Renewable Energy Hybrid Grid Systems for Thai Islands

Project Report

giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

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The information provided has been gathered by Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH within the framework of the "Renewable Energy Hybrid Grid Systems for Thai Islands" project funded by The Rockefeller Foundation.

The project's objective is to implement hybrid grid systems on islands in Thailand to address the issue of limited, expensive and unreliable supply of electricity by fostering sustainable community-based business models and partnerships. Liability claims through the use of incorrect or incomplete information are excluded.

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Abbreviations

CAPEX	Capital Expenditure
CC	Cycle Charging
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH
ILF	ILF Consulting Engineers
LCOE	Levelized Cost of Electricity
OPEX	Operation Expenditure
PEA	Provincial Electricity Authority
PEnOs	Provincial Energy Offices
PV	Photovoltaic
RE	Renewable Energy
SAO	Subdistrict Administrative Organization

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Renewable Energy Hybrid Grid System for Thai Islands

Project Report

1 Introduction

Access to electricity is a top priority for policy-makers in Southeast Asia. Countries across the region have made great progress in addressing the issue, with electrification rates rising by 28 percentage points since 2000, and are now at 90% [1]. The large number of communities situated on remote and difficult to access islands makes the challenge to reach the last mile more difficult. Despite the above-mentioned efforts, it is estimated that 65 million people still lack access to electricity in Southeast Asia [1].

Thailand has one of the highest electrification rates (99 %) in the region, but many Thai island communities remain with limited to no access to electricity. There are more than 900 islands located in the Gulf of Thailand and the Andaman Sea. Out of the 200 inhabited islands, merely 20 islands are connected to the national grid via high voltage cables. Without connection to the national grid, there is limited availability of electricity due to high cost and low reliability of current diesel generator systems: The average cost of electricity per unit (kWh) is USD 0.5 – 0.7, six times higher than electricity from the national grid which is priced at USD 0.08. As such, local villagers only consume electricity for basic household uses and shop lights which offer limited economic activities. Given the maturity of solar photovoltaics (PV) technology over the past years and the solar irradiation resources in the region as well as decreasing battery storage prices, it is expected that integrating these into an island renewable energy hybrid mini-grid system (RE hybrid system) will not only increase hours of electricity supply but also drive down the cost of electricity. An optimally designed hybrid system has the potential to provide electricity for 30-50 % cheaper per unit price compared to pure diesel systems.

Rural electrification remains a multifaceted challenge, achieving universal access across a very diverse region requires careful consideration of the specific situation and needs of different local communities, geographies and political frameworks making one-size-fits-all approaches is unfeasible. This marks the key barrier of RE hybrid system development. Implementers such as governments, utilities and private companies often refrain from efforts to be taken for RE hybrid system development. Project pre-development takes disproportionally more resources than other RE or electrification projects, is time-consuming and cost-intense. Innovation, flexibility and risk readiness emanating from governments, academia and the private sector are required if access to sustainable energy is to be achieved for all.

The “Renewable Energy Hybrid Grid Systems for Thai Islands” project aimed to bridge the project development gap, matching the plentiful market potential for RE hybrid systems and potential implementers through the development of pre-feasibility studies and business model recommendations for two selected pilot sites in Thailand. This report serves to outline the approach, progress and outcomes of the project from December 2016 to February 2018. It first gives background to the project and briefly discusses steps taken and results achieved by implementing the 1-year project. This section also includes lessons learnt and best practices developed throughout the project implementation. After this a general overview of RE hybrid systems, their benefits and design processes are executed followed by a detailed presentation of the two selected pilot sites namely Mak Noi and Bulon Don Island and a project outlook.

2. Project Results

2.1 Background

The “Renewable Energy Hybrid Grid System for Thai Island” promotes the deployment of renewable energy sources on Thai Islands. The Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH - supported by The Rockefeller Foundation - showcases how renewable energy diesel hybrid mini-grid systems (RE hybrid systems) can reach the last mile with reliable electricity access for off-grid communities. These systems are an answer to limited electricity access and expensive, intermittent supply.

Thai off-grid islands are often remote and hard to reach, cost for project development are high, while islands are small. Usually, significant capacity building is needed to convince local communities of the benefits at hands. This project thus aims to address these barriers and pre-develop island solutions by conducting pre-feasibility studies, engaging 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.

2.2 Approach

The overall implementation process is summarized in Figure 1. Out of a pool of five islands, three were selected for a site visit. After data evaluation and analysis, we selected two islands to conduct the pre-feasibility studies. As time was limited, this step-wise approach led us to the most suitable islands as pilot cases within this project. However, roll-out potential to further islands has been identified throughout the project. (see Outlook – Reaching the Last Mile…).

A detailed analysis of the status quo and the local context during the site assessment served as basis for solid load forecasts and future peak demands necessary for system optimization and design. With these system designs and financial figures, we were able to evaluate most suitable operation and business models with different stokeholds active in the field and gathered feedback for their refinement.

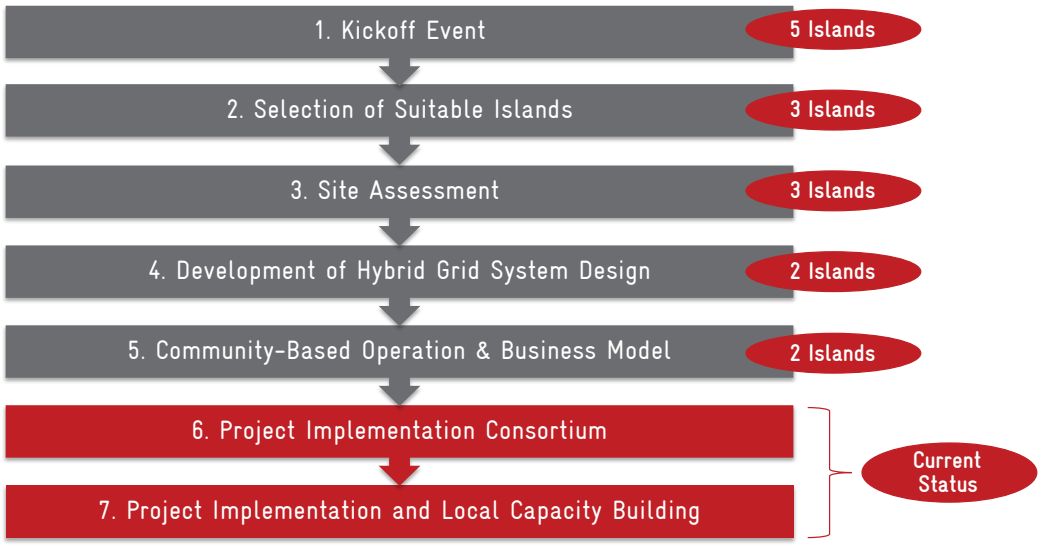


Figure 1: Steps for Sustainable Project Implementation and Project Progress

2.3 Results

2.3.1 Identification of Suitable Islands

To identify suitable islands our first step was to develop a site selection criteria catalogue based on best practices from projects implemented in Asia and Africa. The catalogue provided relevant criteria to which islands could be selected (see Annex 1: Site Selection Criteria Catalogue). Out of five previously identified suitable islands, we selected three for a technical site assessment: Koh Mak Noi, Koh Bulon Don, Koh Bulon Lae.

The actual selection of these three islands was based on desk-research and the information gathered during a Kick-Off Event in January 2017 for which we invited representatives of all communities as well as the Provincial Energy Offices (PEnOs) responsible for these islands.

Lessons Learnt: Build upon developed relationships and trust

The islands were pre-selected based on desk-research and information gathered in a one-day event in Bangkok where the community representatives and PEnOs reported on the current electricity situation and needs of the communities. For this pilot project the approach was the most efficient one due to time constraints. However, relationship management with all relevant local stakeholders was quite time-consuming and information about the islands and their current electricity situation kept changing while consulting these or the local communities. For a follow-up project it is recommended to first focus on the areas we already worked with and support an inter-agency and inter-region exchange (e.g. local governments from different areas including those we already worked with in joined meetings to introduce the project) when working with new areas. This way we can build upon trust and a well-established network to all relevant stakeholders which were gained throughout the project.

Lesson Learnt: Align the data collection process closely with the local stakeholders (SAO, National Park, PEnOs) and PEA in joint meetings

Collecting homogenous information from local stakeholders presented us with a challenge. Different organizations/ entities presented different facts about the respective islands. Sometimes information received changed frequently. It is recommended to align data gathering closely with all involved local stakeholders e.g. Subdistrict Administrative Organization (SAO), National Park Office, PEnOs, community and PEA and to arrange joint meetings to guarantee maximum transparency for simulation inputs as well as to ensure obtaining accurate information.

Good Practice: Stakeholder Involvement and Engagement

Involving relevant stakeholder since the very beginning is crucial even though some will not play crucial roles in project implementation. The local governments and energy offices supported the project and joined many field trips and community meetings. With this endorsement it is easier to communicate to the communities and approach implementing partners.

2.3.2 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 that included interviews, surveys and community meetings to evaluate the feasibility of RE hybrid system implementation. In addition to that GIZ mapped the islands indicating the GPS location of households and their current electricity supply (no supply, solar home systems, private diesel generators or shared diesel generators) and marked the grid connections to respective shared generators (if any). Based on the data and information gathered, two islands were selected to proceed with establishing technical designs for the hybrid system: Koh Mak Noi and Koh Bulon Don.

Lessons Learnt: Plan with sufficient buffer time to compensate last minute meeting changes and necessary logistical rearrangements due to changing weather conditions

The logistical arrangement for site visits to remote islands are quite challenging and it is recommended to plan sufficient buffer time of at least one day to address last-minute changes. Travel schedules had to be adjusted because of changing meeting appointments of local stakeholders (SAO, National Park). We also got stuck on an island for one day because of changing weather conditions (waves were too high for a boat ride).

Lesson Learnt: Take time to conduct the socio-economic surveys and GPS mapping

While conducting the socio-economic surveys on the island we realized how time-consuming this task is on a remote island. The interviewers had to start the surveys with a quick project summary as most villagers could not recall all information provided in the community meetings. To treat them with respect and gain their trust a bit of small talk had to be included in most conducted surveys. Many of the villagers are also quite frustrated by the electricity situation and had the need to express this in their talks with the interviewers. We planned with app. 10 minutes per survey and ended up in some 15-30 minutes talks. As the surveys serve as a basis to understand the islands context and community as well as to analyze current electricity demand, the survey were essential for all further steps and need to be conducted without rush.

Good Practice: Socio-economic survey form

The developed survey form for the socio-economic assessment on the island covered all relevant aspects and made further evaluation simple and meaningful. The form can be found in the Annex (A.2.1 Survey Form)

Good Practice: Conducting socio-economic surveys in-house

To conduct the socio-economic surveys in-house is a great opportunity to really understand the conditions and needs of off-grid island communities. Part of the highly relevant information was shared between the lines while conducting the surveys during the first site visit or in personal talks during follow-up visits. This was because we knew the people from the interviews better and could connect easily with them.

Good Practice: GPS mapping

Mapping the households via GPS and adding information about their current electricity situation and grid connections (if any) in parallel with the surveys turned to be very useful. It helped us to evaluate the results and to get a better overview of the island's situation and the number of households.

2.3.3 RE Hybrid System Design

After assessing the sites and gathering the data needed, we calculated specific hybrid system designs for the two selected islands. These designs became part of a pre-feasibility study which provided a socio-economic, technical and financial assessment of the project.

The simulations showcase how a reduction of the current electricity prices via hybridization with solar and battery capacities can be achieved. Compared to 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. The results are summarized in the figures and tables below.

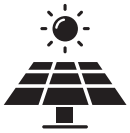
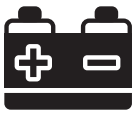
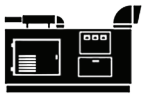
		Mak Noi Island	Bulon Don Island
 Solar-PV	■ Total capacity: ■ PV – inverter: ■ Inverter type:	400 kWp 330 kW AC string inverter	52.14 kWp 46 kW AC string inverter
 Battery	■ Technology: ■ Total capacity: ■ Battery – inverter:	Li-ion 700 kWh 155 kW	Li-ion 100 kWh 27.3 kW
 Diesel generator	■ Total capacity:	3 x 80 kW	3 x 15 kW

Figure 2: System design for Mak Noi and Bulon Don island; Icon Source [2]

	Mak Noi Island	Bulon Don Island
Currently:	25.15 THB/kWh	63.69 THB/kWh
Diesel/PV/Battery Hybrid System:	16.61 THB/kWh	16.44 THB/kWh
Submarine Cable	44.33 THB/kWh	-
100 % Diesel Scenario:	19.56 THB/kWh	22.53 THB/kWh

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

The levelized cost of electricity (LCOE) for the RE hybrid system on Mak Noi are significantly lower (38 %, see Figure 3) than the LCOE for the submarine cable. From an economic perspective, the RE hybrid system would be the best option to electrify Mak Noi island.

