Renewable Energy Hybrid Grid Systems for Thai Islands

Project Summary - PEA

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1 Executive Summary

1.1 Project Background

Within the “Renewable Energy Hybrid Grid System for Thai Island” project GIZ is promoting the deployment of renewable energy sources on Thai Islands supported by the Rockefeller Foundation. Renewable-Energy-Diesel Hybrid Grid Systems can reach the last mile with reliable electricity access for off-grid communities in Thailand. They are a potential answer to limited electricity access and expensive, intermittent supply.

Potential investors, however, do shy away from the effort they need to make to identify suitable islands, provide needed capacity building to local communities and develop the projects on the islands. This project aims to bridge the gap for investors by conducting feasibility studies, engage in stakeholder consultations on selected islands, developing community-based business models and appropriate modes of operation to ensure local value creation and long-term operation.

While developing one of the pilot sites, namely Mak Noi island, GIZ linked their project activities to the Provincial Electricity Authority (PEA) of Thailand as they were planning to electrify this specific island. Mak Noi island is within the PEA network extension plan for 2019 – 2021 and was stated to be electrified through the installation of a submarine cable. In further talks PEA indicated their interest to explore the opportunity to implement an RE-Diesel hybrid system instead of a submarine cable. This document is summarizing the main findings for Mak Noi island and serves to facilitate PEA’s internal decision-making process. GIZ wants to outline the basic results achieved by the project and summarize detailed technical and simulation assumptions as well as outcomes for PEA to get a better understanding and build upon the achievements being made.

1.2 Project Results

1.2.1 Identification of Suitable Islands

A site selection criteria catalogue was developed based on GIZ best practices from projects implemented in Asia and Africa. The catalogue provided criteria according to which islands were selected within the project: Out of five previously identified suitable islands, we selected three islands for a technical site assessment: Koh Mak Noi, Koh Bulon Don, Koh Bulon Lae.

1.2.2 Site Assessments

Together with a technical consultant (namely ILF Consulting Engineers) GIZ travelled to the three selected islands to conduct socio-economic and technical site assessments including interviews, surveys and community meetings to evaluate the feasibility of RE-Hybrid Grid System implementation. Based on the data and information gathered, two islands were selected to pursue with the technical design of an island specific RE-Hybrid Grid System: Koh Mak Noi and Koh Bulon Don. During the community meeting, GIZ learnt that Mak Noi Island is within the PEA network extension plan of 2019 – 2021 which means that Mak Noi is panned to be electrified via a submarine cable to the national grid. However, in further talks PEA showed interest to investigate the opportunity of implementing a RE-diesel hybrid grid system as an alternative to the submarine cable plans. Since then PEA and GIZ are in close collaboration and travelled to the island together in August 2017.

1.2.3 RE Hybrid Grid System Design

After data gathering and site assessment, specific hybrid grid system designs for the two selected islands were calculated. The feasibility studies allow for assessment of not only the technology and system size suggested but also the investment amount needed. The figure below is summarizing the system sizing:

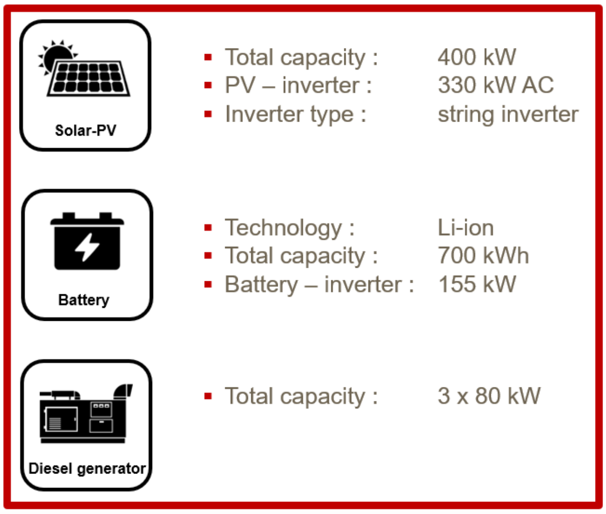


Figure 1: System design for Mak Noi Island

The simulations showcased how a reduction of the current electricity prices via hybridization with solar-photovoltaic (PV) and battery capacities can be achieved (see figure below). Comparing with the current situation of intermittent and unreliable supply (2-5 hours per day), the hybrid system is able to supply the local communities with stable electricity 24/7 for a cheaper price per unit. Furthermore, the Levelized Cost of Electricity (LCOE) for the hybrid system are significantly lower (37 %) than the LCOE for the submarine cable. From an economic perspective, the RE hybrid grid system would be the best option to electrify Mak Noi island.

Currently:	**25.15 THB/kWh**
Diesel/PV/Battery Hybrid System:	**16.61 THB/kWh**
Submarine Cable	**44.33 THB/kWh**

Figure 2: Electricity Cost Comparison for 3 different setups (30 years project time, LCOE)

2 Mak Noi Island

2.1 General Information

Mak Noi Island is situated in Phang-Nga province, under the jurisdiction of Koh Panyee Sub-District Administrative Organization (SAO). The island is located in the Andaman Sea between Phuket and Krabi province. Approximately 1,400 inhabitants are living on Koh Mak Noi in 250 households. The island is affected by dry and rainy season.

Figure 3: Location of Mak Noi Island

Figure 4 shows key facilities on Mak Noi island:

- Public buildings: health center, school, mosque
- Street light: not yet consistently installed (but desired)
- Fresh water supply: water pond and water tower
- Pier and road: concrete pier and main road
- Communication: dtac BTS tower installed, good coverage

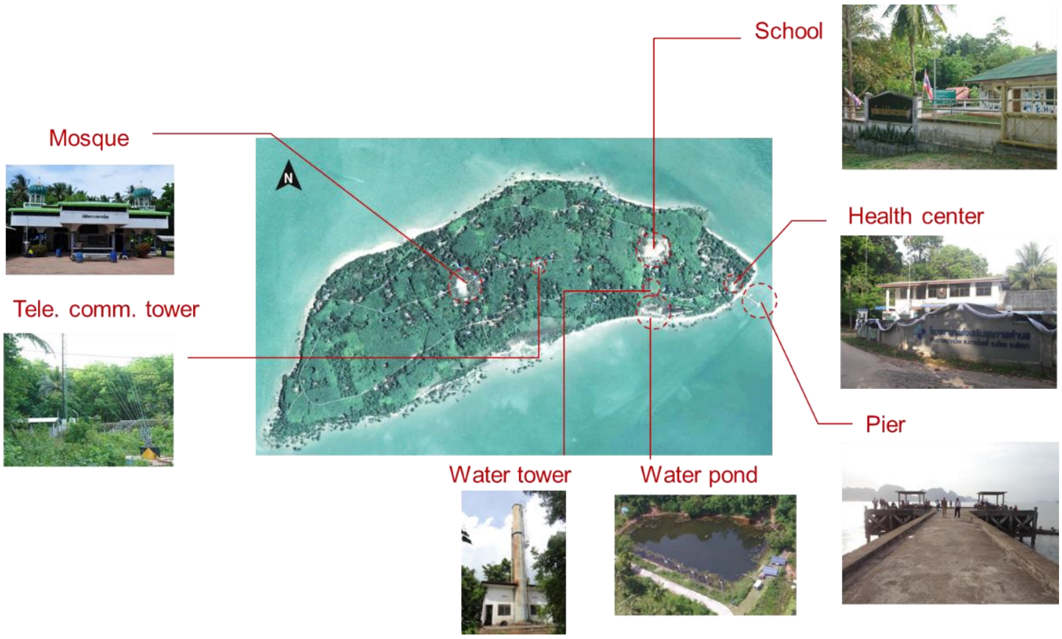


Figure 4: Key facilities on Mak Noi Island

2.2 Occupation and Income Structure

The economy of the island relies mainly on fishery, rubber plantation, coconut farming, and motorbike/boat repair services. The income of the inhabitants covers the wide range from 1,000 THB/month to 90,000 THB/month.

Figure 5: Coconut plantation (left) and fisheries (right); main occupations of Mak Noi island villagers

2.3 Education

Koh Mak Noi School is the only school on the island. It 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.

Currently the school is supplied by an own solar system but is facing frequent electricity shortages. The learning environment for the students and teachers would be improved by stable electricity supply.

Figure 6: Koh Mak Noi school (left), Child care center (right)

2.4 Current Energy Situation

(Status as of August 2017)

2.4.1 Centralized Diesel Generators and Grids

Currently, villagers on the island receive electricity supply mainly through privately-owned and operated diesel generators (Figure 7). There are five independent electricity grids serving certain areas on the island. The largest grid (#40, light blue) supplies up to 100 households. The smallest grid (#62 dark blue) provides electricity to around 10 households.

In August 2017, the diesel generator #68 broke down. This has left the grid out of operation since then. The operator who supplies the two largest grids (#40 & #41) is planning to extend his service to serve the households previously connected to Shade’s grid. His motivation is not necessarily economically driven. He mainly wants to supply the non-served household for a good purpose.

The currently installed grids are not suitable to be integrated in a central electricity supply for Mak Noi Island. The cable types and sizes are not capable to supply higher loads over large distances and are not meant for outdoor use. The grid infrastructure needs to be newly designed and installed in order to fulfill present safety standards.

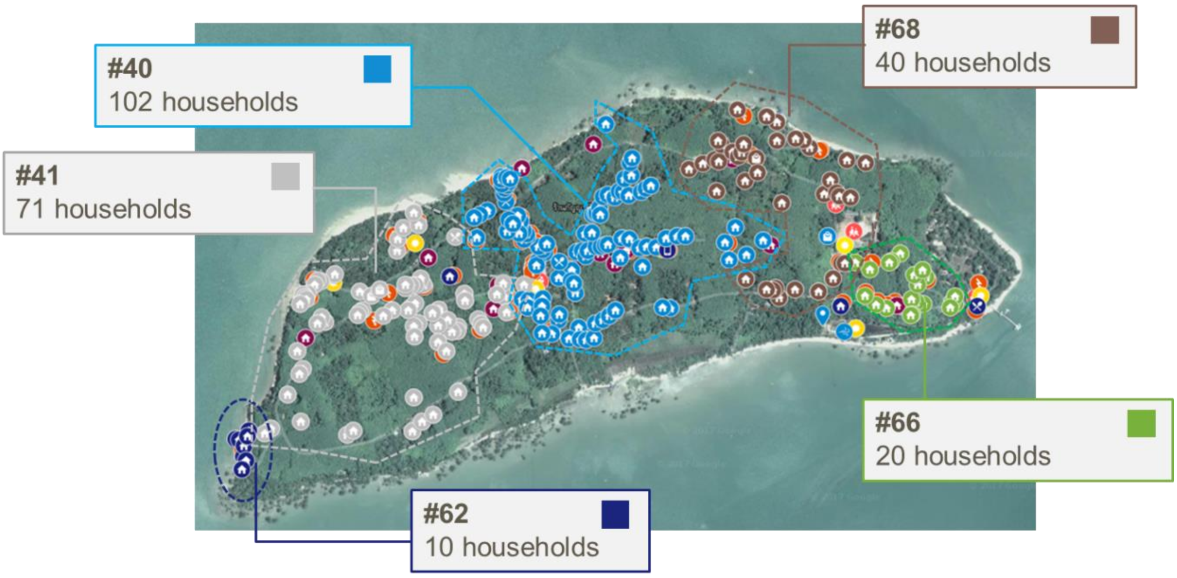


Figure 7 Private-owned electricity grids on Mak Noi island

Table 1: Summary of key facts for the 5 main grids on Mak Noi

Parameter	Grid				
	Light blue	**Grey**	**Brown**	**Green**	**Dark blue**
Electricity generation	40 kW diesel generator *("Mosque generator")*	40 kW diesel generator *("Western generator")*	15 kW diesel generator	15 kW diesel generator	3 kW diesel generator
Operation hours	18:30 – 22:30	18:30 – 22:30	18:30 – 22:30	18:30 – 22:30	18:30 – 22:30
Reference No.	#40	#41	#68	#66	#62
Condition	In operation	In operation	generator broke down in August 2017	In operation	In operation
No. of connected households	~102	~71	~40	~20	~10
Monthly tariff	500 – 600 THB	500 – 600 THB	500 THB	600 THB	n.a.

