23:00-23:30 : 30% 23:30-00:00 : 10%
Power tools	00:00-08:30 : 0% 08:30-09:00 : 50% 09:00-09:30 : 0% 09:30-10:00 : 90% 10:00-10:30 : 0% 10:30-11:00 : 50% 11:00-13:30 : 0%	13:30-14:00 : 50% 14:00-14:30 : 0% 14:30-15:00 : 90% 15:00-15:30 : 0% 15:30-16:00 : 50% 16:00-00:00 : 0%
Welding machine Compressor	00:00-08:30 : 0% 08:30-09:00 : 25% 09:00-09:30 : 0% 09:30-10:00 : 55% 10:00-10:30 : 0% 10:30-11:00 : 5%2 11:00-13:30 : 0%	13:30-14:00 : 25% 14:00-14:30 : 0% 14:30-15:00 : 55% 15:00-15:30 : 0% 15:30-16:00 : 25% 16:00-00:00 : 0%
Other specific appliances		
Washing machine	00:00-09:00 : 0% 09:00-10:30 : 50%-60% 10:30-18:30 : 0%	18:30-20:00 : 30%-40% 20:00-00:00 : 0%
Iron	00:00-06:30 : 0% 06:30-07:30 : 10% 07:30-14:00 : 0% 14:00-15:00 : 15%	15:00-18:30 : 0% 18:30-19:30 : 30%-40% 19:30-00:00 : 0%
Rice cooker	00:00-05:00 : 0% 05:00-07:00 : 30-40% 07:00-16:00 : 0%	16:00-19:30 : 10%-20% 19:30-00:00 : 0%
Fridge	100% all day	
Computer	00:00-08:00 : 0% 08:00-20:00 : 40%-65% 20:00-21:00 : 70%	21:00-22:00 : 65% 22:00-23:00 : 10% 23:00-00:00 : 0%
Blender	00:00-08:00 : 0% 08:00-17:00 : 5%-10%	17:00-00:00 : 0%
Pump	00:00-08:30 : 0% 08:30-10:30 : 10%-25% 10:30-19:00 : 0%	19:00-20:30 : 10%-25% 20:30-00:00 : 0%
Speaker	A speaker shall be utilized in the beginning of the prayer time	

School during the summer season

Appliance	Behaviour (as % of total appliances are running at the same time)	
Mar, Apr (Summer season, end of semester)		
Light bulb	00:00-07:00 : 10% 07:00-08:00 : 5% 08:00-17:00 : 20%	17:00-23:00 : 30%-40% 23:00-00:00 : 10%
Fan	00:00-08:00 : 30% 08:00-17:30 : 40%	17:30-00:00 : 30%
TV	00:00-08:00 : 0% 08:00-17:00 : 15%-20%	17:00-22:00 : 10%-15% 22:00-00:00 : 0%
Computer	00:00-08:00 : 0% 08:00-12:00 : 50% 12:00-13:00 : 0%	13:00-17:00 : 50% 17:00-20:30 : 10% 20:30-00:00 : 0%
Printer	00:00-08:00 : 0% 08:00-17:00 : 50%	17:00-00:00 : 0%
Fridge	100% all day	
Network	100% all day	
Jan, Feb, Nov, Dec (Summer season, school start)		
Light bulb	00:00-07:00 : 10% 07:00-08:00 : 5% 08:00-17:00 : 35%	17:00-23:00 : 30%-40% 23:00-00:00 : 10%
Fan	00:00-08:00 : 30% 08:00-17:30 : 60%	17:30-00:00 : 30%
TV	00:00-08:00 : 0% 08:00-11:30 : 40% 13:00-17:00 : 40%	17:00-22:00 : 10%-15% 22:00-00:00 : 0%
Computer	00:00-08:00 : 0% 08:00-11:30 : 75% 11:30-13:30 : 0%	13:30-17:00 : 75% 17:00-20:30 : 10% 20:30-00:00 : 0%
Printer	00:00-08:00 : 0% 08:00-17:00 : 75%	17:00-00:00 : 0%
Fridge	100% all day	
Network	100% all day	