LCOE for the RE hybrid system on Bulon Don are also significantly lower than current LCOEs (74 %) and in comparison with a 100 % diesel supplied system (27 %). From an economic perspective, the RE hybrid system would be the best option to electrify Bulon Don Island.

Lesson Learnt: 100% RE share scenarios

When initially drafting the technical designs for the hybrid systems, we focused on scenarios where the LCOE was as cheap as possible. This involved finding a good balance between solar/battery and diesel used. A 100% solar/battery scenario we excluded as this constellation requires higher CAPEX costs. However, during the discussions with the involved stakeholders they requested scenarios that got rid of fossil fuels completely.

Good Practice: Technical consultant with international experience in the field

It was a good pick to choose an internationally operating consultant with proven experience in field work and designing RE hybrid systems for remote areas. They added value to the project and the team could benefit and learn from their experience.

2.3.4 Business Models and Implementation Consortium

GIZ explored different business models suitable for implementing RE hybrid systems that add maximum benefit to the local communities while ensuring sustainable long-term operation based on international best practices and lessons learnt. Figure 4 is giving an overview of the different models that were evaluated and considered within the project.

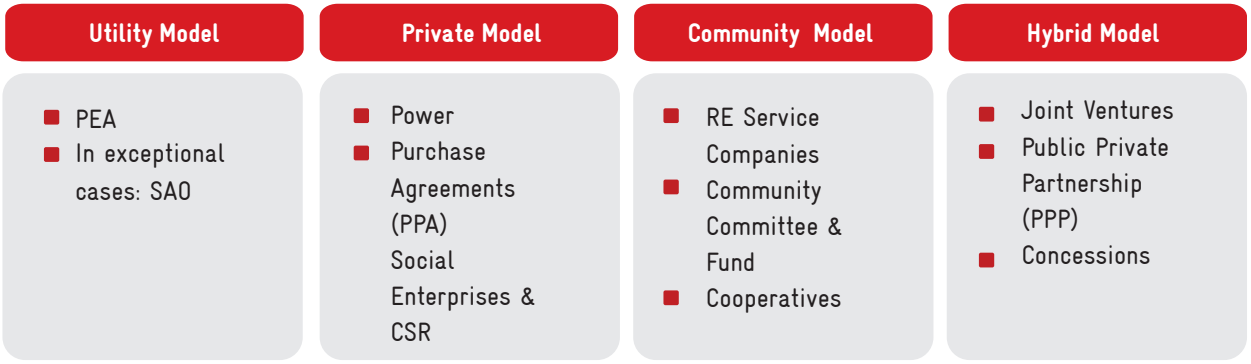


Figure 4: Business models which were explored within the project

Based on this GIZ organized several stakeholder consultations and meetings (28 in total) with potential project implementers such as PEA, private companies and local governments. In these meetings the two most suitable business and project implementation models for each island case were identified and refined.

While developing the first pilot site (**Mak Noi Island**), GIZ involved the Provincial Electricity Authority (PEA) of Thailand as they had plans to electrify this specific island. Mak Noi is listed 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 a RE hybrid system instead of a submarine cable.

Mak Noi Island – Utility Model

Current Status:	From a technical and economic point of view PEA is convinced that a RE hybrid system is the better option to electrify Mak Noi and they informally agreed to implement the system. Official decision-making process is pending as the land acquisition is currently explored by PEA's regional office in Phang Nga together with the local government. PEA's Central Office is elaborating the implementation process further, supported by GIZ.
Implementation Timeline:	App. 2-4 years; this will be PEA's very first RE hybrid system and new ways need to be paved
Tariff Design	PEA applies their usual tariff structure
Impact:	Alternative business model for PEA's rural electrification strategy with high rollout-potential

For the second pilot site, **Bulon Don Island,** GIZ identified a private company to develop one of the first commercially viable RE hybrid systems in Thailand. The focus is purposely set on ensuring commercially viable operation, in full transparency and partnership with the local community.
Too many examples of failed cooperation projects exist, where power systems are donated (with all good intentions) but long-term operation cannot be ensured. The aim of the project is to ensure long-term operation and competitive power production for local people meaning power systems are not donated to island communities, but expert commercial players sell cheaper and cleaner electricity with a long-term commitment to the local people. A solar company plans to develop this first case as a reference project with a view to rolling-out further projects based on the lessons-learnt. The company cooperates with the local government who already installed grid infrastructure on the island.

Bulon Don Island – Public Private Partnership

- Current Status: The company is currently finalizing the proposed tariff structure and is having meetings with all involved stakeholders facilitated by GIZ. Final decision will be made after approval or denial by the National Park to implement the RE hybrid system.
- Implementation Timeline: 1 year
- Electricity Tariff Design: To be negotiated between the private company and the community; currently 22 THB/kWh.
- Impact: Pilot case for a new market segment of the involved company. The project promises potential to scale up and benefit from lessons-learnt. It also raised interest of other companies active in the hybrid sector showing interest in projects on bigger scale (pipeline of projects or bigger project size).

More details for each project setup and implementation consortium is given in the respective pilot case chapter (Pilot Case Mak Noi Island and Pilot Case Bulon Don).

Lessons Learnt: Capacity building and knowledge sharing of involved stakeholders

RE-hybrid grid systems are relatively new to the Thai context. Local governments and public enterprises especially had limited knowledge on these kinds of systems when starting the project. It is recommended to account for sufficient time and opportunities for all involved stakeholders to learn and understand about the details of RE-hybrid systems, their potential, benefits and limitations. Within the project we always addressed this issue and were open to all questions and requests. Changing representatives in follow-up meetings made the task of bringing everyone to the same page a recurring task. A standard presentation or even training about RE-hybrid systems would have been beneficial to facilitate efficient communication and knowledge sharing.

Good Practice: Stakeholder consultations - process to define a project consortium

At the beginning of the project it was not clear which way the implementation of RE hybrid systems on the two pilot islands would go. The strategy to reach out to as many relevant stakeholders as possible was a great success. We presented the feasibility studies to 11 different private companies as well as to PEA and local governments. While discussing and gathering feedback it became clear, that we will get two different models for the two pilot islands. It was a natural selection process and we received many expressions of interest in the case we roll-out the project and build-up project pipelines.

Good Practice: Alternative presenting methods and community-expert consultation

When we were travelling back to the islands after our first visit we presented the results of the system simulation and financial calculation and showed potential project implementation setups to gather feedback, make sure that the developed concepts are addressing their needs and finally get endorsement by the community. We designed posters to visualize the results in layman terms so that it was easily understandable and digestible. In order to do so we consulted with community work experts from the Ministry of Energy and prepared and conducted our community meetings together.

Good Practice: Buzz groups to communicate results and gather feedback from community

In addition to the community meetings we walked through the islands to talk to the villagers in informal setups to gather their feedback. We got the feeling that most villagers are more comfortable to express themselves in smaller informal groups having a real conversation about the island's situation. Applying this method, we received a lot of insights which helped us to address their needs better.

3. Renewable Energy Hybrid Grid Systems

3.1 General Information

RE hybrid systems combine a renewable energy technology (in this case solar power through photovoltaic modules) with another power generating energy source (in this case diesel generators). This PV-diesel-hybrid system is commonly implemented internationally. 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 fluctuates, and the generation capacity of the diesel generators is limited to a certain range, it is often a viable option to include battery storage 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 required. All these factors need to be considered while designing RE hybrid systems. Proper optimization using appropriate tools handled by experts in this field is key to technical and financial viability. For this reason, GIZ hired ILF Consulting Engineers (ILF) as the technical consultant and expert to develop the system design. ILF has international experience in designing RE hybrid systems and are familiar with common state-of-the art simulation tools and technology options.

For readers that are new to mini-grids or are looking for short comprehensive summaries on mini-grids are recommended to read the following publication which included further literature recommendations:
“Mini-grid Policy Toolkit. Policy and Business Frameworks for Successful Mini-grid Roll-outs.”

3.2 Application and Benefits

Access to electricity for remote island communities is mostly restricted to unreliable, expensive and environmentally harmful diesel power generation. The limited electricity access hampers social and economic development such as access to communication, improved healthcare and education opportunities. Creating alternative income structures and economic growth through productive use of electricity is therefore limited. The large number of communities situated on remote and difficult to access islands makes the challenge to reach the last mile more difficult.
RE hybrid systems are a promising solution to tackle these challenges. They come with the promise of increasing electricity supply hours and reliability of supply while decreasing cost per generated electricity unit and thus trigger local value creation.

Figure 5 is outlining the applicability of different electrification approaches (namely grid extension, mini-grid implementation incl. RE hybrid systems and solar home system installation). The "Mini-grid Space" is found where mini-grids have the lowest cost (unsubsidized electricity retail cost on site in THB/kWh) compared to grid extension and stand-alone systems [3]. The cost (per unit) of different electrification approaches is influenced to different degrees by various local conditions: the size of the community, the density of the population, the distance to the existing national grid, the topography and general socio-economic factors such as energy demand and economic growth potential [3].

On most Thai off-grid islands, the density of the population is medium, the distance to the national grid high and the economic strength medium making these islands a perfect match for mini-grid development (e.g. RE hybrid systems).

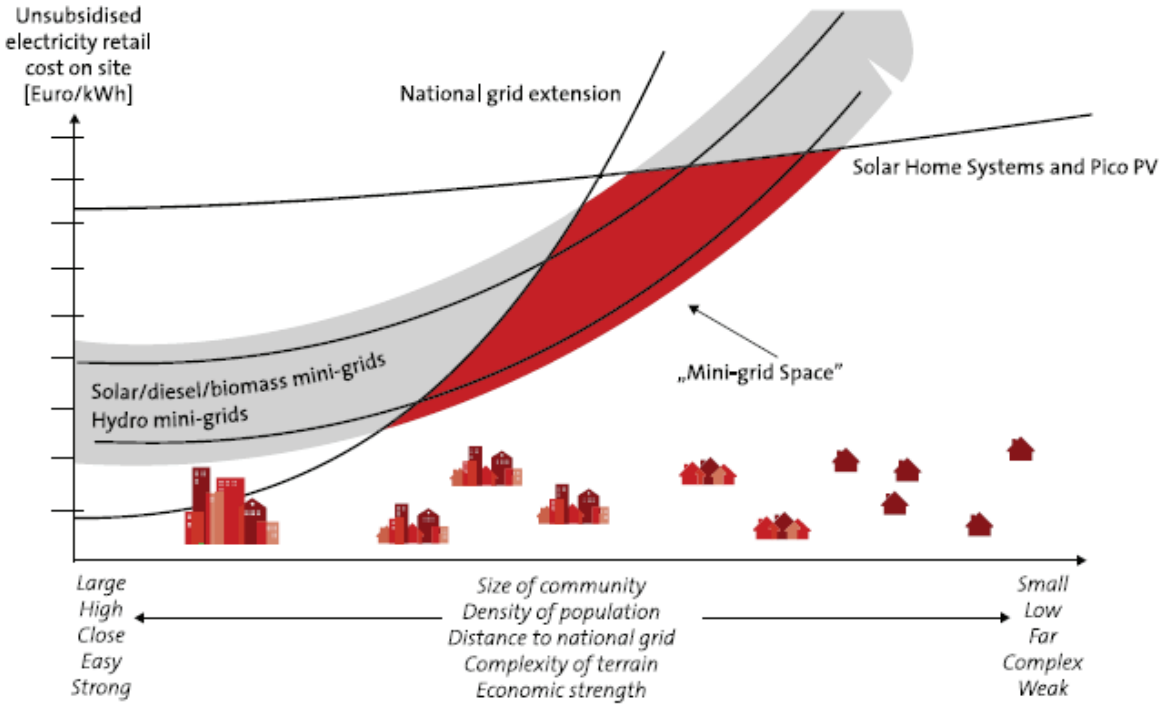


Figure 5: Illustrating the mini-grid space [4]

Compared to national grid extension, mini-grids have several benefits including possible speed of deployment, additional private sector growth, and flexibility of technical and operational models [3].