Currently, villagers pay a flat-rate of typically 500 – 600 THB per month for their electricity supply. The tariff depends on the type and number of appliances installed and used in each household. The flat-rate tariff is not reflecting the actual electricity consumption of the respective household. The electricity supply is limited to nighttime only (typically, between 18:30 to 22:30). Therefore, some households own additional smaller diesel generators for their daytime electricity usage (as needed). Additionally, some households are partly electrified by solar home systems (SHS, 1-2 PV modules incl. battery storage).

2.4.2 Renewable Energy Systems

There are some renewable energy technologies (PV and small wind turbines) installed on Mak Noi island (Figure 8). Each system was developed for a different purpose addressing a certain common need and not meant to supply the whole community.

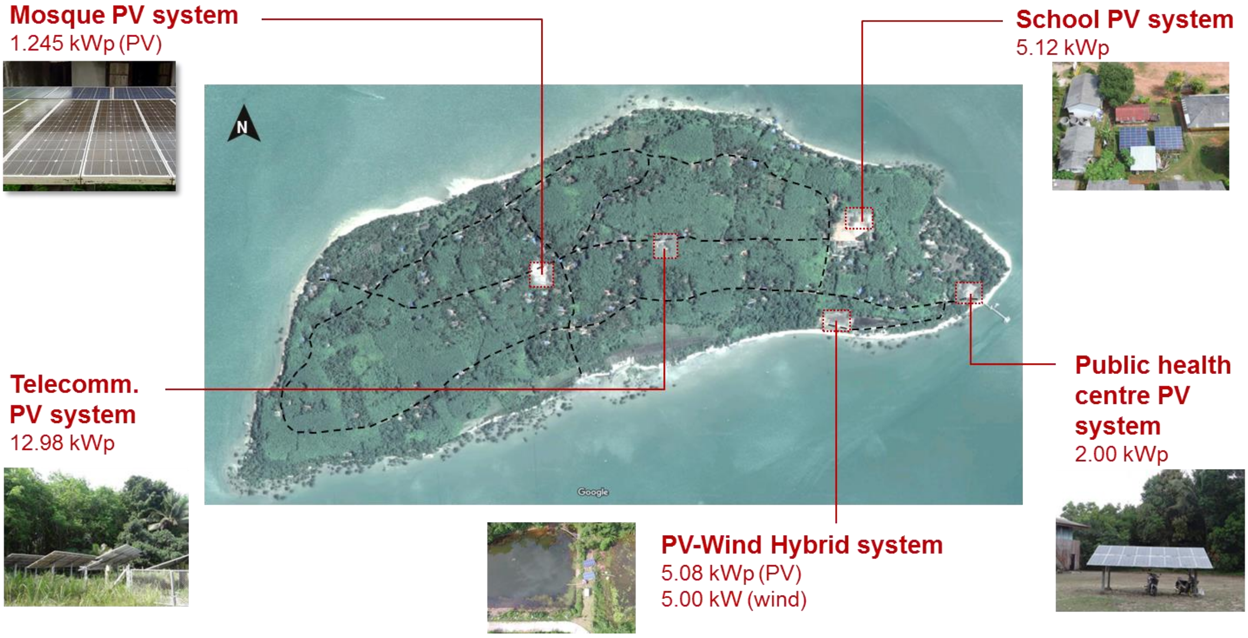


Figure 8 Renewable energy systems on Mak Noi island

2.4.3 Electricity Demand

The residential sector counts for the biggest part of electricity demand on the island. The socio-economic survey conducted during the site assessment shows that typical household appliances are light bulbs, TVs, mobile phones and electric fans. Some households also own a washing machine, radio, rice cooker, blender, speaker or even electric irons. The motorbike and boat repair shops have certain power tools (e.g. drills, saws, sanding tools etc.), welding machines, and compressors.

Besides the residential households, there are three public buildings namely the health center, school and the mosque. These buildings have a higher quantity of the standard appliances than a regular household (no. of light bulbs, fans, TVs increased) as well as additional appliances (computers, medical equipment etc.).

A detailed list of appliances and current electricity cost for different types of households and public buildings can be found in the survey summary (“Annex 1: Survey Results”).

2.4.4 Load Measurement and Profile

Two load measurement devices (Eco Sense 3) were installed to monitor two large diesel generators on the island for one month:

- #40 generator supplying 102 households
- #41 generator supplying 71 households

This detailed data of electricity supply to 173 households was collected from 6th March 2017 to 8th April 2017. The devices measured relevant grid parameters like voltage, current, active and reactive power and frequency for each phase separately.

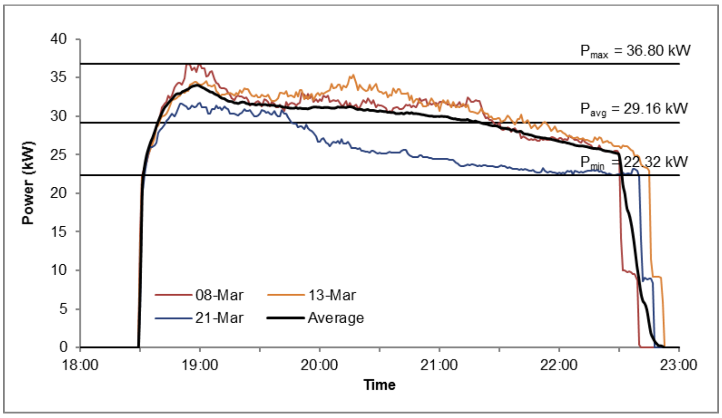


Figure 9: Load profile for three different days as well as the average load profile over one month

This data was extrapolated to the actual number of households on the island based on the findings of the survey to form the baseline (current load) for the load forecast assumptions. Figure 10 shows the current estimated load profile for a typical day in March including the whole island. PEA's load forecast unit took this analysis as basis for further load forecast assumptions and simulations (see chapter 3.2.).

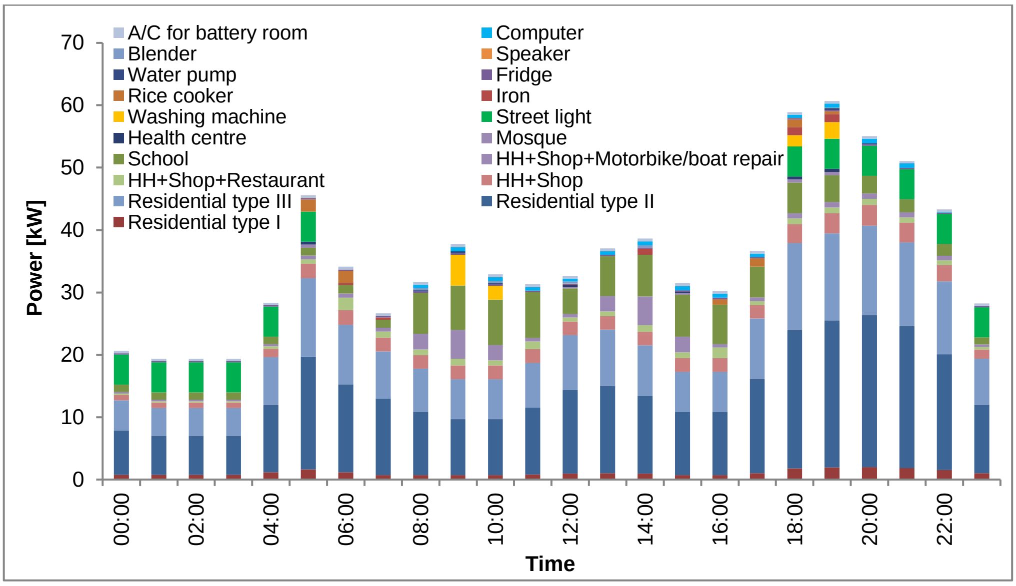


Figure 10: Anticipated 24-hour load profile of Mak Noi Island (in March)

3 Renewable Energy Hybrid Grid System

3.1 General Information

Renewable Energy (RE) hybrid grid systems combine a renewable energy technology (in this case solar power through photovoltaic modules) with another power generating energy source. A common type is a photovoltaic (PV) diesel hybrid system. PV has hardly any marginal cost and is usually treated with priority on the grid. The diesel generators are used to constantly fill in the gap between the present load and the actual generated power by the PV system. As solar energy is fluctuating, and the generation capacity of the diesel generators is limited to a certain range, it is often a viable option to include battery storage in order to optimize the renewable energy share of the hybrid system. These systems are a capable and reliable option to supply remote off-grid areas with electricity in a sustainable and cost-efficient way.

Solar power depends on weather conditions and daytime usage. Cost for battery storage solutions are decreasing but are still comparably expensive. Therefore, 100% RE systems are not yet economically viable compared to RE-diesel setups in most areas. However, combustion of diesel fuel is highly polluting and fuel costs on remote islands are high due to additional logistical efforts to be taken. All these factors need to be considered while designing RE hybrid grid systems. Proper optimization using appropriate tools handled by experts in this field is key to technical and financial viability. That is why GIZ hired ILF Consulting Engineers (ILF) as technical consultant and expert to develop the system design. ILF has international experience in designing RE hybrid grid systems and their staff is familiar with common state-of-the art simulation tools and technology options.

3.2 Technical Analysis and System Configuration

3.2.1 Simulation Tools and Inputs

ILF used a combination of three different tools for system optimization:

- PVSyst — for PV Simulation and Optimization
- HOMER Pro 3.9.1 — for system integration, load profile generation and analysis, environmental and financial analysis
- ILF Financial Tool — for detailed financial analysis

The target of the simulation was twofold:

- 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;
- To financially optimize the system to obtain the best Levelized Cost of Electricity (LCOE) of each scenario.

A PV/Diesel/Battery hybrid system as well as a 100% diesel scenario were simulated and compared. In the financial analysis was then compared to the economics of the submarine cable scenario.

The results of the PVsyst simulation and financial parameters as observed in the market with standard market prices were essential part of the simulation input. As a summary, simulation inputs consisted of:

- **Load profile** as provided by PEA's load forecast unit

  The following figure is only showing the energy demand over a 30-years' time frame. More details such as energy sells and peak demand are shown in "Annex 2: Load Forecast (PEA)".