Mosque in March

Appliance	Behaviour (as % of total appliances are running at the same time)	
Light bulb	00:00-05:00 : 0% 05:00-06:00 : 50% 06:00-18:00 : 0%	18:00-20:00 : 50% 20:00-00:00 : 0%
Fan	00:00-05:00 : 0% 05:00-06:00 : 50% 06:00-12:00 : 0% 12:00-13:00 : 50% 13:00-15:00 : 0%	15:00-16:00 : 50% 16:00-18:00 : 0% 18:00-20:00 : 50% 20:00-00:00 : 0%
Speaker[1]	00:00-05:00 : 00% 05:00-05:30 : 50% 05:30-12:00 : 0% 12:00-12:30 : 50% 12:30-15:00 : 0% 15:00-15:30 : 50%	15:30-18:00 : 0% 18:00-18:30 : 50% 18:30-19:00 : 0% 19:00-19:30 : 50% 19:30-00:00 : 0%

[1] In case of the speaker, the percentage is as % of total power consumption of the appliance.

Health centre in March

Appliance	Behaviour (as % of total appliances are running at the same time)	
Light bulb	00:00-08:00 : 20%-30% 08:00-18:00 : 30%-40% 18:00-20:30 : 40%-50%	20:30-21:30 : 30% 21:30-00:00 : 20%
Fan	00:00-08:00 : 30% 08:00-17:00 : 60%-80%	17:00-00:00 : 30%
TV	00:00-08:00 : 0% 08:00-17:00 : 70%	17:00-22:00 : 30% 22:00-00:00 : 0%
Computer	00:00-08:00 : 0% 08:00-17:00 : 30%-50%	17:00-00:00 : 0%
Printer	00:00-08:00 : 0% 08:00-17:00 : 50%	17:00-00:00 : 0%
Fridge	100% all day	
Electric scale	00:00-08:00 : 0% 08:00-17:00 : 100%	17:00-00:00 : 0%

Appendix 2: Summary of the inputs for HOMER simulation

Parameters	Values	Parameters	Values
Diesel generator		**Battery & inverter**	
Brand/model	Generac Protector	Battery Technology	Li-ion
Rated power	60 kW x 3 (Total 180 kW)	Battery capacity	440 kWh
Minimum load	30%	Battery Lifetime curve	1/N = A*(DOD)^Beta A = 0.000216 Beta = 1.7945
Lifetime	20,000 hours	Battery Initial SOC	100%
Fuel curve	Intercept: 0.0417 l/hr Slope: 0.220 l/hr/kW	Battery Minimum SOC	20%
Total Capital	15,000 USD	Inverter capacity	90 kW
Replacement / generator	4,500 USD	Inverter Lifetime	15 years
O&M	0.105 USD/hour	Efficiency	95.8%
Diesel fuel price (2018)	0.75 USD/litre	Total O&M	1,224 USD/kWh/year
Solar PV		**Dispatch strategy**	
Total capacity	270 kWp	Strategy	Cycle charging (CC)
Derating factor	80%	Set point SOC	30%
Lifetime	30 years		
Capital	1,300 USD/kWp		
Replacement	0 USD/kWp		
O&M (PV & Inverter)	20 USD/kWp/year		
PV inverter			
Total capacity	240 kW		
Efficiency	98%		
Lifetime	15 years		
Capital	included in PV costs		
Replacement	120 USD/kW		

Appendix 3: Definition of inputs for LCOE calculation

$$LCOE = \frac{\sum_{n=1}^{N} \frac{I_n + F_n + O\&M_n}{(1+d)^n}}{\sum_{n=1}^{N} \frac{Q_n}{(1+d)^n}}$$

- I_n Investment or Capital Expenditure in year n
- F_n Financing costs in year n
- $O\&M_n$ Operating & Maintenance costs or Operating Expenditure in year n
- Q_n Net electricity production in year n
- d Discount rate of 6 %
- N Analysis period of 30 years has been taken into consideration

PV/Diesel/Battery hybrid system

Investment or Capital Expenditure: I_n

$$I_n = CAPEX_{year0} + \text{Replacement costs}$$

$$\text{CAPEX}_{\text{year0}} = \text{CAPEX}_{\text{PV}} + \text{CAPEX}_{\text{battery}} + \text{CAPEX}_{\text{generator}} + \text{CAPEX}_{\text{other}}$$