Mini-grids for example ones that are implemented as RE hybrid systems are modular. They can easily be upgraded after a certain time 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 systems are a flexible, low-cost option to electrify remote communities and are contributing to higher grid stability than systems supplied by purely diesel generators. RE hybrid system developers usually calculate with a 10-15 years' time frame for the first system design and setup. They constantly evaluate and reassess their systems and determine necessary system upgrades according to actual load and consumption development. The modularity of these systems helps to reduce risks on implementer side and might compensate for load forecast insecurities.

3.3 System Performance and Accounting

It became obvious that proper monitoring and evaluation of RE hybrid systems is crucial for long- term operation. To facilitate this, the usage of smart energy meters in combination with a central monitoring unit is recommended. These combined systems come with benefits for both sides: the customers and electricity suppliers. The customers are enabled to monitor their electricity usage and develop a more conscious consumption behavior. The payment method can be adjusted to the needs of the electricity supplier and the customers as these systems usually come with a variety of payment functions (e.g. cash payment through local accountant, mobile payment etc.). There is no need to send staff to check the energy meters and collect the payment as it is often the case now. Human failure and social tensions are minimized.

The electricity supplier can easily collect detailed information on both, demand and supply side, and monitor the system's performance remotely. The usage of smart meters and state-of -the art payment systems helps the supplier to get a better understanding on demand behavior of connected communities and is thus enabled to plan system maintenance, replacement and upgrades effectively.

The following functions and services are suggested to be minimum requirements and were developed based on lessons learnt from Thai off-grid communities and system operators:

Household meter:

- Easy to install, suitable for outdoor installation and difficult to bypass
- Display or automatic messaging service to show past and actual consumption & remaining credit (kWh & THB)
- Sending demand/supply data continuously to control unit/cloud server
- Automated shut down when overload occurs (e.g. through utilization of high wattage appliances that are not allowed or connecting additional households illegally)
- Sending alarm messages when abrupt drop of demand over a long time period (sign of bypassing)

Central control and accounting unit / interface to cloud server:

- On-site (local operator/accountant) and remote (electricity supplier) access
- Easy to handle and self-explaining interface; language can be adjusted to meet requirements of local operator/accountant
- Monitoring functions:
  - sending alarms when malfunctioning of generation units or bypassing at client's place (overload or demand drop) automatically
  - daily/weekly/month reports
  - display nominal and actual generation
  - supply and demand monitoring (differentiate between different demand and supply sources)

Accounting Functions:

- add credit to client's account/meter number (ideally without prepaid card) & send credit confirmation automatically; payment either through mobile-payment, bank transfer or cash to local accountant
- send low credit warning to client automatically
- able to process different tariff structures (time of usage, monthly plan, pay as you go, block rates) and load limits

It is also recommended 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.

3.4 Modes of Operation

Figure 6 shows the schematic system architecture of a RE hybrid system. The 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.

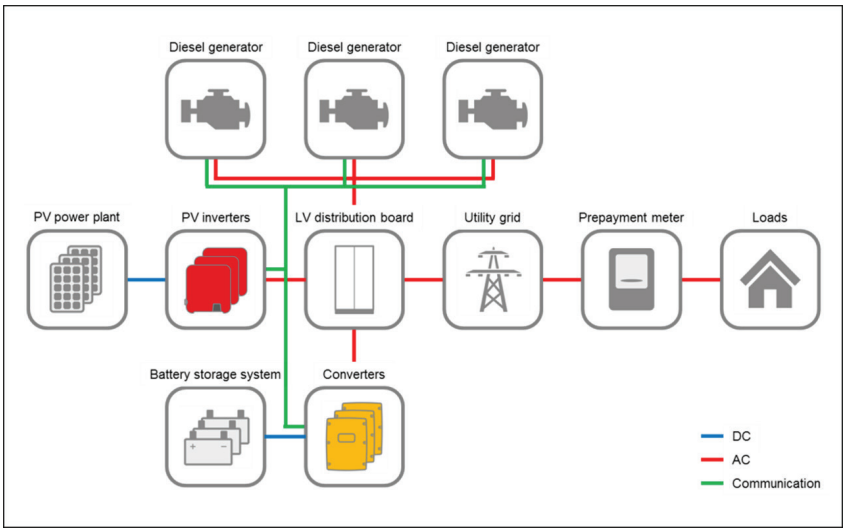


Figure 6: System architecture of a RE hybrid system [5]

During daytime the output power of the 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 7 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 parts (A & B in Figure 7) 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 7).

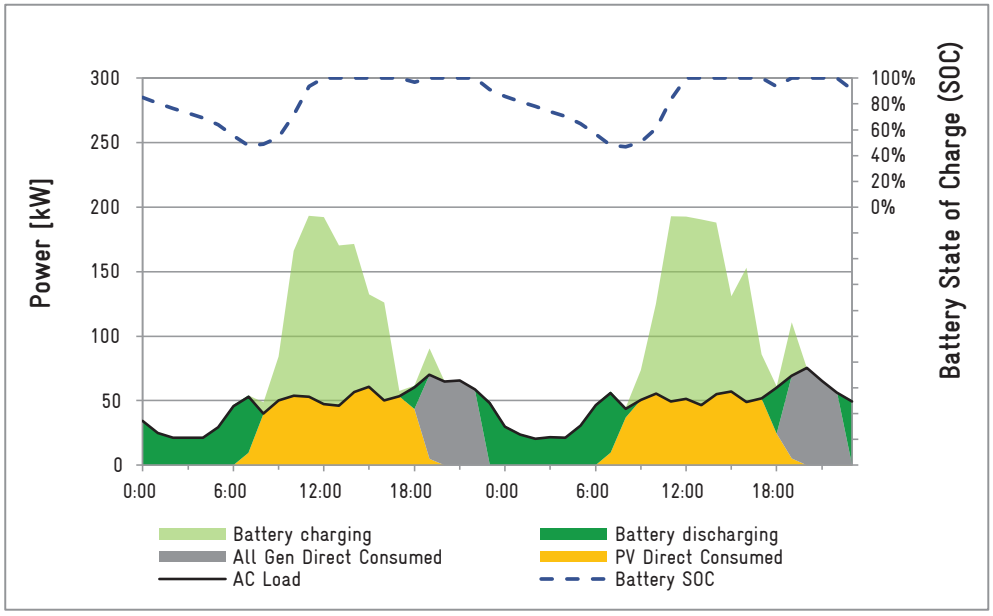


Figure 7: 24h example of RE hybrid system operation with CC [5]

The heart of the hybrid system is the battery inverter together with the hybrid system controller.
To control the operation of a RE hybrid system, there are two common types of communication systems:

The battery inverter is the grid forming unit, providing frequency and voltage. The hybrid system controller communicates in a separate network (see Figure 6) 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. This methodology is suitable for PV system sizes above 300 kWp and is therefore recommended to be applied on Mak Noi Island.

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. The frequency droop control is usually used within smaller and less complex systems (PV system capacity below 300 kWp) and could therefore be applied to the RE hybrid system on Bulon Don island.

3.5 Simulation, Optimization and Sizing Methodology

3.5.1 Simulation Tools

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 these two scenarios were compared to the current situation and – in the case of Mak Noi Island- to the economics of the submarine cable scenario.

3.5.2 Simulation Inputs

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 and forecast**
  Bulon Don: Determined based on the social-economic surveys conducted during the site visits and usual forecast scenarios applied in the simulation tools
- **Mak Noi:** Provided by PEA's forecast unit, based on the social-economic surveys conducted during the site visits
- **Weather data set**
  For the calculation of the expected annual PV yield, ILF used the weather data set of Meteo norm 7 (with hourly resolution). The monthly average values of global horizontal irradiation (GHI), diffuse irradiation (DHI) and ambient temperature are considered.
- **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)

3.5.3 Optimization Criteria

The simulation was aiming to design a RE hybrid 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 systems 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 the specific systems a project lifetime of 30-years was considered in order to reflect PEA's usual project life time when simulating submarine cable connection projects.

3.5.4 Diesel Generator Sizing

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 8 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.

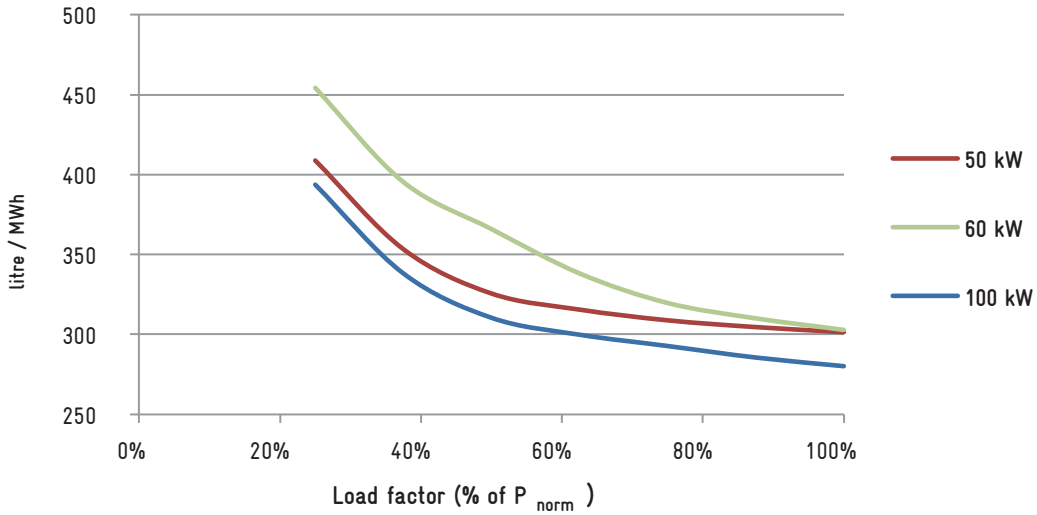


Figure 8: Specific consumption curve for different size of diesel generator [5]

3.5.5 PV/Battery Sizing

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).

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%.

3.5.6 Influence of Weather Conditions

HOMER simulates real time system operation over the required project time period (in this case 30-years) taking changing weather conditions into consideration. The weather data set came from Meteonorm 7 as mentioned above and reflects real ambient conditions in Thailand. RE hybrid 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.

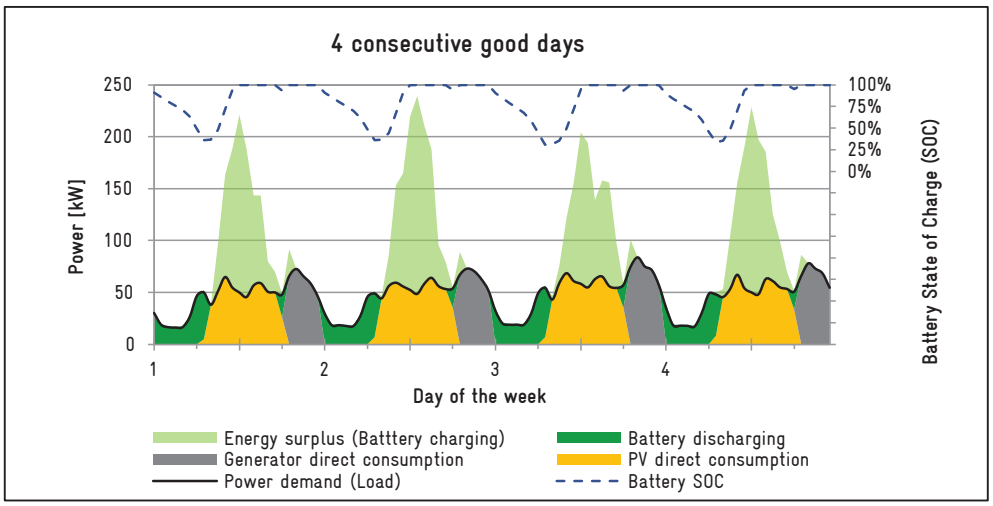


Figure 9: System operation for 4 consecutive good/sunny days [5]

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.