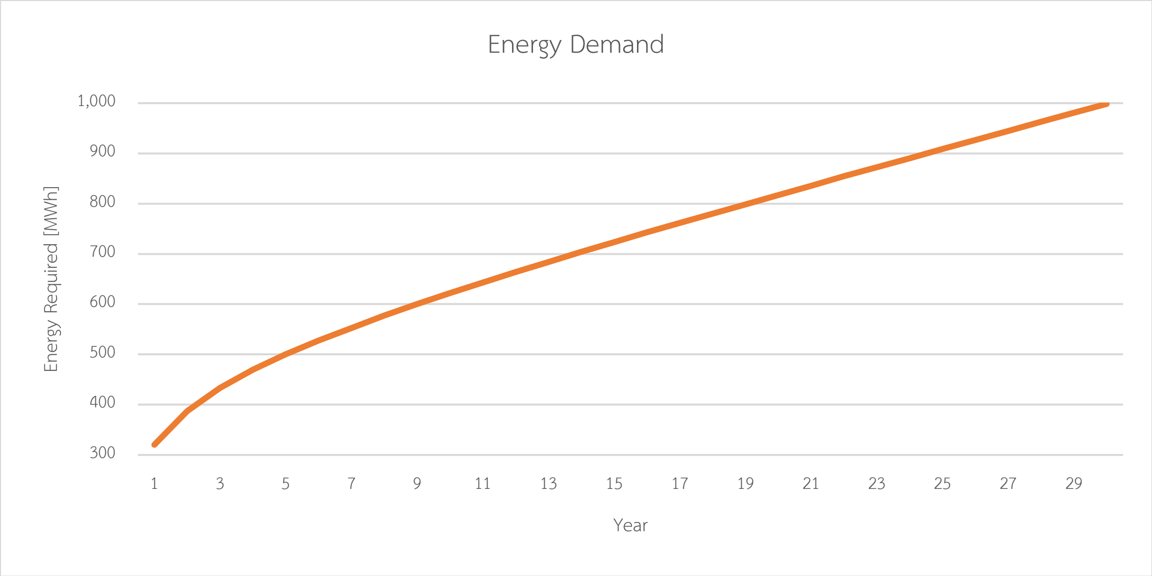


Figure 11: Energy demand in MWh as forecasted by PEA, version as of 29.09.2017

- **Weather data set**

  For the calculation of the expected annual PV yield, ILF used the weather data set of Meteonorm 7 (with hourly resolution). The data is shown in the following graph. The monthly average values of global horizontal irradiation (GHI), diffuse irradiation (DHI) and ambient temperature are considered.

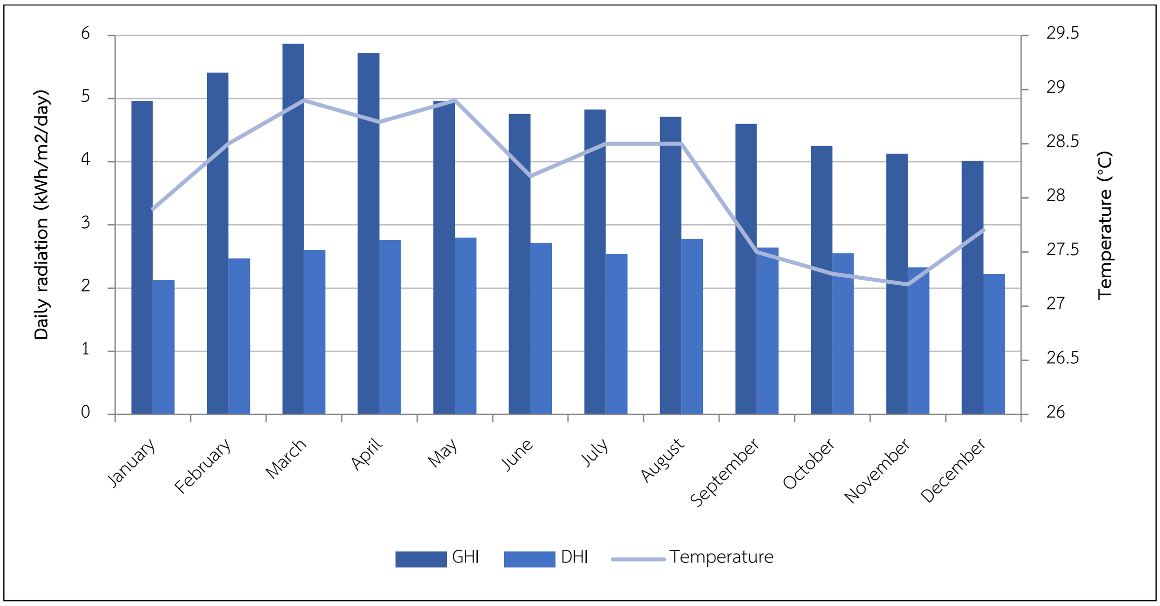


Figure 12: Meteorological data for HOMER and PVSyst simulation

- **Technical parameters of each system component**

  Such as fuel consumption curves of the diesel generator; PV, battery and inverter specifications etc.

- **Financial parameters of each system component**

  Such as CAPEX, OPEX, replacement costs and lifetime (physical and operational)

Further details of simulation inputs are given in “Annex 3: Simulation Inputs” and the financial analysis (Chapter 3.3).

The simulation was aiming to design a RE hybrid grid system that:

- Ensures reliable and sustainable energy supply over 24 hours and 7 days a week (24/7)
- Has a high renewable energy share
- Is optimized technically and economically according to the LCOE
- Is capable and sized sufficiently for at least 10 years (optimized for 10 years’ time frame).

Typically, a load forecast for such standalone hybrid grids is carried out to cover a period of 10 years. This forecast is then used for the simulation and design of the system, ensuring sufficient reserves and sizing of the system. After 10 years the systems are usually evaluated and PV/battery upgrades are considered. For the further financial calculation of this specific system a project lifetime of 30-years was considered in order to reflect PEA’s usual project life time when simulating submarine cable connection projects.

3.2.2 Mode of Operation

Figure 13 shows the schematic system architecture of a RE hybrid grid system. The hybrid system consists mainly of the following components as mentioned above:

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

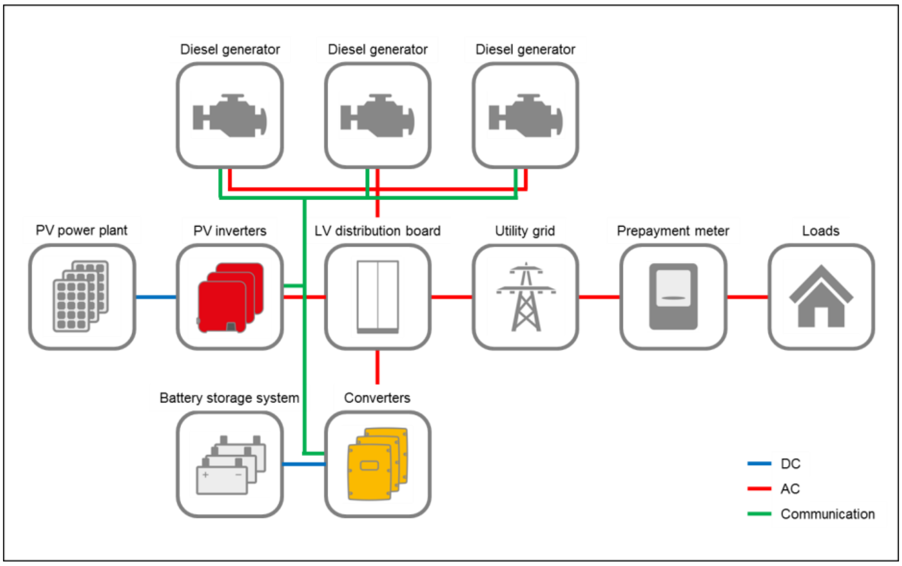


Figure 13: System architecture of a RE hybrid system

During daytime the output power of PV system is meant to cover the whole load and generates sufficient surplus energy to fully recharge the battery. During the evening peak hours (~18:00-23:00), the diesel generators are forced to run. Ideally the generators run at their rated capacity (load factor ~80%). This is why a modular setup of several small generators instead of one big unit is beneficial: The smaller units are able to address different load levels in an efficient way instead of one big unit running below its rated capacity having a negative impact on its lifetime and the overall system efficiency. Running at rated capacity might generate a surplus of energy to charge the battery up to the defined state of charge (SoC). Furthermore, whenever the energy feeding from the PV system or the battery is insufficient to cover the load, the diesel generators will be activated to cover the remaining load and create surplus energy to charge the battery.

This operation methodology is called **Cycle Charging ("CC")**. The benefit of CC is to reduce the operating hours of diesel generators at low load factor (below 50%) significantly, as the generator is mostly running at its rated capacity. Figure 14 is giving an example of the CC operation mode. The yellow part is the load covered by PV which is being directly consumed. The dark green part is covered by the battery system. Only the grey part of the load is supplied by the diesel generator. The first and third light green part (A & B in Figure 14) are representing the portion of battery being charged by a surplus of solar energy. Whereas the second and fourth light green shape show the battery charging covered by the diesel generator surplus (C & D in Figure 14).

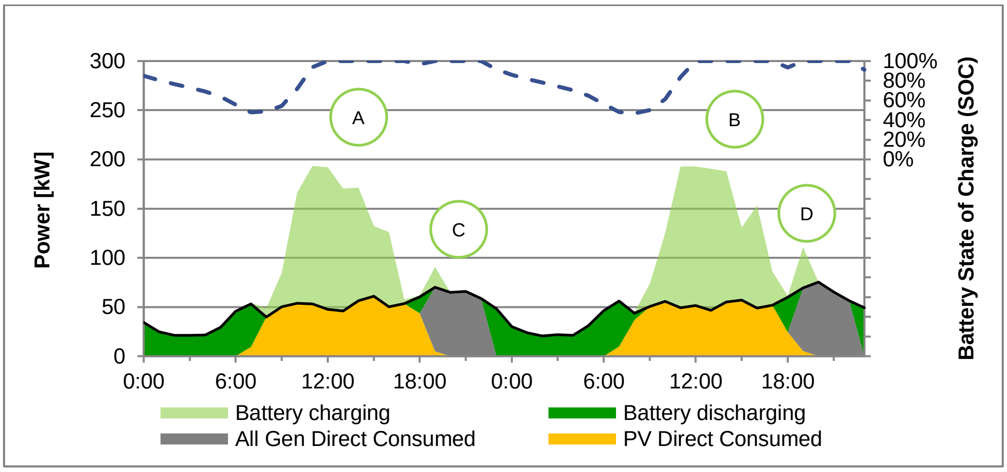


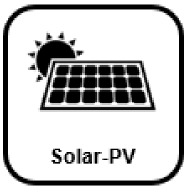
Figure 14: 24h example of RE hybrid grid operation with CC

The heart of the hybrid system is the battery inverter together with the hybrid system controller. To control the operation of a RE hybrid grid system, there are two common types of communication systems. For PV-diesel hybrid system of Mak Noi Island, the **battery inverter is the grid forming unit**, providing frequency and voltage. The hybrid system controller communicates in a separate network (see Figure 13) 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.

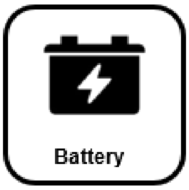
Another way of communication between the battery and PV system is the so-called **"frequency droop control".** This means, the battery inverters use only the frequency as a communication medium to control the output power of the PV inverters. This solution avoids additional communication cables between battery inverter and PV inverter making the hybrid system controller to be 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 kWp) and is therefore not recommended for Mak Noi Island.