- CAPEX_{PV} = \$351,000 ; Section 6.3
- $\text{CAPEX}_{\text{battery}}$ = \$316,800 ; Section 6.3
- $\text{CAPEX}_{\text{generator}}$ = \$45,000 ; Section 6.3
- $\text{CAPEX}_{\text{other}}$ = \$447,067 ; Section 6.3

$$\text{Replacement costs} = \text{Replacement}_{\text{PV}} + \text{Replacement}_{\text{Battery}} + \text{Replacement}_{\text{generator}}$$

$$\text{Replacement}_{\text{PV}} = \sum_{n=1}^{N} (\text{Replacement}_{\text{PV}} \times \text{kWp}) \times (1+k)^n + \sum_{n=6}^{N} (\text{Replacement}_{\text{inverter}} \times \text{kW}) \times (1+k)^n$$

- k Inflation rate of 2%
- There is no replacement for PV, therefore, $\text{replacement}_{\text{PV}}$ = 0
- $\text{Replacement}_{\text{inverter}}$ = \$120/kW/year (Section 6.3.2.2 inverter replacement after year 6)

$\text{Replacement}_{\text{Battery}} = \$110{,}000$; Section 6.3.2.3 battery replacement in year 8 , 15, 22 and 29

$$\text{Replacement}_{\text{generator}} = \sum_{n=1}^{N} (\text{Replacement}_{\text{generator}} \times \text{kW}) \times (1+k)^n$$

- $\text{Replacement}_{generator}$ = \$75/kW
  (Section 6.3.2.1 generator replacement occurs in year 9, 14, 17, 24 (2 generators) as per simulation)

Financing costs: F_n

There is no any financing costs for the project due to 100% Equity project.

Operating & Maintenance costs: $O\&M_n$

$$O\&M_n = O\&M_{Total.PV} + O\&M_{Total.battery} + O\&M_{Total.generator} + O\&M_{other}$$

$$O\&M_{Total.PV} = \sum_{n=1}^{N} (O\&M_{PV}) \times (1+k)^n$$

- $O\&M_{PV}$ = \$5,400 per year ; Section 6.3.2.2

$$O\&M_{Total.battery} = \sum_{n=1}^{N} (O\&M_{battery}) \times (1+k)^n$$

- $O\&M_{battery}$ = \$5,386 per year ; Section 6.3.2.3

$$O\&M_{Total.generator} = O\&M_{generator} + O\&M_{fuel}$$

- $$O\&M_{generator} = \sum_{n=1}^{N} (O\&M_{generator,cost} \times \text{Production}_n) \times (1+k)^n$$
- $O\&M_{generator,cost}$ = \$0.11 kWh/year ; Section 6.3.2.1
- $$O\&M_{fuel} = \sum_{n=1}^{N} (\text{Fuel}_{\text{consumption,n}} \times \text{Fuel}_{\text{Price,n}}) \times (1+k)^n$$
- $$\text{Fuel}_{\text{Price,n}} = \text{Fuel}_{\text{Raw}} \times (1 + k + \text{fuel escalation})^n + \text{Fuel}_{\text{other}} \times (1+k)^n$$
- Fuel_{Raw} = \$0.42 per litre
- Fuel escalation = 3.1% ; Section 6.2.3 and 6.2.4
- Fuel_{other} = \$0.3059 per litre

$$O\&M_{other} = \sum_{n=1}^{N} (O\&M_{transmission line}) \times (1+k)^n$$

- $O\&M_{transmission\ line}$ = \$100 per year ; Section 6.3.2.4

Net electricity production: Q_n

Based on energy demand as described in chapter 4

100% Diesel scenario

Investment or Capital Expenditure: I_n

$$I_n = CAPEX_{year0} + \text{Replacement costs}$$

$$\text{CAPEX}_{\text{year0}} = \text{CAPEX}_{\text{generator}} + \text{CAPEX}_{\text{other}}$$

- $\text{CAPEX}_{\text{generator}}$ = $45,000 ; Section 6.3
- $\text{CAPEX}_{\text{other}}$ = $447,067 ; Section 6.3

$$\text{Replacement costs} = \text{Replacement}_{\text{generator}}$$

$$\text{Replacement}_{\text{generator}} = \sum_{n=1}^{N} (\text{Replacement}_{\text{generator}} \times \text{kW}) \times (1+k)^n$$

- $\text{Replacement}_{\text{generator}}$ = $75/kW/year
  (Section 6.3.2.1 generator replacement occurs in year 3, 5, 7, 10, 11, 12, 14, 16, 17, 19, 21, 23 (2 generators), 26, 28 and 30 (2 generators) as per simulation)
- k Inflation rate of 2%

Financing costs: F_n

There is no any financing costs for the project due to 100% Equity project.