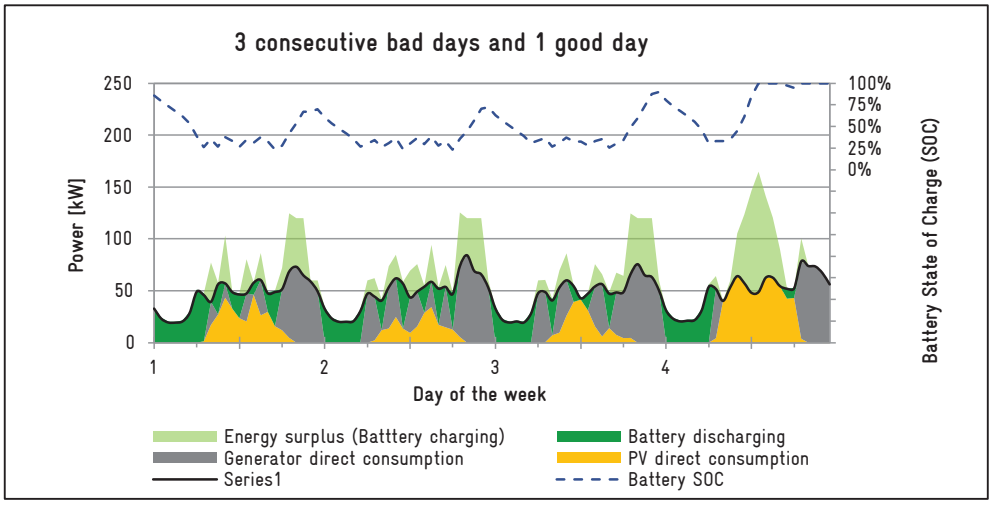


Figure 10: System operation for 3 consecutive bad/cloudy/rainy days and 1 good/sunny day [5]

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.

4. Pilot Case Mak Noi Island

4.1 General Information

Mak Noi Island is situated in Phang-Nga province, under the jurisdiction of Koh Panyee Subdistrict 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

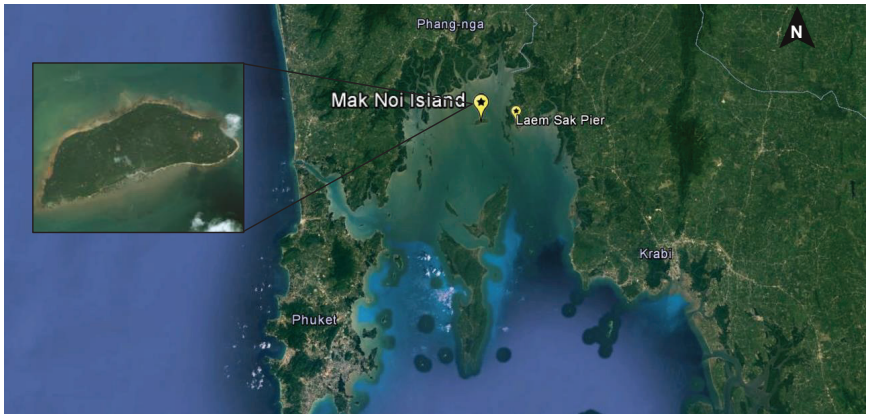


Figure 11: Location of Mak Noi Island [6]

Figure 12 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

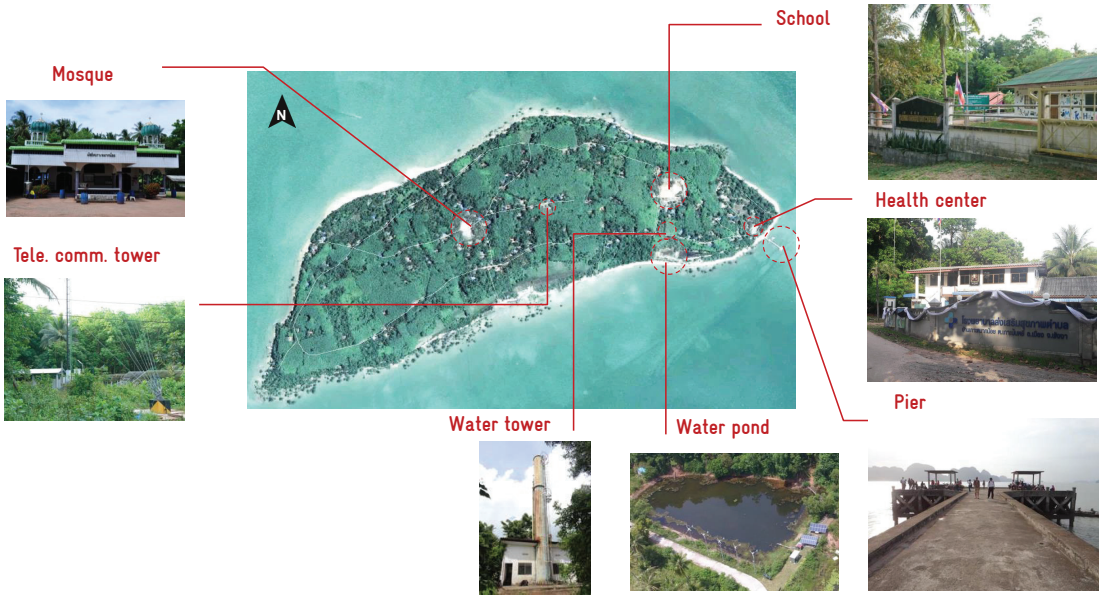


Figure 12: Key facilities on Mak Noi Island [6]

4.1.1 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 a wide range from 1,000 THB/month to 90,000 THB/month.

Figure 13: Coconut plantation (left) and fisheries (right); main occupations of Mak Noi island villagers

4.1.2 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 theirown solar system but is facing frequent electricity shortages. The learning environment for the students and teachers would be improved by stable electricity supply.

Figure 14: Koh Mak Noi school (left), Child care center (right)

4.1.3 Current Energy Situation

4.1.3.1 Centralized Diesel Generators and Grids

Currently, villagers on the island receive electricity supply mainly through privately-owned and operated diesel generators (Figure 15). There are five independent electricity grids serving certain areas on the island. The largest grid supplies up to 102 households. The smallest grid provides electricity to around 10 households.

In August 2017, the diesel generator of operator No. 2 broke down. This has left the grid out of operation since then. The operator of the two largest grids (1a & 1b) is planning to extend his service to serve the households previously connected to grid 2. His motivation is not necessarily economically driven. He mainly wants to supply the non-served household for a good purpose.

In December 2017, the diesel generator serving grid 1b (serving 71 households) also failed. The operator had to call technicians from the mainland to fix it. The overall maintenance cost (app.70,000 THB) for this second-hand generator is already counting for half of its CAPEX cost (150,000THB). The operator stated that operation and maintenance is a big burden and he is willing to relinquish one part of his income to get relieved from his responsibility as electricity supplier.

> "The implementation of a centralized renewable energy hybrid system will have a small impact on my income, but this is marginal compared to the benefits it offers to the community. It also relieves me from my responsibility as generator operator; finally, I will find my sleep again. At the moment my customers are calling me all night long to complain about black- and brownouts."
>
> Mr. Abdullah Sinto, diesel generator operator on Mak Noi Island and member of the village committee

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.

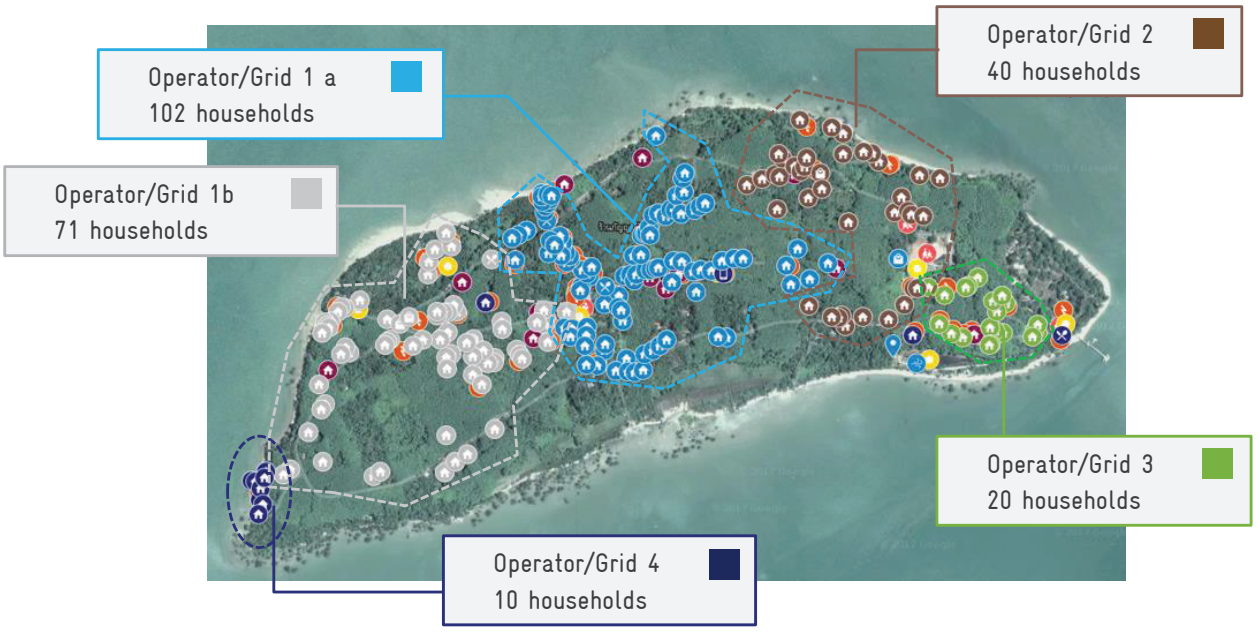


Figure 15: Privately-owned electricity grids on Mak Noi island [6]

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
Operator No.	1a	1b	2	3	4
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 households. 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).

4.1.3.2 Renewable Energy Systems

There are some renewable energy technologies (PV and small wind turbines) installed on Mak Noi Island (Figure 16). Each system was developed for a different purpose addressing a certain common need and not meant to supply the whole community.

Figure 16 Renewable energy systems on Mak Noi island [6]

4.1.3.3 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 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 in the Annex (A.2.2 Survey Results).

4.1.3.4 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:

- Mr. Abdullah's "Mosque" generator supplying 102 households
- Mr. Abdullah's "Western" 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.

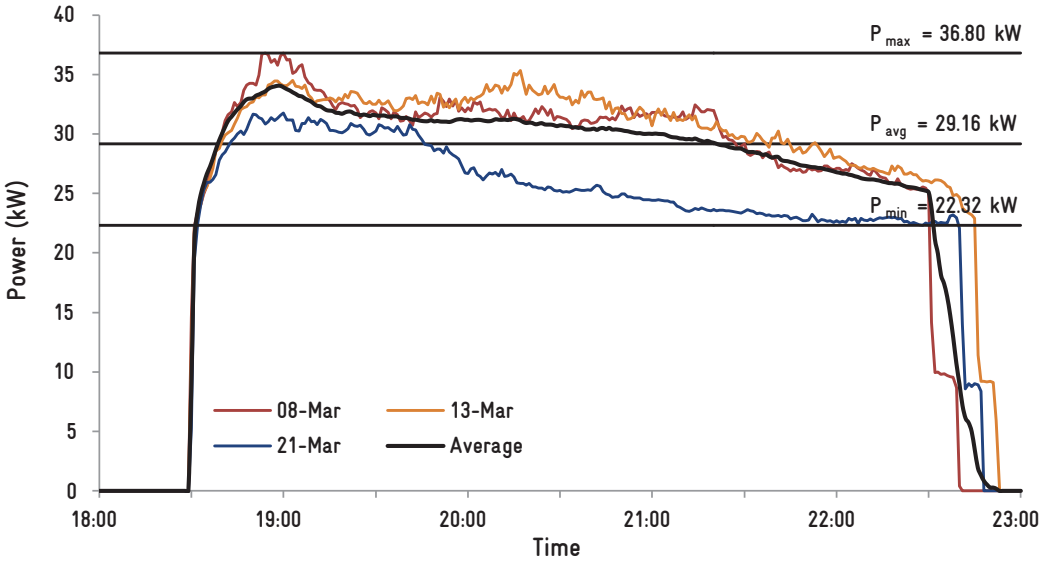


Figure 17: Load profile for three different days as well as the average load profile over one month for #40 and #41 generators (173 households connected), Mak Noi [5]

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 18 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 4.2.1).