3.2.3 System Design

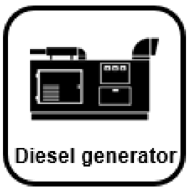
With the above-mentioned tools and methodology ILF optimized the RE hybrid grid system size for Mak Noi to be:



- Total capacity : 400 kWp
- PV – inverter : 330 kW AC
- Inverter type : String inverter



- Technology : Li-ion
- Total capacity : 700 kWh
- Battery – inverter : 155 kW



- Total capacity : 3 x 80 kW

Figure 15: RE hybrid grid system size

The energetic results of the simulation are summarized in the table below.

Table 2: Energetic results of the simulation

Parameters	Unit	2018	2022	2027
Total electricity production (demand)	kWh/a	231,255	463,667	593,633
Electricity generation from diesel generators	kWh/a	73,249	169,520	255,679
Electricity generation from PV and battery	kWh/a	158,006	294,147	337,954
Excess PV energy	kWh/a	405,290	239,213	175,943
	%	71	43	32
Total diesel consumption	l/a	22,198	46,121	69,506
Specific diesel consumption	l/MWh	303	272	272
Renewable fraction *(combination of PV and battery)*	%	68	63	57
Total diesel operating hours	hr/a	1,133	5	1
Operation hours below 50% (Operation hours below 40%)	%/a	62 (19)	0.25 (0)	0.04 (0)
CO_2 emission	t/a	59	122	183

More details are given in the following chapters. The Single Line Diagram (SLD) is shown in “Annex 4: Single Line ”.

3.2.3.1 Diesel Generator

The main objectives of sizing the diesel generator were:

- 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 16 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 MWh. Frequent undercutting of this threshold value may impair the generator and lead to higher maintenance effort and consequently to a limitation of its average operation lifetime.

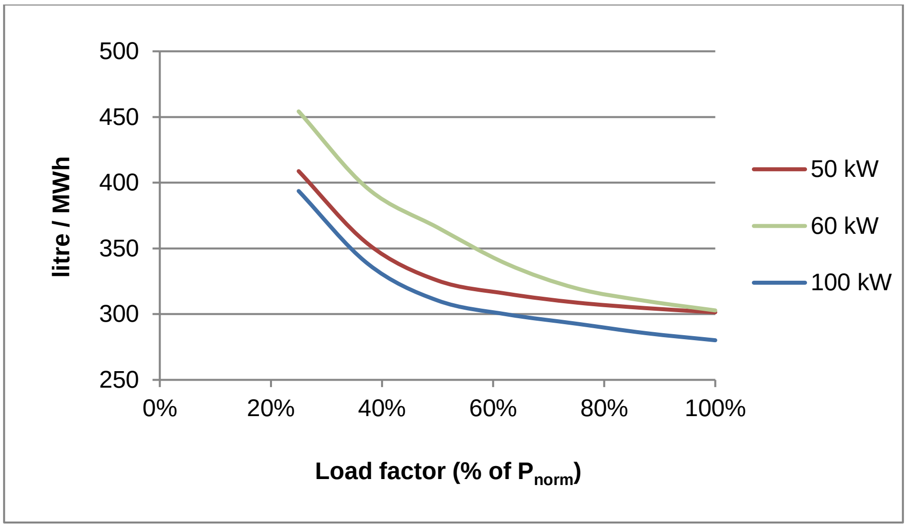


Figure 16: Specific consumption curve for different size of diesel generator[1]

The optimized diesel generator capacity, for the case of the island has been identified to be 3 x 80 kW considering a power factor of 0.80. In the first year of operation, one generator should be sufficient to serve the load during the average peak load hours in the evening for most of the time. In case the output power will no longer be sufficient, the second generator will switch on and they share the load. In the later years, the load will increasingly require the second generator. The third generator serves as a backup, in case of a failure or maintenance demand and will play an increasing role from year 10 onwards.

The main characteristics of the generators are summarized in Table 3. Most of the parameters were implemented and considered in the HOMER simulation. But it is not possible to define the power factor or the overload capacity in HOMER itself.

Table 3: 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	3 x 80 kW
Power factor (cosφ)	0.8
Minimum load ratio	30%
Possible (short-term) overload capacity	10%
Lifetime (operating hours) before general revision or replacement	20,000 hrs
CO_2 emission (diesel fuel)	1.64 g/l

[1] *Source: Generac diesel generator datasheet*

3.2.3.2 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% (at the optimized year, 10th year).

Table 4: Main characteristics of PV power plant

Parameter	Value
Total PV capacity (DC, STC)	400 kWp
Total inverter capacity (AC)	330 kW_{AC}
DC/AC ratio	1.13
Power factor (cosφ)	0.8

The capacity of the Li-ion based battery was optimized according to the following criteria:

- The battery storage is usually able to cover the load during the night and early morning hours,
- the operation hours of the battery with an SOC of more than 20% shall be increased to extend the battery's lifetime. The battery is always operated at SOC above 10%.

Table 5: Main characteristics of battery storage system

Parameter	Value
Technology	Li-ion
Total battery capacity	700 kWh
Battery inverter capacity	155 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 (load of air-conditioning system is already considered in load profile - Figure 10) ▪ Battery storages shall be housed in specially made cabinet rated for salt mist protection.

To achieve the above criteria the PV capacity was optimized to be 400 kWp, and battery capacity 700 kWh.

Figure 17 shows an overview of the designed PV system. The power station building for batteries and diesel generators are placed at the same spot in order to reduce the amount of connection and communication cables as stated above.

Figure 17: PV system layout at the SAO area behind the health center (required area app. 6,000 m^2; available area app. 7,000 m^2)

3.2.3.3 Smart Meter

The usage of smart energy meter on the island is recommended due to its benefits for the customers and electricity suppliers. The customers are enabled to monitor their electricity usage and develop a more conscious consumption behavior that is beneficial for RE hybrid grid system and their long-term operation stability. The payment method can be adjusted to the needs of PEA and the customers. There is no need to send a person to check the energy meters and collect the payment from users. This also prevents human error from meter reading. Smart meters also collect detailed information and can help the power supplier to have more understanding on demand behavior.

ILF recommends to install the energy meters in outdoor areas to avoid bypassing. With regard to the safety, a fuse, residual-current device (RCD) and surge arrestor shall comprise a high level of safety and installation quality according to international installation standards.

The smart meter main functions shall include:

- Anti-tampering functions against reverse connection, magnetic and meter/terminal cover open detection
- Two-way communication
- Internal relay for load control
- 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 off-power.

3.2.3.4 Recommendations for the Grid Line

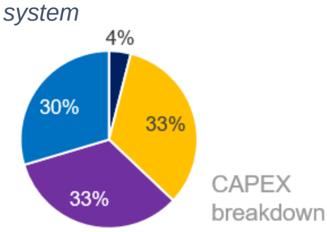
Since the island is large, approx. 2.5 km^2, and the locals are living spread out around the island, the current low voltage transmission line is not feasible for the hybrid system. To implement a centralized electricity supply system covering all households on the island, grid transmission and distribution lines need to be installed. A high voltage transmission line with 3 phases is recommended to minimize the voltage drop in the line. Consequently, a 22kV transmission line shall be considered. The grid may consist of:

- Transmission Line: 3 x 5,400 m of 22 kV 50 sq.m SAC aluminium
- Distribution Line: 25,000 m of 750 V 50 sq.m THW-A Aluminium
- 5000 m OHGW 25 sq.m: 5,000m
- 140 concrete poles (height 6 m)
- 275 street lights
- Transformers: 100kVA (West) + 160kVA (Middle) + 100kVA (East) + (350kVA; spare)

3.3 Financial Analysis

The approach was to compare different electrification scenarios for Mak Noi island as mentioned above (Chapter 3.2.1). Table 6 gives an overview of all CAPEX and OPEX cost. The CAPEX is covering all expenditures to implement the RE hybrid grid system at the beginning and are based on a market review conducted by ILF. Offers from different technology suppliers were requested in order to determine realistic estimations for the Thai market. Operation and maintenance cost as well as replacement expenditures for all components are summarized in the OPEX as stated. The HOMER simulation served as a basis to estimate the year and number of replacements needed for each component. Therefore, HOMER simulated real time system operation over the time period of 30-years taking changing weather conditions into consideration. Together with the specifications that were entered to the software for each system component the operation hours of the components were determined and replacement schedules calculated.

Table 6: CAPEX and OPEX for the RE hybrid grid system



Components	CAPEX	OPEX	No. of Replacement
Diesel Generators	2,042,400 THB	3.74 THB/kWh (500,438 THB in 2018)	6
Solar PV	17,020,000 THB	272,320 THB	Inverter: 1
Battery	17,156,160 THB	291,655 THB	Battery: 3 Inverter: 1
Others (i.e. grid, meters, etc.)	15,219,284 THB	51,060 THB	-
Total	**51,437,844 THB**		

PEA provided GIZ with the load forecast (as mentioned earlier) as well as an overview on CAPEX and OPEX for the implementation of a submarine cable to Mak Noi Island. Figure 18 is highlighting the difference between the CAPEX and OPEX of the RE hybrid grid system in comparison with the submarine cable scenario. With implementation of a RE hybrid grid system, PEA can safe especially upfront on the CAPEX, but also on a long-term basis as the OPEX comparison is showing.

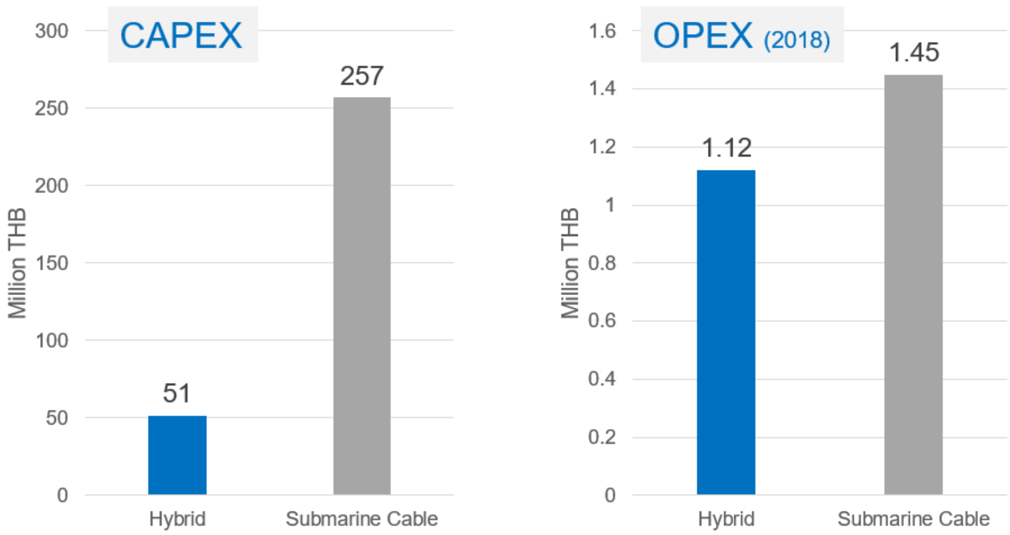


Figure 18: CAPEX and OPEX comparison for RE hybrid grid system and submarine cable scenario

To get a better understanding on the cost of electricity that is generated, the levelized cost of electricity (LCOE) were calculated for both scenarios as well as for the current situation.

- **Current Situation** **25.15 THB/kWh**
  2-5 hours of electricity supply
  decentralized diesel generator
  here calculated for #40 and #41 grids

- **Submarine Cable** **44.33 THB/kWh**
  24/7 electricity supply
  30-years project lifetime

- **RE Hybrid Grid System** **16.61 THB/kWh**
  24/7 electricity supply
  30-years project lifetime

The number show that an RE hybrid grid system would be the most economic option to electrify Mak Noi island.