Operating & Maintenance costs: $O\&M_n$

$$O\&M_n = O\&M_{Total.generator} + O\&M_{other}$$

$$O\&M_{Total.generator} = O\&M_{generator} + O\&M_{fuel}$$

- $$O\&M_{generator} = \sum_{n=1}^{N} (O\&M_{generator,cost} \times \text{Production}_{\text{n}}) \times (1+k)^n$$
- $O\&M_{\text{generator,cost}}$ = $0.11 kWh/year ; Section 6.3.2.1
- $$O\&M_{fuel} = \sum_{n=1}^{N} (\text{Fuel}_{\text{consumption,n}} \times \text{Fuel}_{\text{Price,n}}) \times (1+k)^n$$
- $$\text{Fuel}_{\text{Price,n}} = \text{Fuel}_{\text{Raw}} \times (1 + k + \text{fuel escalation})^n + \text{Fuel}_{\text{other}} \times (1+k)^n$$
- Fuel_{Raw} = $0.42 per litre
- Fuel escalation = 3.1% ; Section 6.2.3 and 6.2.4
- $\text{Fuel}_{\text{other}}$ = $0.3059 per litre

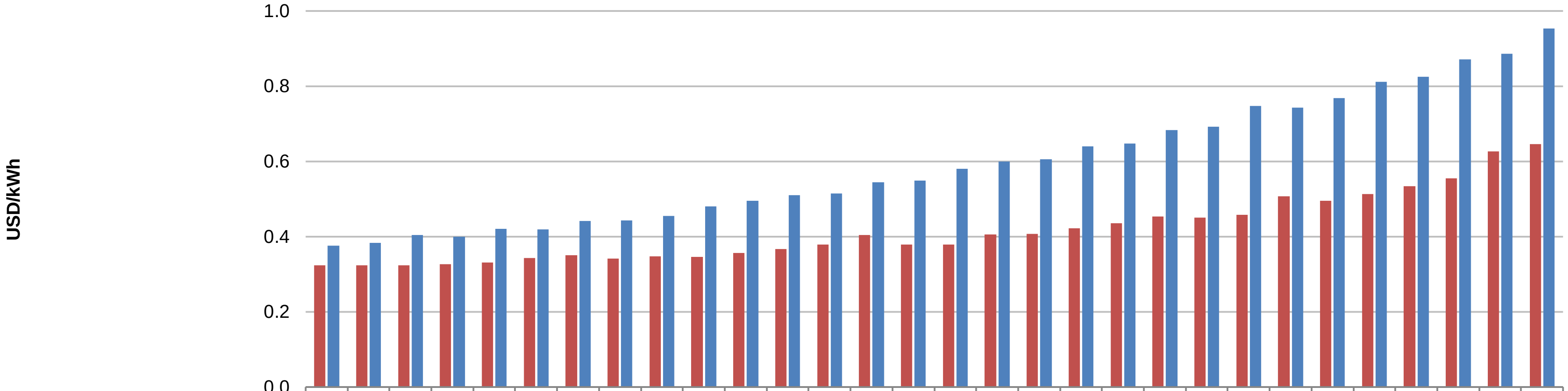
$$O\&M_{other} = \sum_{n=1}^{N} (O\&M_{transmission\,line}) \times (1+k)^n$$