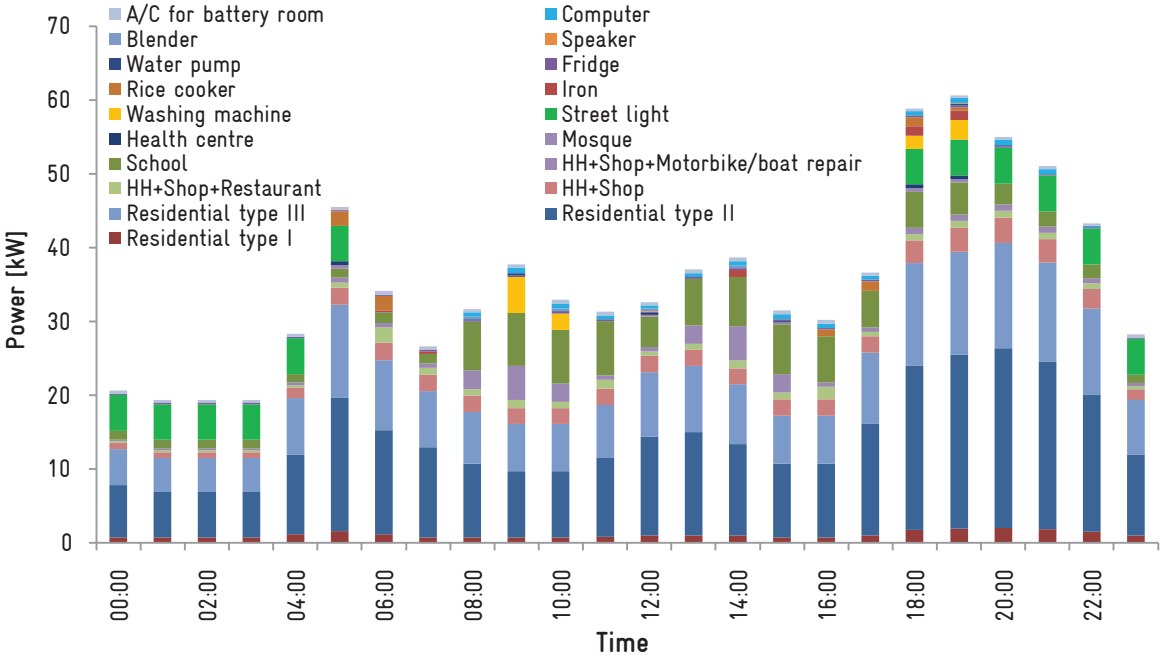


Figure 18: Anticipated 24-hour load profile of Mak Noi Island (in March) [5]

4.2 Renewable Energy Hybrid Grid System

4.2.1 Load Profile and Forecast

For Mak Noi the load profile and forecast were provided by PEA's load forecast unit specialized on rural electrification on island setups and based on the findings of the socio-economic surveys conducted by GIZ. The following figure is showing the forecasted energy and peak demand over a 30-years' time frame.

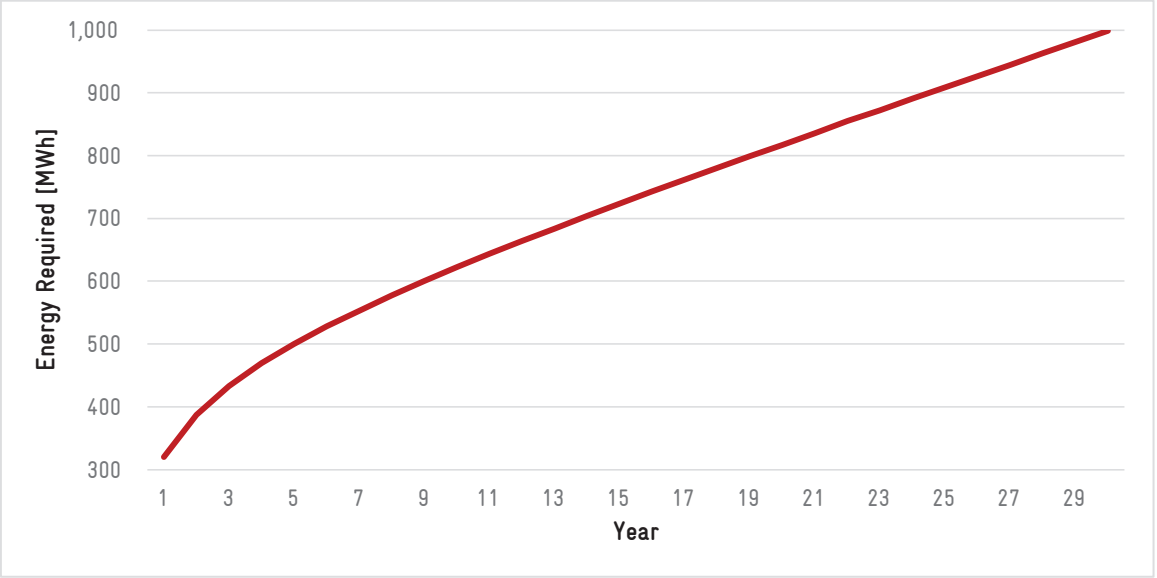


Figure 19: Energy demand in MWh as forecasted by PEA, version as of 29.09.2017

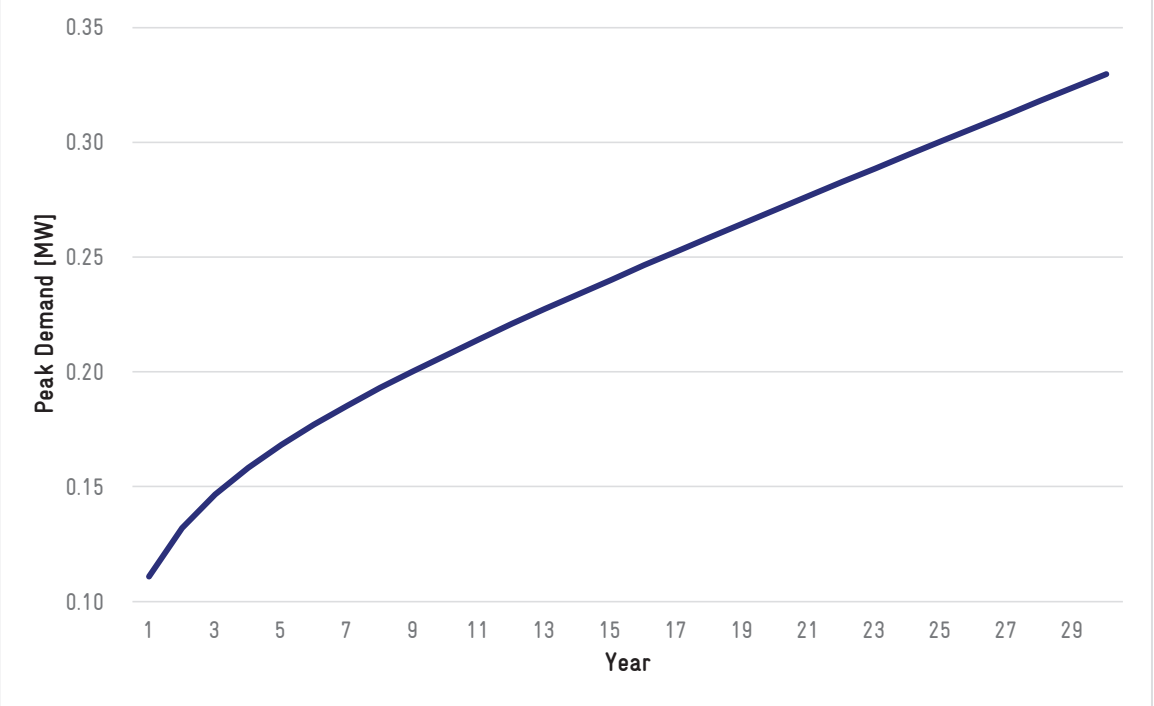


Figure 20: Peak demand in MW as forecasted by PEA, version as of 29.09.2017

4.2.2 System Design

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

- Diesel Generator 3 x 80 kW
- Solar PV 400 kWp
- Battery Storage 700 kWh

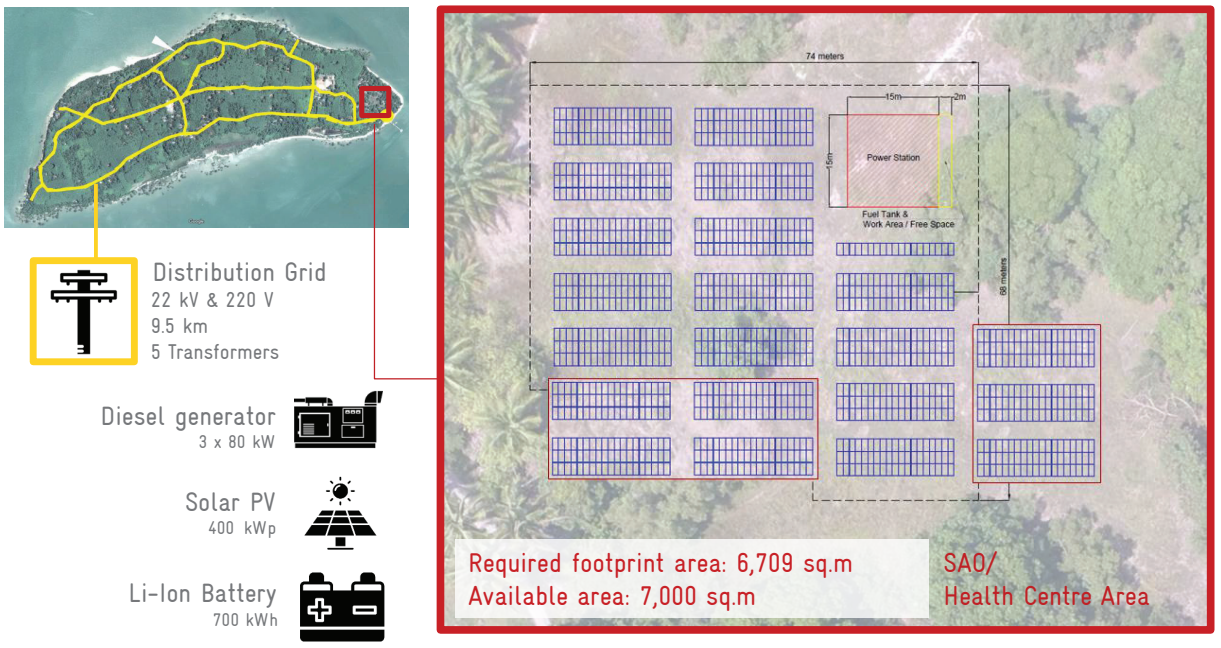


Figure 21: RE hybrid system design and size for Mak Noi Island; Icon Source [2]

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

Table 2: Energetic results of the simulation [5]

PV / Diesel / Battery Hybrid System	Unit	2018	2022	2027
System Parameters				
Total capacity diesel generators	kW	240 (3 x 80 kW)		
Number of diesel generators	Unit	3		
Total PV capacity	kW_p	400		
Total PV inverter	kW_{AC}	330		
Total battery capacity	kWh	700		
Usable total battery capacity (SOC_{min} 10%)	kWh	90		
Battery inverter capacity	kW	115		

PV / Diesel / Battery Hybrid System	Unit	2018	2022	2027
Homer simulation output				
Total energy production (demand)	kWh/a	231,255	46 3,667	593,633
Share Diesel	kWh/a	73,249	169,520	255,679
Share PV and battery	kWh/a	158,006	294,147	337,954
Excess PV energy	kWh/a	405,290	239,213	175,943
Excess PV energy	%	71	43	32
Total diesel consumption	l/a	22,198	46,121	69,506
Specific diesel co nsumption	l/MWh	303	272	272
Renewable fraction (PV and battery)	%	68	63	57
Excess PV energy	%	71	43	32
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 A.4.1 Mak Noi.

4.2.2.1 Diesel Generator

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 [5]

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

4.2.2.2 PV and Battery Storage

To achieve the above criteria (see Chapter 3.5.5) the PV capacity was optimized to be 400 kWp, and battery capacity 700 kWh.

Table 4: Main characteristics of PV power plant [5]

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

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 -Error! Referencesource not found.) ▪ Battery storages shall be housed in specially made cabinet rated for salt mist protection.