All technical and financial in- and output is summarized in a separate file ("Annex 5: Summary of Technical and Financial Input").

3.4 Regulatory Framework

As PEA has been established under the Provincial Electricity Authority Act which clearly indicates PEA's mandate in provision of electricity supply, PEA owns the authority to develop this project under the existing regulatory framework.

Only complication is on the land use regulation which has just been announced in Phang-Nga province. The details are as the following: In March 2017, the town planning regulation was officially announced in Phang-Nga province. Under this regulation, Mak Noi Island is considered in the "white-light green" zone, meaning the island is situated in a "forest conservation" area (Figure 19).

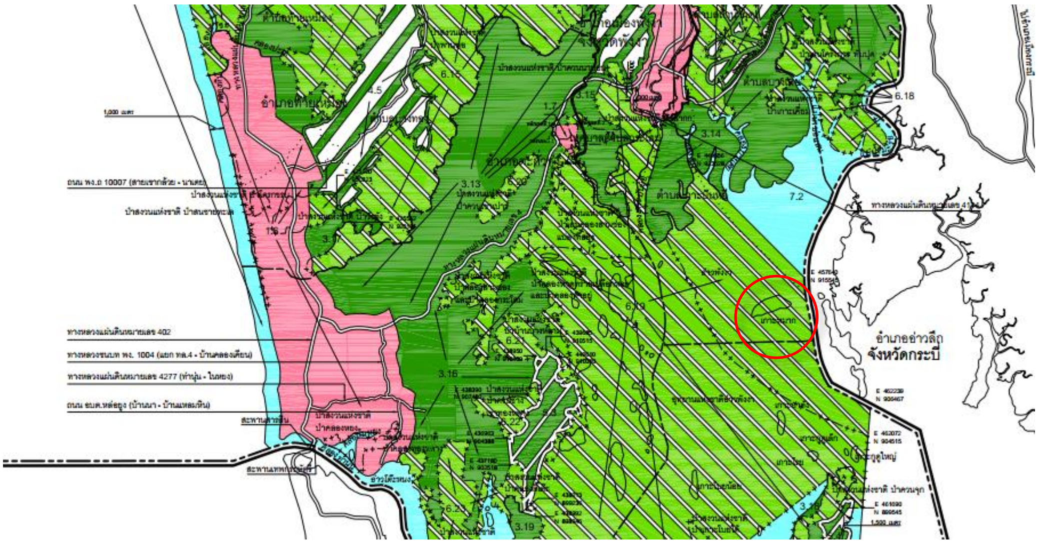


Figure 19 Phang-Nga town planning regulation

This type of land shall be used "for preservation and conservation of forest, animal, water resources, and other natural resources. For a land owned by private, use of this land for agricultural or residential purpose is allowed (area of building no more than 200 sq.m., height of building not higher than 6 m.

For use of area close to public water body, a space must be provided (6 m. measured from water body) unless for construction of water transport infrastructure or other infrastructure."

The definition of this regulation is rather vague and open for interpretation. Unlike other type of land where clear prohibition on use of land for construction of certain application is provided. There is no clear prohibition on use of this type of land. Therefore, there is no clear regulation which prohibits the use of this land for construction of certain factories (solar panels are considered as factories) or infrastructure.

PEA who holds the mandate in provision of electricity has a higher chance in developing the project under this town planing regulation. By classifying this project as infrastructure project and close coordination / exchange with the office of urban and town planning, the permission to develop the project on Mak Noi should be possible.

4 Implementation Plan

4.1 Proposed Project Setup

PEA showed interest to investigate the opportunity to implement a RE-diesel hybrid grid system as an alternative to the submarine cable on Mak Noi island. That is why PEA is the leading stakeholder to implement the project. The proposed project setup is in line with PEA's mandate to connect the remaining off-grid communities of Thailand and act as the grid operator and electricity supplier to the local population. PEA's overall role would be the same as for other PEA electrification projects where they supply communities via an isolated grid running on centralized diesel generators. But instead of installing generators only, the system would comprise additional PV modules, inverters and battery capacities. Figure 20 shows the proposed project setup where PEA is supplying the community with electricity through a centralized grid.

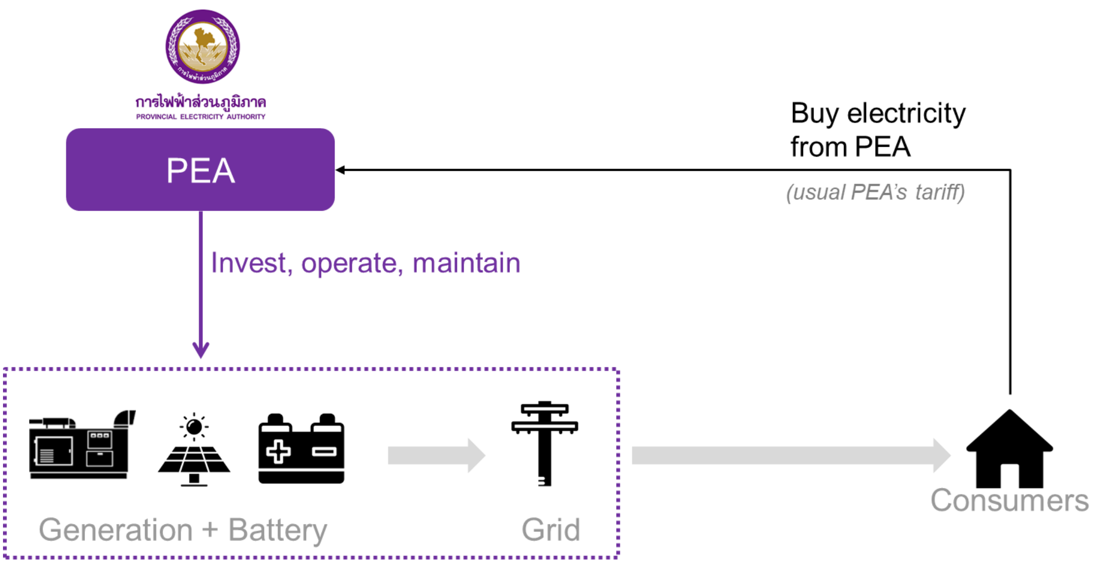


Figure 20: Proposed project setup for Mak Noi island

4.2 Next Steps and Timeline

This document serves to facilitate PEA's internal decision-making process. Apart from the technical and financial analysis one key aspect to make a decision is the land use right as explained above.

1) Land Usage Rights: PV system and power house
   Therefore, clarification on the land availability on Mak Noi is key. ILF, GIZ, Mak Noi community as well as the SAO came up with the most suitable location to install the PV system as well as the power house. The identified area belongs to the SAO and is right behind the health center (see Figure 21). Official approve needs to be received before developing the project further. PEA Bangkok Office together with the PEA Regional Office in Phang-Nga offered to clarify this issue as a first step.

Figure 21: Suitable area for PV installation (behind the health center, close to the pier

2) Technical and economic evaluation by PEA – decision making
   GIZ will assist PEA to evaluate the project from a technical and economic point of view and will support PEA's internal processes.

3) Development of project proposal and detailed layout plan
   In case PEA's decision results to be positive towards the development of a RE hybrid grid system on Mak Noi, a detailed proposal including the engineering and layout plan needs to be developed based on the knowledge gained through the GIZ project, GIZ can take a supporting role in this process and feed in information wherever needed.

4) Public hearing
   After this a public hearing has to be held to get official endorsement.

5) <u>Procurement of equipment and construction</u>
To start the actual construction, PEA might apply their usual procurement processes (tendering etc.). Usually RE hybrid grid systems can be planned, installed and commissioned within 6-9 month. Depending on PEA's internal, engineering and procurement processes, the system might be ready for operation within the upcoming year. Figure 22 is summarizing an approximate implementation plan for the system.

Figure 22: Proposed implementation plan

5 Preliminary Risk Analysis

As an introductory remark for the risk analysis it has to be mentioned that RE-diesel hybrid grid developers usually calculate with a 10-15 years' time frame for the first system setup and evaluate their systems and the actual load and consumption development during and after this time period. The benefit of RE hybrid grid system is their modularity. These systems can easily be upgraded after a certain time period to address actual load developments in the local community and their needs. These upgrades typically consist of additional PV panels and battery storage, but might also include generator capacities. RE hybrid grid systems are a flexible, low-cost option to electrify remote communities. In order to address PEA's needs for long term planning, the following risk analysis is conducted for a 30-years' time frame.

5.1 Technical Risk

5.1.1 Redundancy Check

The following analysis is looking at the peak load that is expected to reach 330 kW on Mak Noi within a 30-years time frame. Figure 23 shows the available capacities of the simulated system to serve the demand of 330 kW. If all system components work under an ideal situation, the system could easily serve the peak demand.

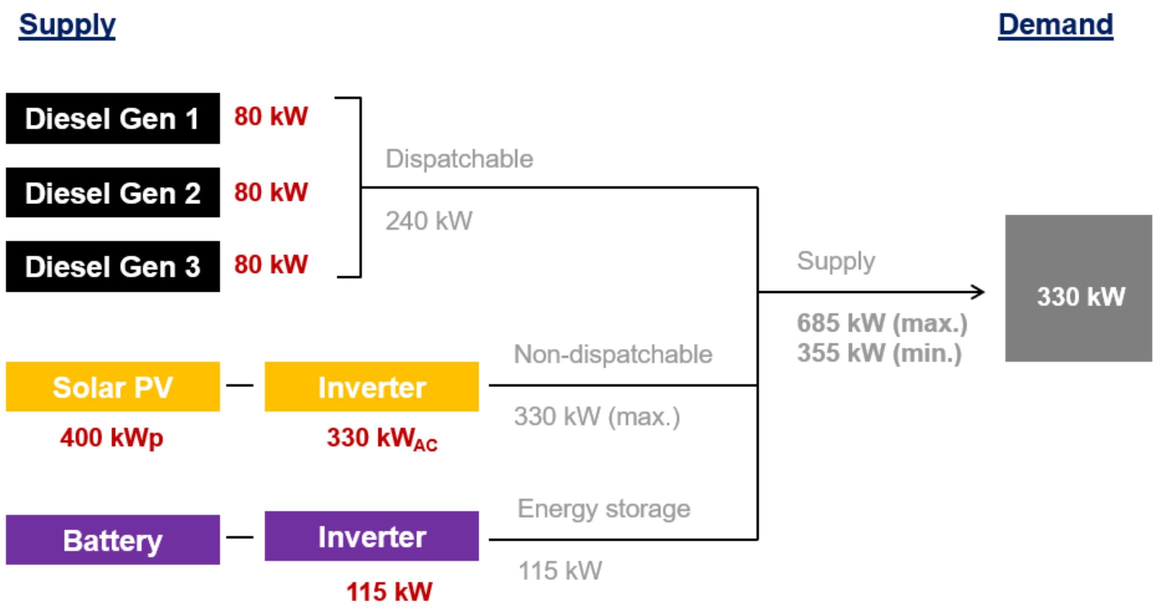


Figure 23: Available capacities to serve the demand

Having said this, we want to look into 3 different scenarios:

- PV failure
- Diesel failure
- Battery failure.

If the PV system fails, the system is still able to serve the demand. The batteries will jump in and get recharged during off-peak time.