- $O\&M_{transmission\ line}$ = $100 per year ; Section 6.3.2.4

Net electricity production: Q_n

Based on energy demand as described in chapter 4

Appendix 4: Real generation costs

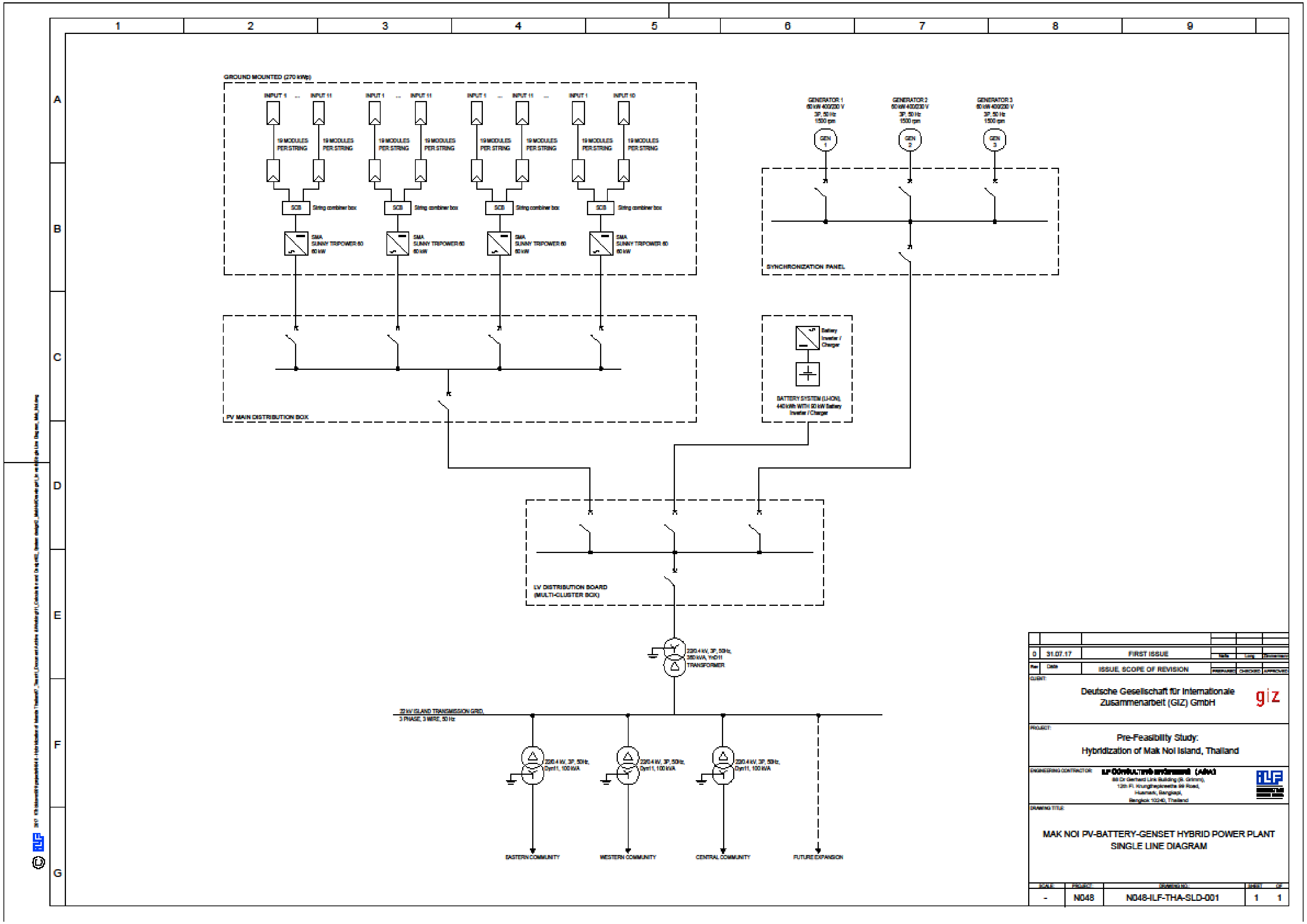


Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
PV/Diesel/Battery hybrid system	0.32	0.32	0.32	0.33	0.33	0.34	0.35	0.34	0.35	0.35	0.36	0.37	0.38	0.40	0.38
100% Diesel	0.38	0.38	0.40	0.40	0.42	0.42	0.44	0.44	0.46	0.48	0.50	0.51	0.51	0.54	0.55

Year	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
PV/Diesel/Battery hybrid system	0.38	0.41	0.41	0.42	0.44	0.45	0.45	0.46	0.51	0.50	0.51	0.53	0.56	0.63	0.65
100% Diesel	0.58	0.60	0.61	0.64	0.65	0.68	0.69	0.75	0.74	0.77	0.81	0.83	0.87	0.89	0.95

Year

Appendix 5: Single Line Diagram (SLD) of the hybrid system



Appendix 6: PV power plant layout