Figure 22 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.

Figure 22: PV system layout at the SAO area behind the health center (required area app. 6,000 m2; available area app. 7,000 m2) [5]

4.2.2.3 Electricity Grid

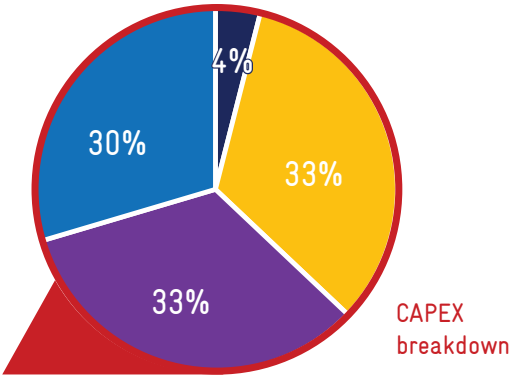
Since the island is large, approx. 2.5 km2, and the locals are living spread out around the island, the current low voltage transmission line is not feasible for the hybrid system. To implement a centralized electricity supply system covering all households on the island, grid transmission and distribution 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)

4.2.3 Financial Analysis

The approach was to compare different electrification scenarios for Mak Noi Island as mentioned above (Chapter 3.5). Table 6 gives an overview of all CAPEX and OPEX cost. The CAPEX is covering all expenditures to implement the RE hybrid system at the beginning and are based on a market reviews 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 system on Mak Noi [5]



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 23 is highlighting the difference between the CAPEX and OPEX of the RE hybrid system in comparison with the submarine cable scenario. With implementation of a RE hybrid system, PEA can save, especially upfront on the CAPEX, but also on a long-term basis as the OPEX comparison is showing.

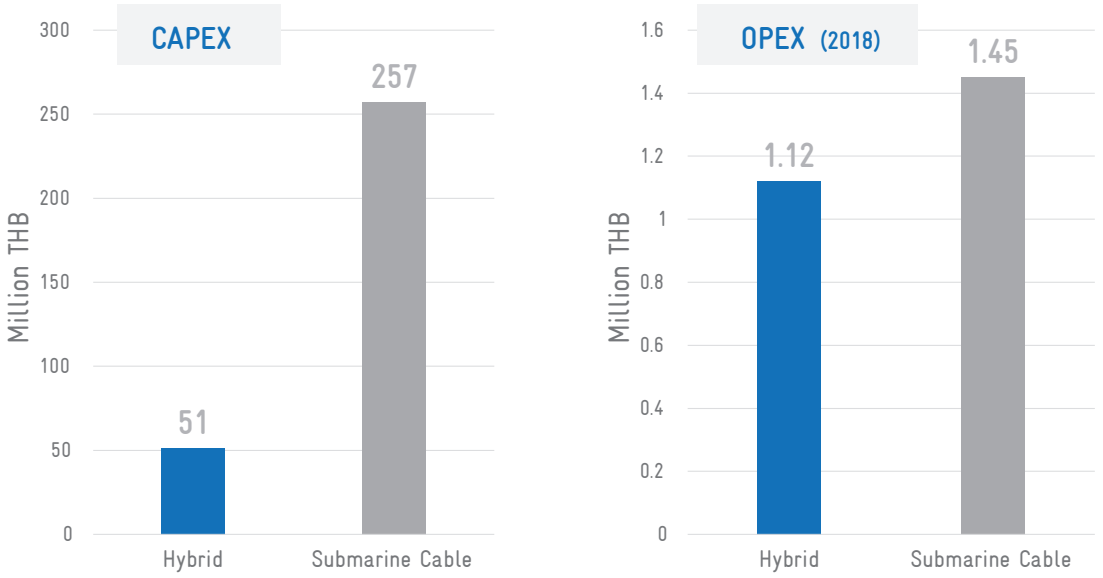


Figure 23: CAPEX and OPEX comparison for RE hybrid system and submarine cable scenario [7]

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 K. Abdullah's grids

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

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

The figures show that an RE hybrid system would be the most economic option to electrify Mak Noi Island. All technical and financial in- and output are summarized in Annex 3: Simulation Inputs and Outputs

4.2.4 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 24).

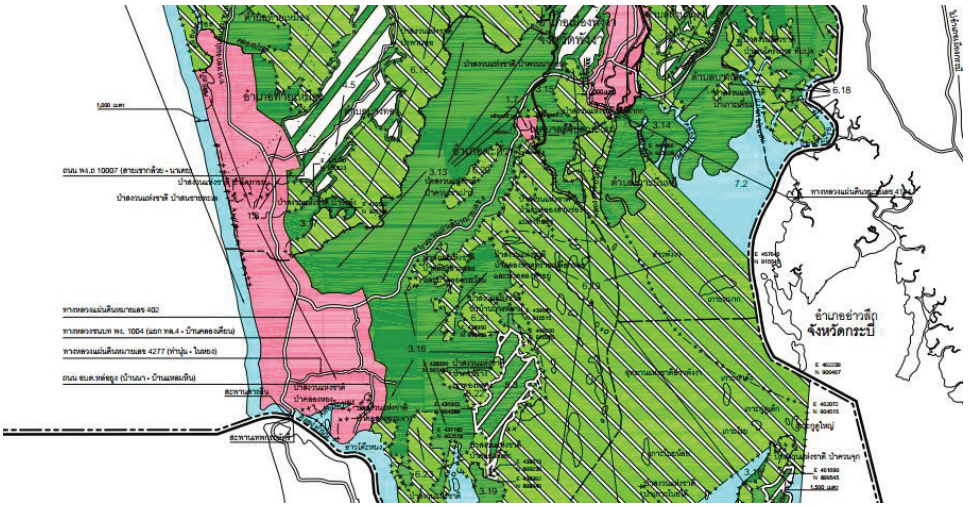


Figure 24 Phang-Nga town planning regulation [8]

The land categorized as “forest conservation area” 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 m2., 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 categories of land where clear prohibition on land utilization for construction of certain applications is provided. There is no clear prohibition to use this type of land. Therefore, there is no clear regulation for construction of certain types of buildings e.g. factories (solar panels are considered as factories) or infrastructure.

NOTE: 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 in close coordination / exchange with the office of urban and town planning, the permission to develop the project on Mak Noi should be possible.

4.3 Implementation Plan

4.3.1 Proposed Project Setup: Utility Model

During the 1st community meeting on Mak Noi iIsland, GIZ learnt the island is part of PEA’s network extension plan (2019 – 2021) meaning they were planning to connect Mak Noi via submarine cable to the national grid. However, in further talks, PEA - the governmental utility in the provinces - showed interest to investigate the opportunity of implementing a RE hybrid system as an alternative to the submarine cable as part of their innovation strategy. PEA is the leading stakeholder to implement the project on Mak Noi. 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 electrification projects where they supply communities via isolated mini-grids running on centralized diesel generators. Instead of installing generators only, the system would comprise additional PV modules, inverters and battery capacities. PEA would supply the community applying their regular tariff structure.

PEA and GIZ are in close collaboration and has had several meetings in Bangkok, the local PEA office in Phang Nga and travelled together to the island to gain mutual understanding on the project site. GIZ is facilitating in providing details of the feasibility studies and financial calculation and assisting in mutual understandings of hybrid systems.

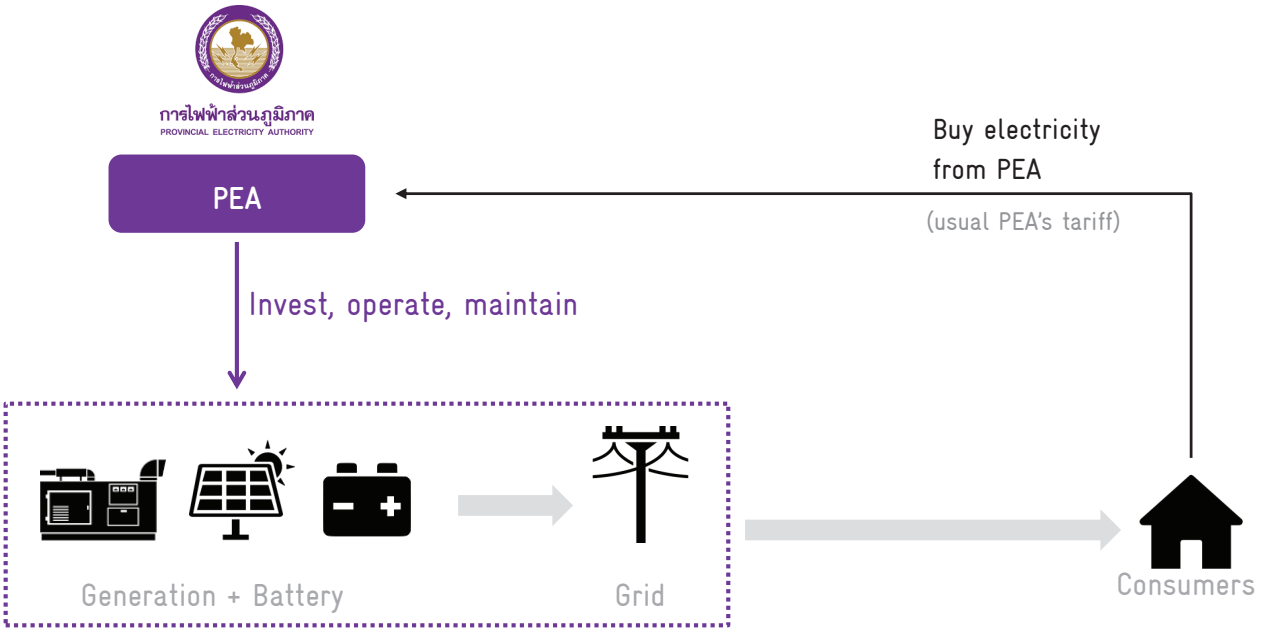


Figure 25: Foreseen business model: Utility Model - Mak Noi island; Icon Source [2]

4.3.2 Next Steps

The decision-making and implementation timeline depends on PEA's internal processes. As this is the very first RE hybrid system project for PEA, no clear timeline can be provided as new ways have to be paved.

Apart from the technical and financial analysis where PEA is already convinced that a RE hybrid system is the best electrification option for Mak Noi, one key aspect to make the final decision is the acquisition of land to construct the system.

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 SAO came up with the most suitable location to install the PV system as well as the power house that is situated behind the health center (see Figure 26). The identified area belongs to the Treasury Department and is currently being rented to three different private persons who are not using their leased land at the moment. In the latest meeting between GIZ, PEA Regional Office, PEA Central Office and SAO in February 2018, the local government (SAO) agreed to approach the three tenants and ask them for permission to rent the land for PEA's RE hybrid system project. A compensation fee might be necessary in order to convince the tenants.

After negotiations, the three current tenants have to send a termination confirmation letter to the Treasury Department. At the same time PEA needs to apply for this land with the Treasury Department. The Department will come up with a new rental fee which is adjusted to current lease indexes.

NOTE: Official land usage approval needs to be received before developing the project further. PEA Bangkok Office together with the PEA Regional Office in Phang-Nga and SAO are currently clarifying this issue.

Figure 26: Suitable area for PV installation (behind the health center, close to the pier [5]

2) **Development of project proposal and detailed layout plan**

Once the land usage issues are solved, a detailed project proposal including the engineering and layout plan needs to be developed based on the knowledge gained through the GIZ project. GIZ will take a supporting role in this process and provide information and support to PEA wherever needed.

3) **Public hearing**

After this a public hearing has to be held to get official endorsement. No obstacles are expected to come out of the public hearing as land rights are clarified by that time and the project is to benefit of the community and environment.

4) **Procurement of equipment, construction, commissioning**

To start the actual construction, PEA might apply their usual procurement processes (tendering etc.). Usually RE hybrid 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 next 2-4 years.

4.4 Sensitivity Analysis

In order to evaluate the influence of different parameters set in the simulation of the system on the LCOE, the technical consultant provided a sensitivity analysis (30-year project duration). The aim was to get an idea to what extent 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. The results are listed below:

- 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 directly be controlled, but 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 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). Electricity will become affordable for more and more costumers and thus provoke a jump in electricity demand on customer side. Additionally, a lower energy demand than expected is not affecting overall system stability and thus PEA's reputation as a reliable electricity supplier. It will only affect the system's economics.