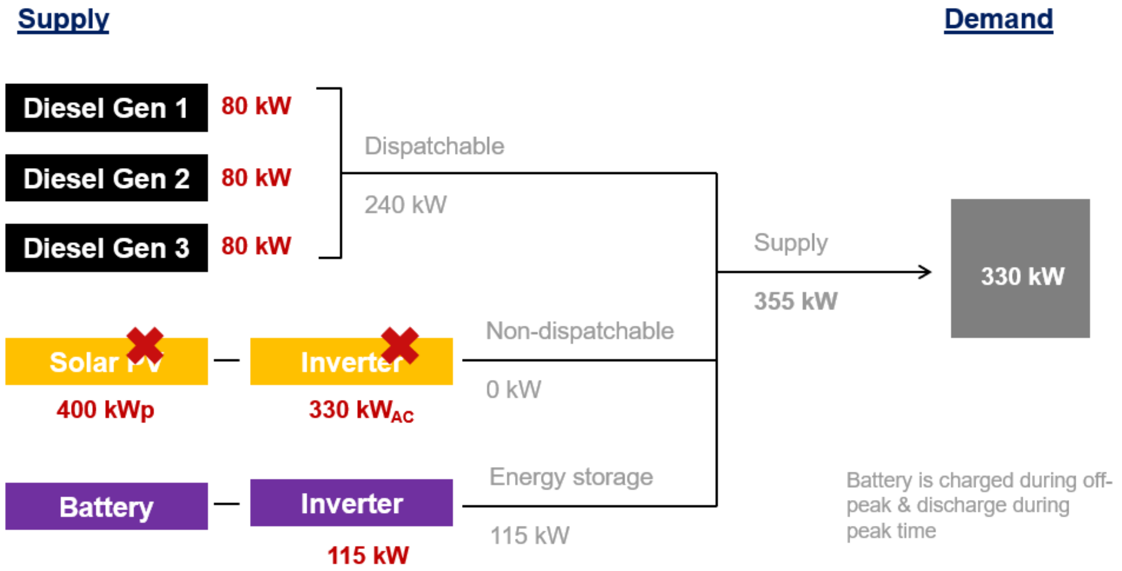


Figure 24: System setup in case of PV failure

If one of the diesel generators fails, the system is lacking 55kW to cover the peak demand which is projected to be in the evening time around 7pm when no PV capacities are available. Looking at the peak demand curve in “Annex 2: Load Forecast (PEA)”, the system would be ready to serve the peak demand in this scenario until year 20.

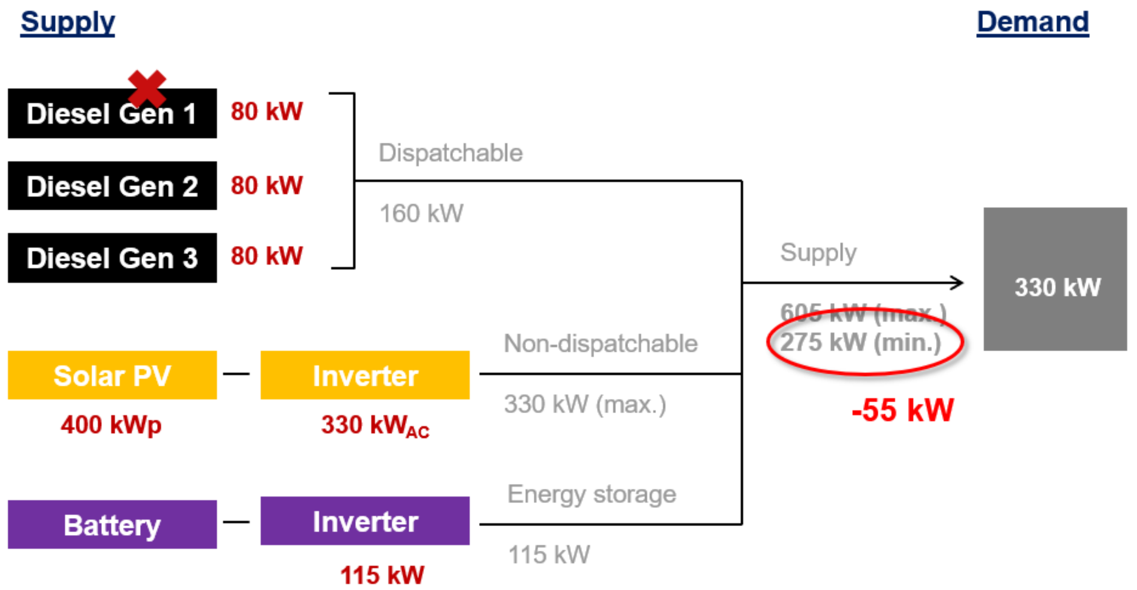


Figure 25: System setup in case of diesel failure

In case of battery failure, the system has a maximum capacity of 570 kW and a minimum capacity of 240 kW to serve the peak demand. As mentioned earlier the peak demand is likely to happen during evening time with no or low sunlight. In this case the system will lack 90 kW of capacity. Looking at the peak load curve again reveals that the system within this scenario is able to fully supply the demand until year 15.

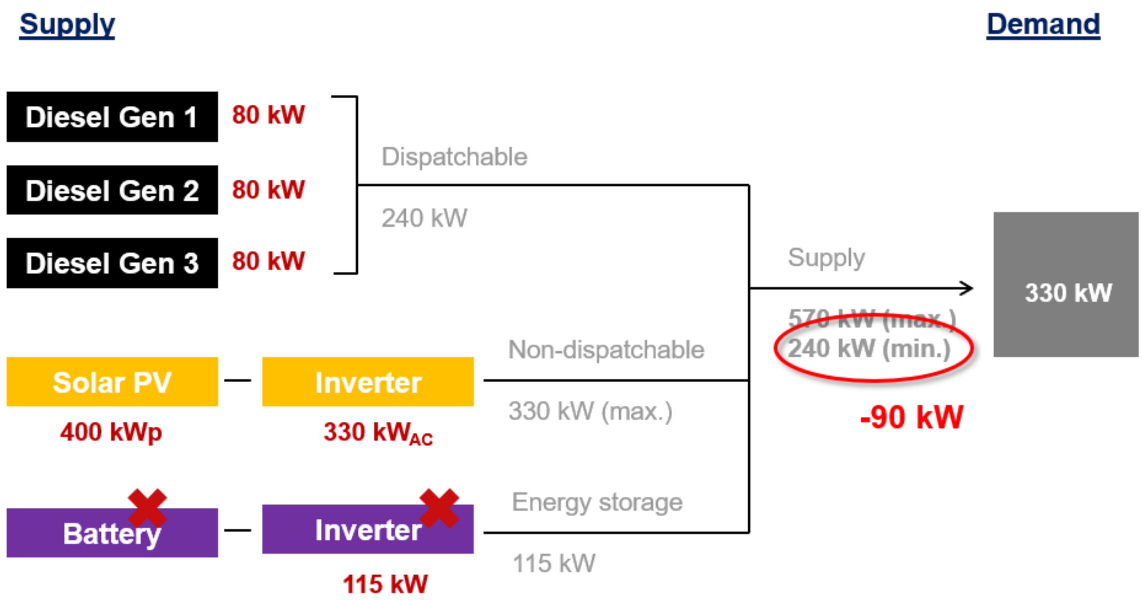


Figure 26: System setup in case of battery failure

Error! Reference source not found. summarizes the evaluated scenarios. The system will be able t o cover the peak demand until year 15 after system installation. As recommended earlier, a load and consumption analysis will be beneficial after year 10 of installation. That way the system can be adapted to the actual situation and continue to run in its original setup or get an upgrade to ensure stable and reliable electricity supply from year 10 onwards.

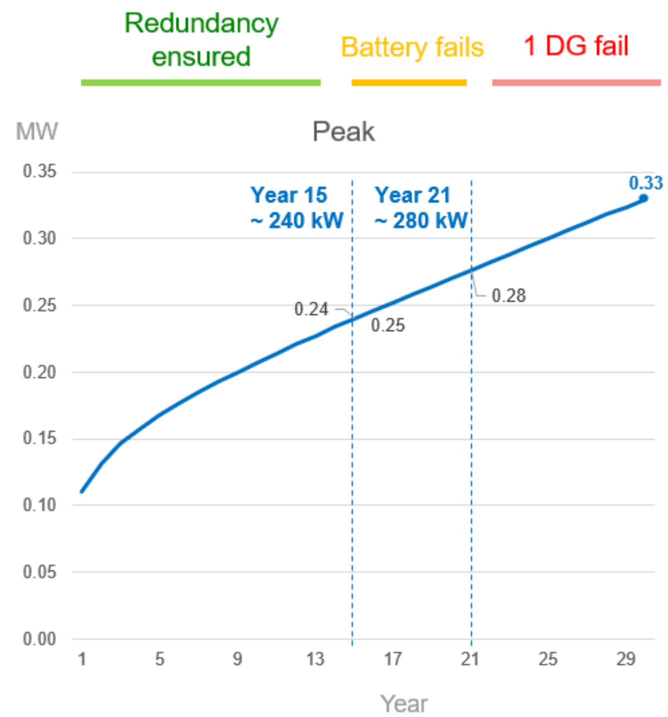


Figure 27:Redundancy summary

An alternative suggested by PEA is to upgrade the diesel generator size at this stage in order to cover the peak load over the next 30 years. This might be a requirement of PEA to develop the RE hybrid grid system and is up for PEA's consideration. Instead of installing three 80 kW diesel generators, the units will have a capacity of 110 kW each (summing up to 330 kW). Technically, it is possible to do so. However, the economics behind will change due to higher CAPEX cost and increased diesel operation hours under their stated capacity within the first years.

5.1.2 Influence of Ambient Conditions

HOMER simulated real time system operation over the time period of 30-years taking changing weather conditions into consideration. The weather data set came from Meteonorm 7 and reflected real ambient conditions in Thailand. RE hybrid grid systems are usually designed in a way to cope with bad weather conditions over a long time period. In this case the diesel generator would jump in and supply the majority of the load.

The following two figures are showing the operation mode (which source supplies the load; charging and dis-charging cycle of the batteries) for “4 consecutive good days” as well as “3 consecutive bad days and 1 good day” as an example.

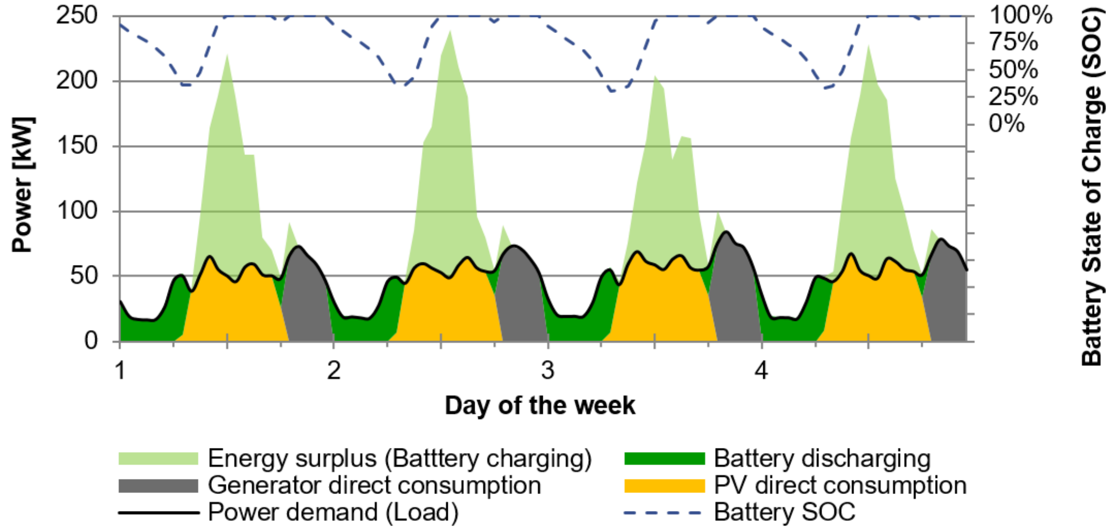


Figure 28: System operation for 4 consecutive good/sunny days

On sunny days the load during daytime is served from the PV system, during early morning from the battery storage and only for the peak evening hours from the diesel generators. The excess energy is used to charge the batteries. This applies to daytime operation, when the solar panels produce a surplus, and the evening peak time, when the batteries are balancing the actual demand with the ideal operation mode of the diesel generators.