The project is also benefitting from PEA's long-term experience to calculate realistic load forecasts for off-grid areas which is minimizing the risk of unrealistic energy demand estimations.

4.5 Impact Assessment

The following analysis will evaluate the impact of RE hybrid system development on the involved stakeholders.

4.5.1 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 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. Existing businesses such as restaurants, repair shops and grocery shops can expand and new businesses will appear enabled by reliable electricity supply.

> "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 reduce their concentration, and also suffer from a lack of modern digital teaching measures."
>
> Dumrong Sinto, Chief Executive of the regional Subdistrict Administrative Organization responsible for Koh Mak Noi

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

The local health care will also improve as medicine can be chilled and stored over long periods of time, curing basic diseases promptly will no longer be an issue.
The good reputation of solar and green energy will increase over time and make the community more aware of the benefits of renewable energy and thus might lead to the implementation of additional renewable energy technologies on the island. Mak Noi community could be a role model for other island communities.

4.5.2 PEA

Implementing the RE hybrid system instead of a submarine cable would lead to reduced investment and operation cost on PEA's side. These savings are upfront (lower CAPEX) as well as on a long-term basis as OPEX for the RE hybrid system are lower compared to the submarine cable.

By developing this pilot site, Mak Noi can serve as a role model for other islands, the up-scaling potential is high. Especially for very remote Thai islands far from shore, this is the best option to receive reliable and sustainable electricity supply.

In addition to the financial savings, PEA will benefit from the green image and innovative approach in connecting 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 and PEA's responsibility to connect the remaining off-grid communities in an efficient way (generally RE hybrid systems can be developed faster than submarine cables).

5. Pilot Case Bulon Don

5.1 General Information

Bulon Don Island is located in the Andaman Sea in Satun province under the jurisdiction of Pak Nam Subdistrict Administrative Organization (SAO). Around 300 local inhabitants are living on the island in a total of 81 households on the small island situated approx. 22 km West of Pak Bara pier. All households are clustered towards the South-East of the island as visible on the close-up picture in Figure 27. The island is part of the Mu Koh Phetra National Park and affected by dry and rainy season.

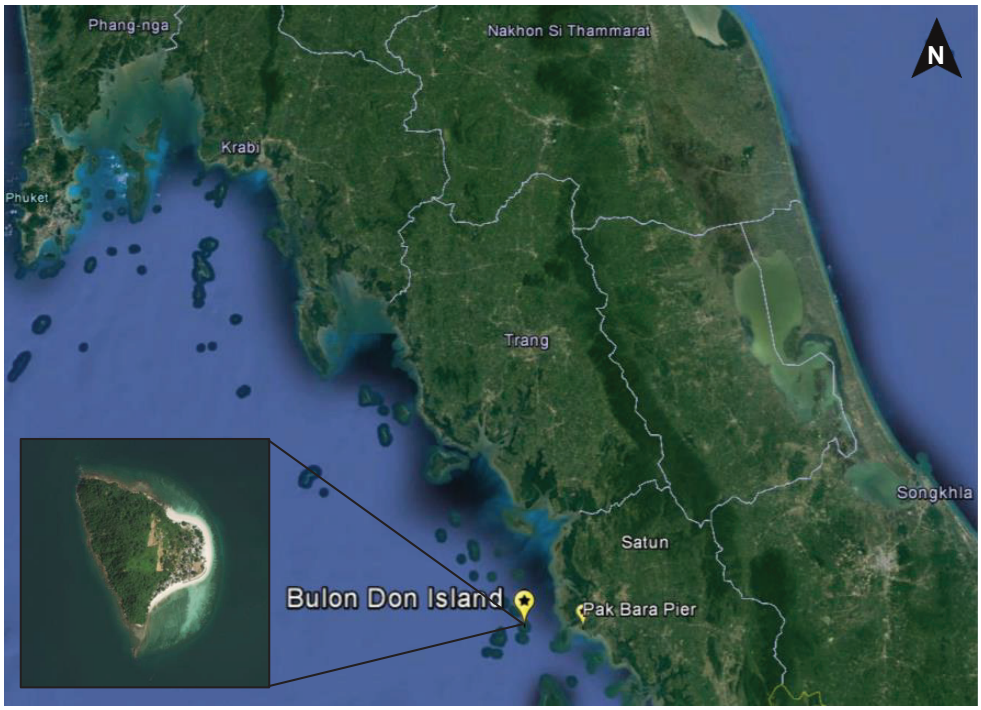


Figure 27: Location of Bulon Don Island [6]

Figure 28 shows key facilities of Bulon Don:

- Public Buildings: health centre, school, mosque
- Fresh water supply: water tanks, water pond

NOTE: Due to BTS tower on a neighboring island the reception on the island is usually good.

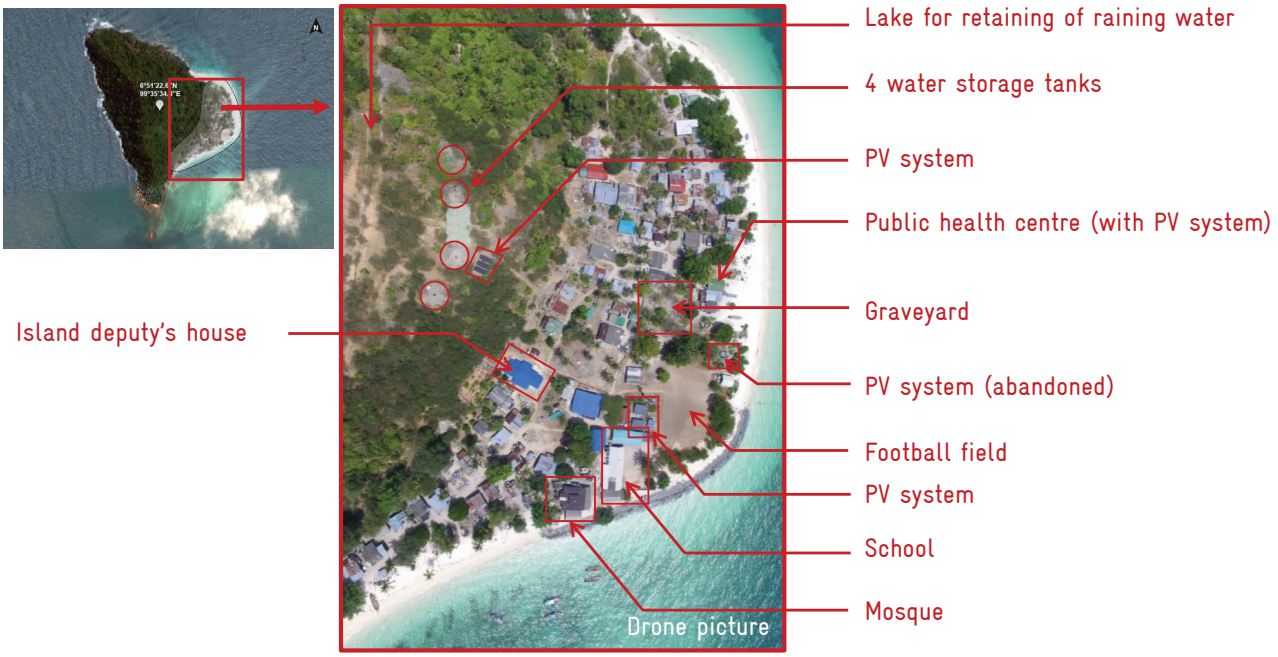


Figure 28: Key facilities on Bulon Don Island [6]

5.1.1 Occupation and Income Structure

Main income source on the island is fishery. Some residents are running small restaurants or shops. The income of the population is widely spread, ranging from approx. 4,500 THB/month to 45,000 THB/month, averaging around 8,000 THB/month in mode average. As a fisher´s island, the generated income always depends on the day-to-day results and seasonal condition of the ocean as people stated in the socio-economic survey.

Figure 29: Fisher boat on Bulon Don

5.1.2 Education

There is a combined elementary (1st to 6th grade) and secondary (7th to 9th grade) school on Bulon Don Island, currently educating 72 students. After elementary school the students go to the mainland for higher education (30%, mostly children with relatives on the mainland), visit the island's secondary school (40%) or stop institutional education; joining the family fishery or gastronomy business (30%).

9 teachers are currently working and living on the island. Next to the school is a building to host them, but it is lacking sufficient capacity (the building was planned to host 5 teachers only). At this time, the remaining 4 teachers are staying at the library building. The community is currently constructing a second teacher's building next to the mosque.
A 3 kWp solar system is supplying the school to run basic appliances such as lights and fans. The supply is often insufficient especially during dry season and hot weather conditions.

5.1.3 Local Habits and Seasonality

Fishing Schedule

The main income source of the villagers is fishery. Their habits and schedules are therefore following the movement of fishing grounds:

- At 06:00 the fishermen are usually leaving the island and return around 09:00
- some fishermen leave the island again around 16:00 for squid fishing and return around 21:00-22:00
- App. 5-6 days a month the island experiences low tides and the fishermen cannot leave according to their regular schedule: they depart later between 08:00 to 09:00 and return around 12:00

Seasonal Fluctuations

Apart from being fishermen, some villagers leave the island to work on neighboring tourist islands such as Koh Lipe:

- High (Tourist) Season: October- April:
  - 80 % of people are leaving the island (to work in Koh Lipe) and come back to Don occasionally
  - 20 % of the remaining population are students, women with young children/babies & old people
- "Transition" Season: After April (depends on each year, May/June):
  - 100 % on the island
- Monsoon Season: After May (depends on each year):
  - If fishing grounds are sufficient around the island, the villagers stay on the island.
  - If there is not, 60 % of the people are leaving for 4-5 days a week to fish in other areas.

These habits and seasonal fluctuations have a high importance for the RE hybrid system design as peak hours and low demand periods are influencing the system design economics

5.1.4 Current Energy Situation

5.1.4.1 Centralized Diesel Generators and Grids

Centralized community diesel generator & decentralized diesel mirco-grids

A 25-kW community diesel generator and central transmission line were installed around 3.5 years ago. The generator was provided by the local government (SAO). All households were connected to the generator via a central grid transmission line on the island. In a community meeting Mr. Pun was elected to be the operator of the generator.

NOTE: SAO procured and installed the transmission line as well as the generator, but actual operation and maintenance lay with the community. This includes the connection of each household to the transmission line.

Approximately 1.5 years ago, the generator failed after just 2 years of operation. Until February 2018 the community was not supplied by this centralized system. As a result, residents organized themselves and are sharing diesel generators to have basic power supply.

During the first site visit, 15 generators were observed on the island as shown together with the connected households in Figure 30. Each is supplying 2-10 households, shops and restaurants via decentralized separate micro-grids.

Figure 30: Overview of diesel generators and household locations observed on Bulon Don (left); impressions of the cable connections (right) [5,6]

Table 7 summarizes the basic information of the decentralized diesel generators serving 2-10 households on Bulon Don. Some generators are for specific purposes such as boat repair, washing machines, etc. only.

Table 2: Energetic results of the simulation [5]

No.	Generator Ref.	No. of connected households/purpose
1	Generator #91	boat repair only
2	Generator #31	8 households
3	Generator #32a	4 households
4	Generator #32b	washing machine only
5	Generator #33	4 households, plus rest area
6	Generator #34	6 households
7	Generator #35	2 households
8	Generator #36	3 households
9	Generator #42	backup in case of insufficient supply by PV
10	Generator #93	N/A
11	Generator #40	1 household, 1 restaurant
12	Generator #41	3 households
13	Generator #38	10 households
14	Generator #37	9 households, incl. 2 shops
15	Generator #39	5 households

Figure 31: Examples of diesel generators supplying 2-10 households on Bulon Don

In October 2017, SAO replaced the broken centralized community generator with a new 50-kW diesel generator. As the quality of the centralized transmission line degraded over the past 1.5 years, SAO adjusted the grid and reduced it to a 2-phase system (formerly 3 phases). The system is in operation since November 2018. The location of the generator also changed as the first location was too close to some households. Figure 32 gives and overview of the centralized transmission line, the old and new community diesel generator location.

Figure 32: Overview of the existing centralized transmission line and locations of the community generators (left); impressions of the grid line installed on Bulon don (right) [5,6]

Central Transmission Line

For the central transmission line solid steel poles were installed as shown in Figure 32. However, the cables are connected to the poles in a height between 2 m – 2.5 m above the ground. This may result in cables hanging down between poles in a height which is accessible for the villagers causing hazards. Therefore, it is recommended to increase their height to at least 2.5 m according to Thai standards.