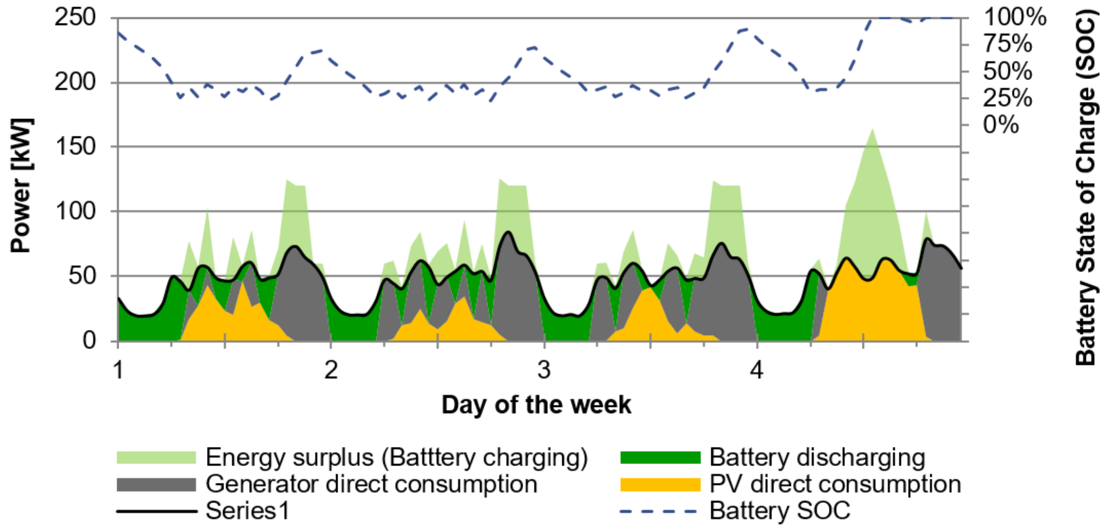


Figure 29: System operation for 3 consecutive bad/cloudy/rainy days and 1 good/sunny day

For the second setup of "3 consecutive bad days" (meaning cloudy or raining days), the system is still able to serve the load reliably. This will be the case for even more consecutive bad days, even though very unlikely in Thailand. The mode of operation is changing and the majority of the load is supplied by the diesel generators. The batteries are charged by the generator only and the PV supplies a small portion of the daytime load.

5.2 Economic Risk

In order to evaluate the influence of different parameters set in the simulation of the system on the LCOE, ILF provided a sensitivity analysis (30-year project duration). The aim was to get an idea to what extend an increase or decrease of assumed key factors such as CAPEX cost, energy demand and fuel price will influence the economics of the designed system.

- CAPEX ± 30% variation in CAPEX leads to a ± 13.73% variation in LCOE
- Energy Demand + 20% variation in energy demand leads to a – 4.66% variation in LCOE

  - 20% variation in energy demand leads to a + 6.18% variation in LCOE
- Fuel Price ± 10% variation in fuel price leads to a ± 3.53% variation in LCOE

This analysis shows, that a variation of CAPEX and a lower energy demand than initially estimated would have the biggest influence on the system's economics (higher price per generated unit). The project developer (in this case PEA) is responsible for the procurement and has a direct influence on the CAPEX. Thus, it is an easy to control risk. The energy demand cannot be directly controlled, but can be influenced through different measures. These measures are e.g. time of usage tariffs or smart meter installation to enable conscious consumption and address mainly the risk of having higher energy consumption than expected. However, a lower energy demand in this special case is very unlikely to happen due to the fact that the cost per electricity for the consumer will dramatically decrease (about 72 %; from 25 THB/kWh to 7 THB/kWh). The electricity is affordable for more and more costumers and thus will provoke a jump in electricity demand on customer side. The project is also benefitting from PEA's long-term experience to calculate realistic load forecasts which is minimizing the risk. In addition to this, the lower energy demand is not affecting system stability and thus PEA's reputation, but has an influence only on the system economics.

6 Impact Assessment

6.1 Local community

For the local community the establishment of a centralized reliable 24/7 electricity supply will mean a lot. Currently they have limited supply hours and are facing frequent black- and brownouts which is

> *Access to a stable electricity supply means a lot, especially to the children living on the island. They often struggle to compete with students from the mainland as they have to learn in hot classrooms, which reduces their concentration, and also suffer from a lack of modern digital teaching measures.* ***- Dumrong Sinto, Chief Executive of the regional Sub-District Authority Organization responsible for Koh Mak Noi***

not only difficult to handle for the people but also affecting the lifetime of the electronic devices connected to the grids. With PEA's involvement, the nation-wide electricity tariff will apply to the island making electricity affordable for the people (currently they pay app. 25 THB/kWh). With grid reliability and cheaper rates, productive use of electricity on the island will be triggered and economic growth is enabled as well as alternative income sources are generated.

As the above quote of K. Dumrong Sinto shows, the quality of education will increase with reliable 24/7 electricity supply. The island's children suffer from over-heated classrooms and a missing access to modern teaching methods. It is hard for them to compete with onshore students for higher education. The implementation of a RE-diesel hybrid grid system will help to tackle these challenges.

The good reputation of solar and green energy will increase over time and make the community more aware on the benefits of renewable energy and thus might lead to additional renewable energy technologies on the island. Mak Noi community could play a role model for other island communities.

6.2 PEA

Implementing the RE hybrid grid system instead of a submarine cable would lead to reduced investment and operation cost on PEA's side. These saving are upfront (lower CAPEX) as well as on a long-term basis as OPEX for the RE hybrid grid system are lower compared to the submarine cable. Developing this pilot site, Mak Noi can serve as a role model for other islands, the upscaling potential in high. Especially for very remote Thai islands very far from shore this is the best option to receive reliable and sustainable electricity supply. Figure 30 is outlining the applicability of different electrification approaches (namely grid extension, mini-grid implementation and solar home system installation). On most Thai off-grid islands, the population is quite dense and the distance to the national grid high making these islands a perfect match for RE-diesel mini-grid development.

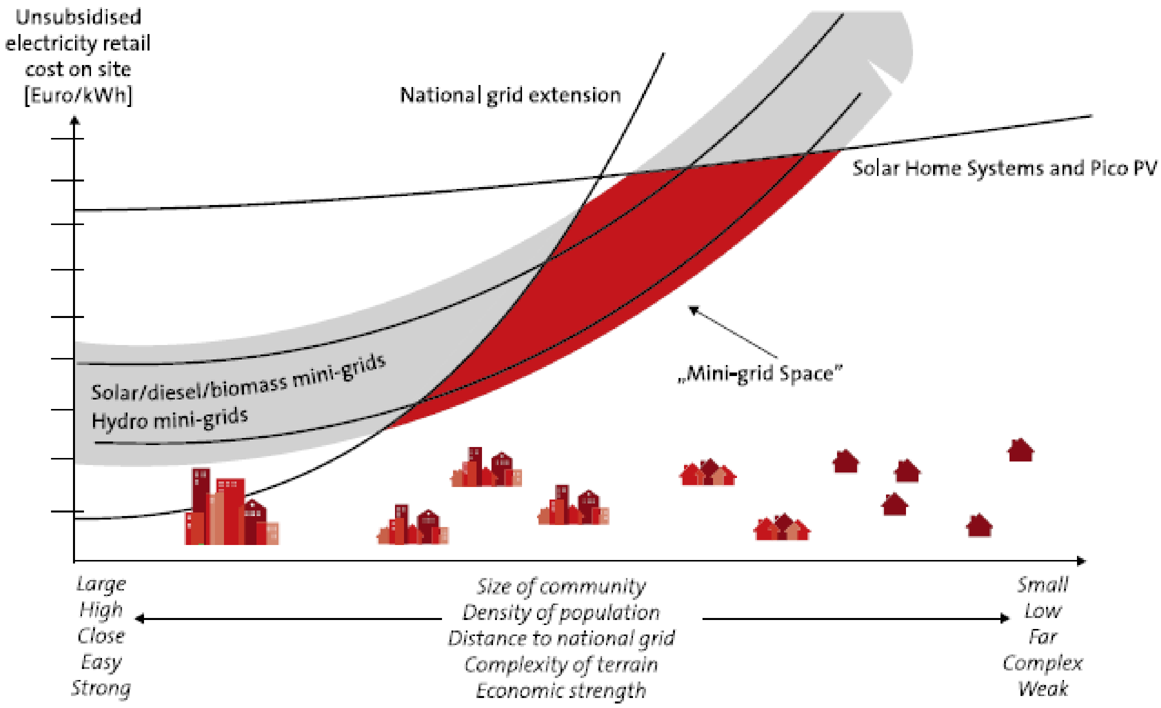


Figure 30: Illustrating the mini-grid space [Source: Inensus]

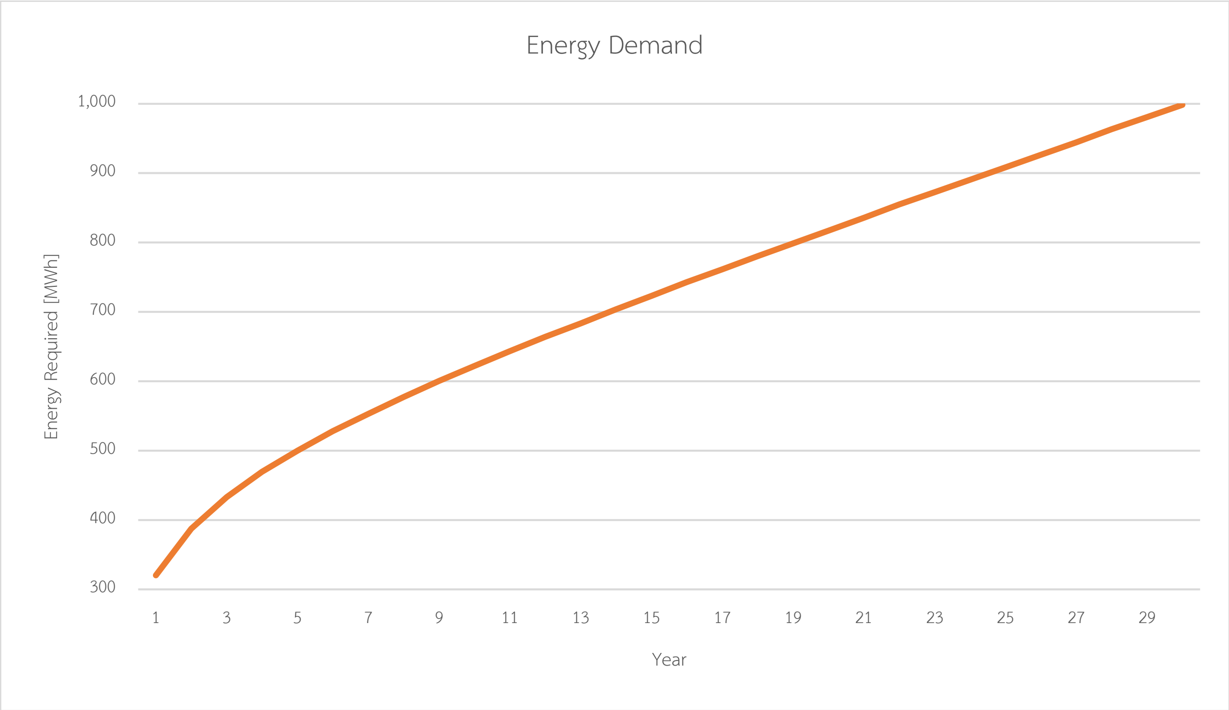
In addition to the financial savings, PEA will benefit from the green image and innovative approach to connect the island. There is also the opportunity to use this project as a reference in pursuit of the smart grid action plan, fulfilling public requests (e.g. from EPPO) and PEA's responsibility to connect the remaining off-grid communities in an efficient way (generally RE hybrid grids can be developed faster than submarine cables).

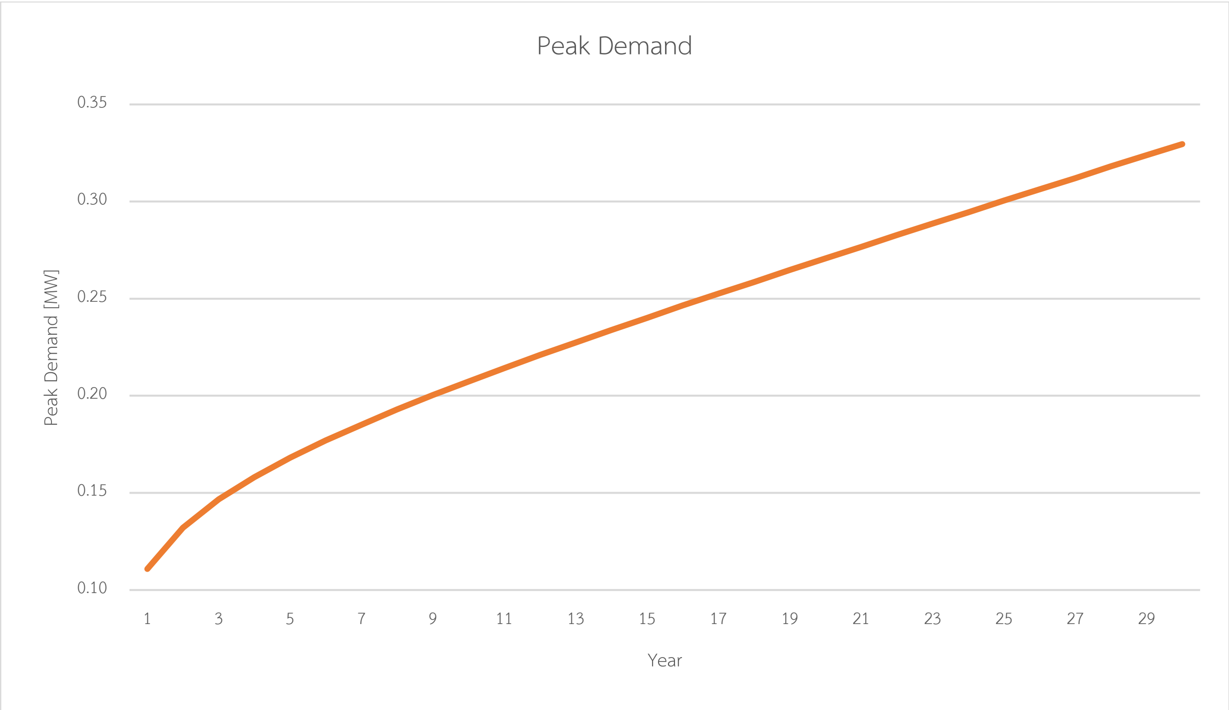
Annex 1: Survey Results

See separate Excel file:

“Annex 5_Project Summary Table_Hybrid System_MakNoi”

Annex 2: Load Forecast (PEA)



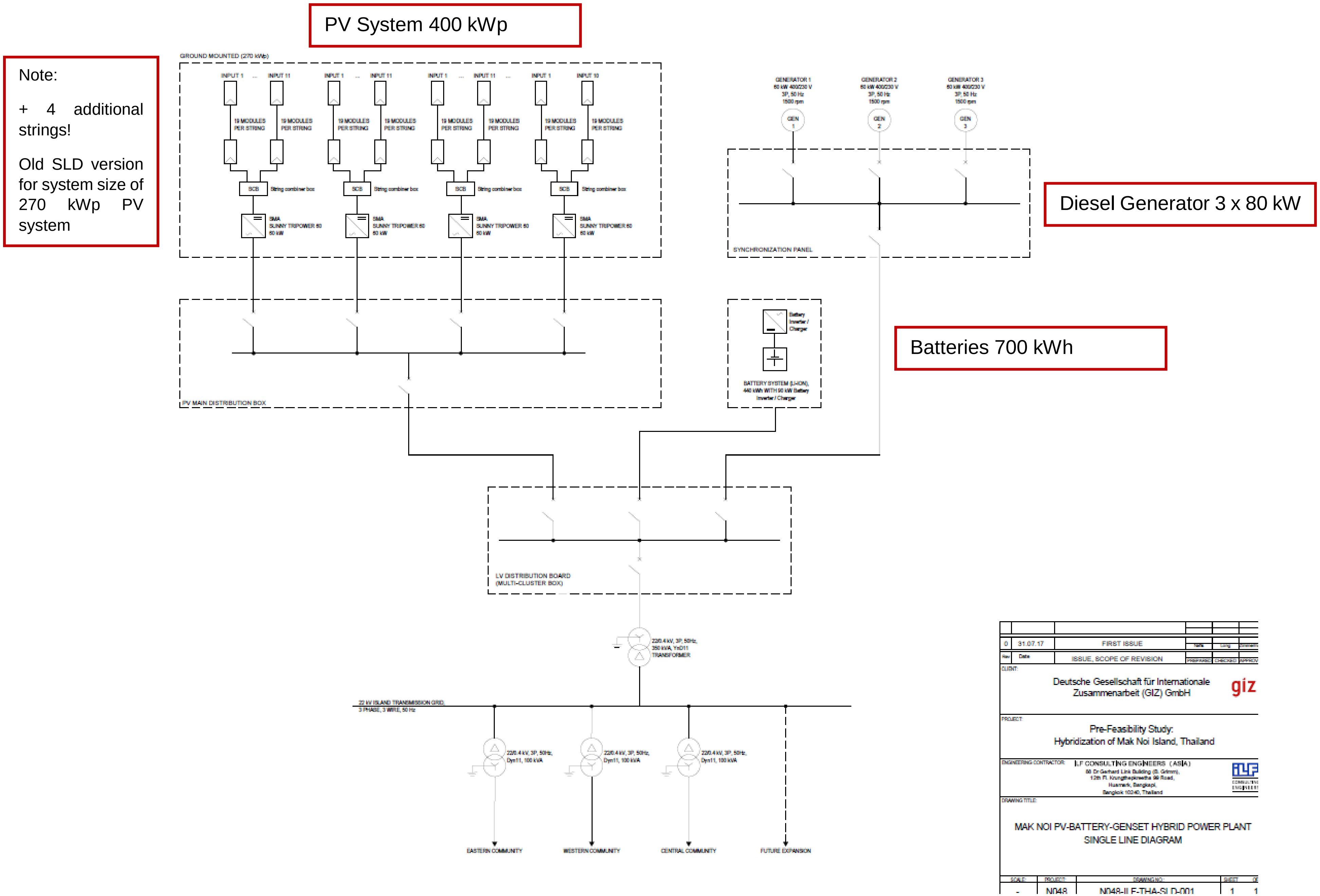


PROGRAM YEAR	RESIDENTIAL (MWh)	%GROWTH (MWh)	SMALL GENERAL SERVICE (MWh)	%GROWTH (MWh)	OTHER (MWh)	%GROWTH (MWh)	TOTAL SALES (MWh)	%GROWTH	ENERGY REQ. (MWh)	PEAK DEMAND (MW)	LOAD FACTOR (%)
1(2564)	249		43		6		298		320	0.11	32.98
2	295	18.64	59	37.31	6	0.00	360	20.96	387	0.13	33.49
3	327	10.87	70	17.63	6	0.00	403	11.80	433	0.15	33.72
4	352	7.70	78	12.16	6	0.00	436	8.36	469	0.16	33.88
5	374	6.25	85	8.52	6	0.00	465	6.57	500	0.17	33.96
6	394	5.20	91	7.48	6	0.00	491	5.55	528	0.18	34.05
7	412	4.53	96	5.82	6	0.00	514	4.72	553	0.19	34.10
8	429	4.19	102	5.61	6	7.14	537	4.49	578	0.19	34.17
9	445	3.76	106	4.54	7	6.67	558	3.94	600	0.20	34.21
10	460	3.46	111	4.61	7	0.00	579	3.64	622	0.21	34.26
11	476	3.34	116	3.80	7	0.00	598	3.39	643	0.21	34.27
12	491	3.08	120	3.98	7	0.00	618	3.22	664	0.22	34.31
13	505	2.90	124	3.32	7	0.00	636	2.95	684	0.23	34.32
14	519	2.78	128	3.54	7	6.25	655	2.97	704	0.23	34.37
15	533	2.65	132	2.97	8	5.88	673	2.75	723	0.24	34.39
16	547	2.63	137	3.21	8	0.00	691	2.72	743	0.25	34.41
17	560	2.48	140	2.71	8	0.00	708	2.49	761	0.25	34.42
18	573	2.37	144	2.96	8	0.00	726	2.46	780	0.26	34.44
19	587	2.38	148	2.50	8	0.00	743	2.38	799	0.26	34.44
20	600	2.25	152	2.75	8	0.00	760	2.33	817	0.27	34.46
21	613	2.17	156	2.33	8	5.56	777	2.24	836	0.28	34.48
22	627	2.18	160	2.58	9	5.26	795	2.30	855	0.28	34.50
23	640	2.07	163	2.19	9	0.00	811	2.08	873	0.29	34.51
24	653	2.01	167	2.44	9	0.00	828	2.07	891	0.29	34.52
25	666	2.03	171	2.07	9	0.00	845	2.02	909	0.30	34.52
26	679	1.93	175	2.32	9	0.00	862	1.99	927	0.31	34.54
27	691	1.87	178	1.97	9	5.00	878	1.92	944	0.31	34.55
28	704	1.90	182	2.21	10	4.76	896	1.99	963	0.32	34.57
29	717	1.81	185	1.88	10	0.00	912	1.81	981	0.32	34.57
30	730	1.76	189	2.11	10	0.00	929	1.81	998	0.33	34.58

Annex 3: Simulation Inputs

Parameters	Values	Parameters	Values
Diesel generator		**Battery & inverter**	
Brand/model	Generac Protector	Battery Technology	Li-ion
Rated power	80 kW x 3 (Total 240 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		

Annex 4: Single Line Diagram



Annex 5: Summary of Technical and Financial Input

See separate Excel file:

“Annex 1_Survey Summary_MakNoi”

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