Since installation of the grid, the community expanded for several households in the North. An extension of the existing line is therefore needed. Additionally, all households shall be connected to the grid by the implementing partner to ensure the tapings are conducted professionally and not causing hazards as it is the case at the moment. An overview of recommended grid extension and a potential location for the PV system and new powerhouse is shown in Figure 33.

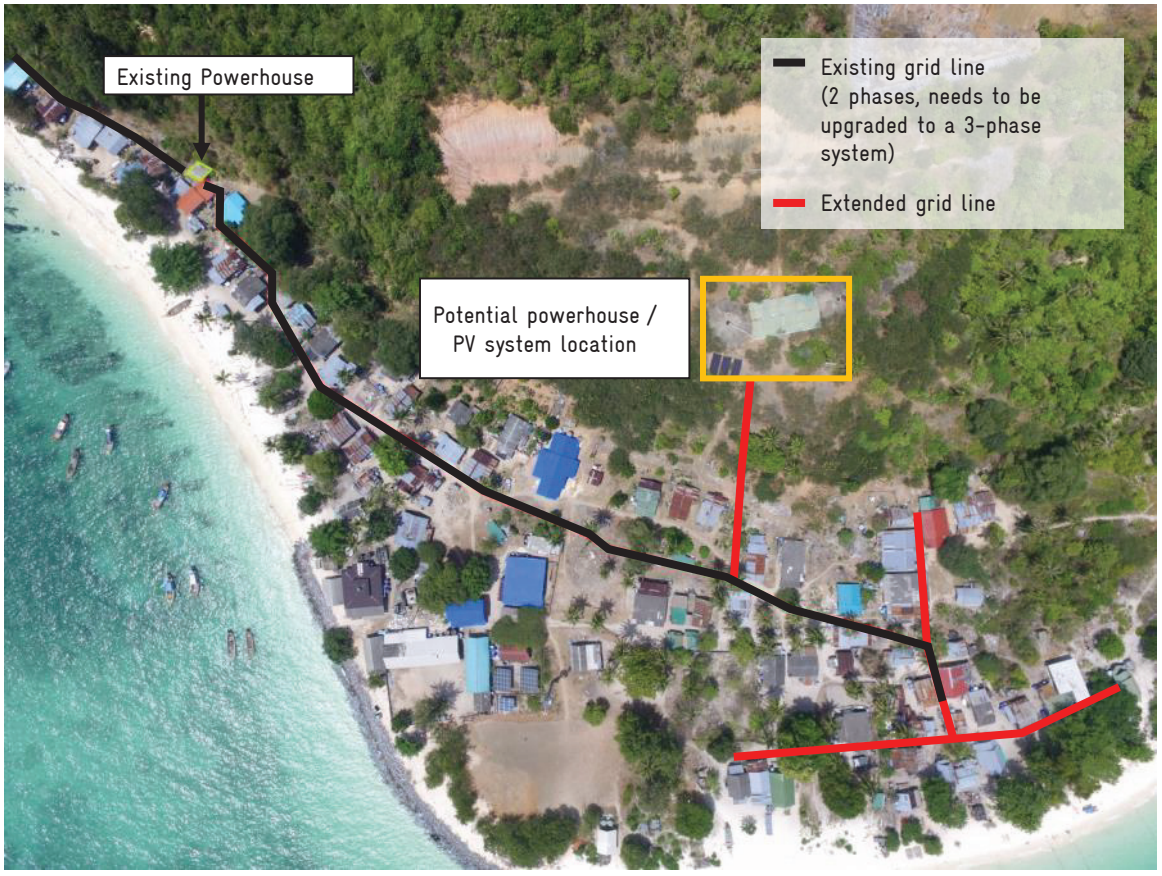


Figure 33: Recommendations for transmission line extension and powerhouse & PV system location [5, 6]

Tariff Structure – Community Diesel Generator

With the old 25 kW generator the community agreed on a flat rate tariff of 300 THB/month for operation hours between 18:00 and 22:00 daily. It was agreed that only light bulbs, TVs, and fans can be used. Since there were no meters installed, the electricity was consumed without monitoring. Therefore, the actual generation costs can hardly be assessed. The price agreement was a decision of a community meeting.

It can be estimated that the total income for the community diesel generator was approx. 24,000 THB/month with 79 connected households. If the generator consumed diesel fuel of around 900 litre per month at a price of approximately 25 THB/l, total costs for diesel fuel would have been 22,500 THB per month. Diesel transport costs approx. 300 THB per roundtrip. Since a community diesel generator has been operating for only two years, no major maintenance costs during this time occurred. Operational costs for water, lubricant oil and others are unknown.

With the new 50 kW generator operation hours stay the same with 4 hours daily between 18:00 and 22:00. The price structure determined in community meetings however is more complex:

- Basic Tariff light bulbs only 200 THB/month
- Add-On 1 plus fans 300 THB/month
- Add-On 2 plus TV 450 THB/month
- Add-On 3 plus washing machine 600 THB/month

Tariff Structure – Decentralized Diesel Micro-Grids

For the period of decentralized diesel generators supplying 2-10 households via micro-grids the tariff was agreed upon by the different households sharing one generator ranging from 435 – 2,160 THB/month. Every generator had different operating hours depending on the needs of the people connected to it, therefore the diesel consumption and pricing differs a lot. Most diesel generators run in the evening hours between 18:00-22:00. The diesel and transportation costs are usually equally divided by the households connected. In few cases where one household has much more electronic appliances than others or one household has a lower ability to pay, the electricity tariff per household connected to the same generator differed.

The payment was usually done by a rotation of the connected households being responsible for diesel purchasing and transport. Every 2-4 days one of the households connected was driving to the mainland to buy new diesel supply at a price between 25 – 30 THB/litre.

5.1.4.2 Renewable Energy Systems

There are some solar systems installed on Bulon DonIsland. Figure 34 gives and overview of the system sizes and locations. Each system was developed for a different purpose addressing a certain common need and not meant to supply the whole community.

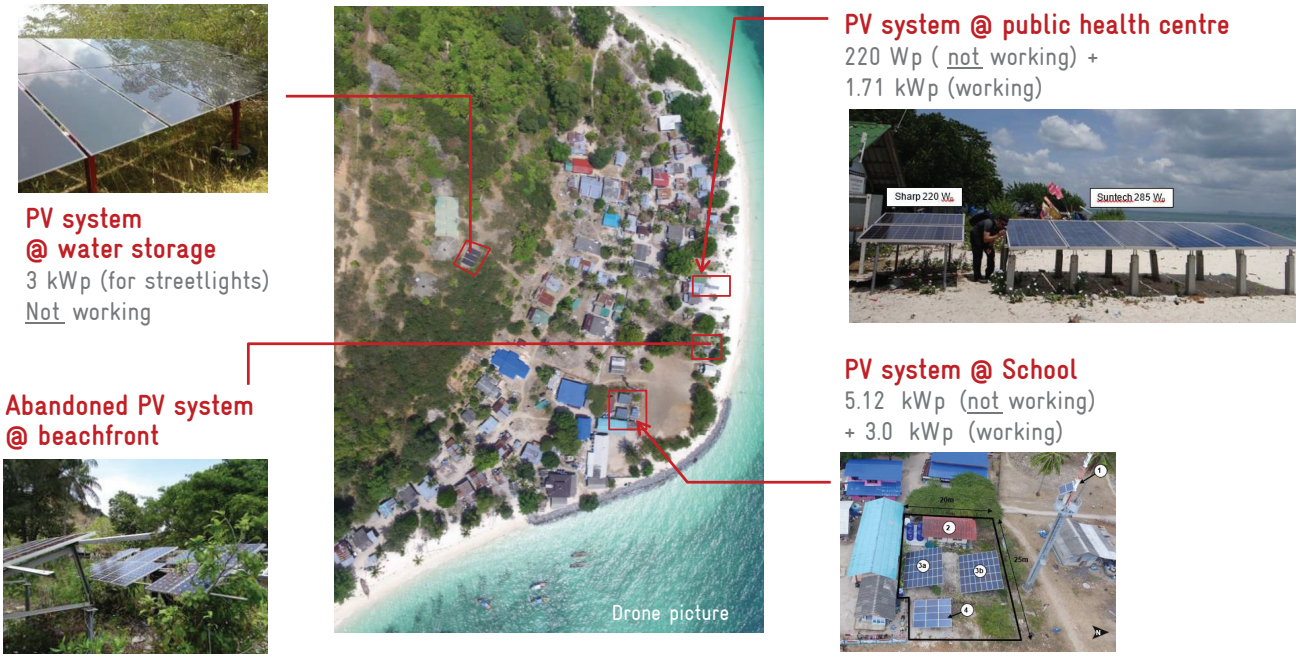


Figure 34: Overview of installed solar systems on Bulon Don Island [5,6]

In addition to these bigger systems, app. 20 Solar Home Systems were observed during the site visit. Most of these are still in operation and are used to run basic appliances or to charge phones

5.1.4.3 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, mobile phones, fans and mostly a TV. Some households also own a washing machine and a CD player. The three public buildings (school, health centre, and mosque) have more electric appliances installed (additional light bulbs, fans, TVs as well as speakers, fridge etc.); details can be found in the survey evaluation table in the Appendix (A.2.2 Survey Results).

5.1.4.4 Load Measurement and Profile

Since there are no electricity meters or recorded energy data available on the island, a load measurement device (Eco Sense 3) was installed on 1st March 2017 to measure the energy consumption of the connected generator loads until 1st April 2017. The device measured relevant grid parameters like voltage, current, active and reactive power and frequency for each phase separately.

The measurement device was connected to one of the biggest diesel generators (Ref. #37, 5 kW diesel generator), which supplied electricity to 9 residential households, including 2 shops. Based on the information provided by the surveys, the shops have similar loads to residential households.

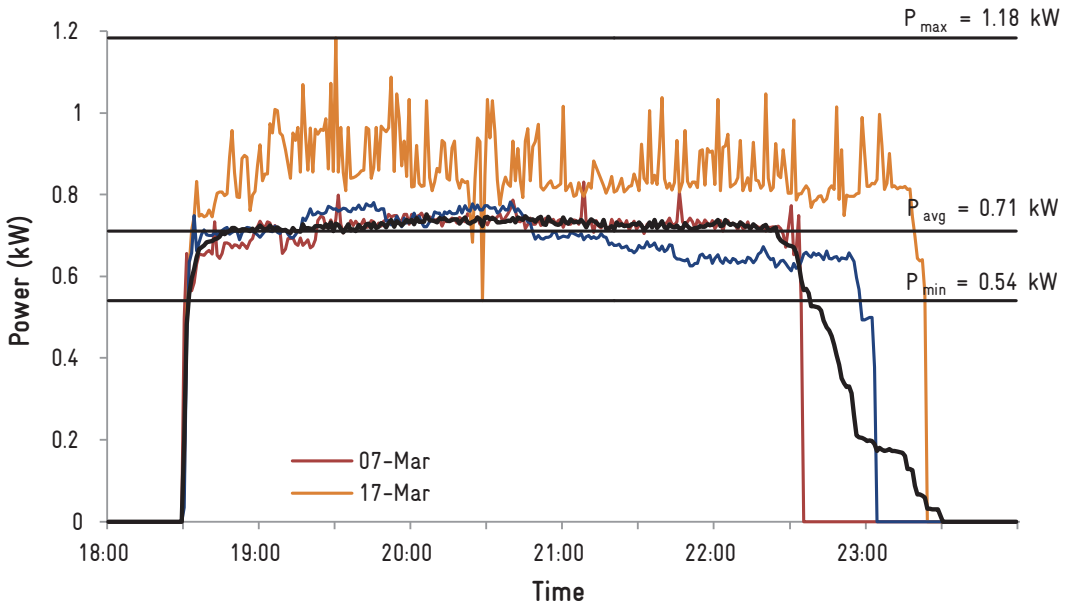


Figure 35: Load profile for three different days as well as the average load profile over one month for #37 generator (9 connected households), Bulon Don [5]

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 36 shows the current estimated load profile for a typical day in March including for the whole island. This load profile served as basis for further load forecast assumptions and simulations (see Chapter 5.2.1).

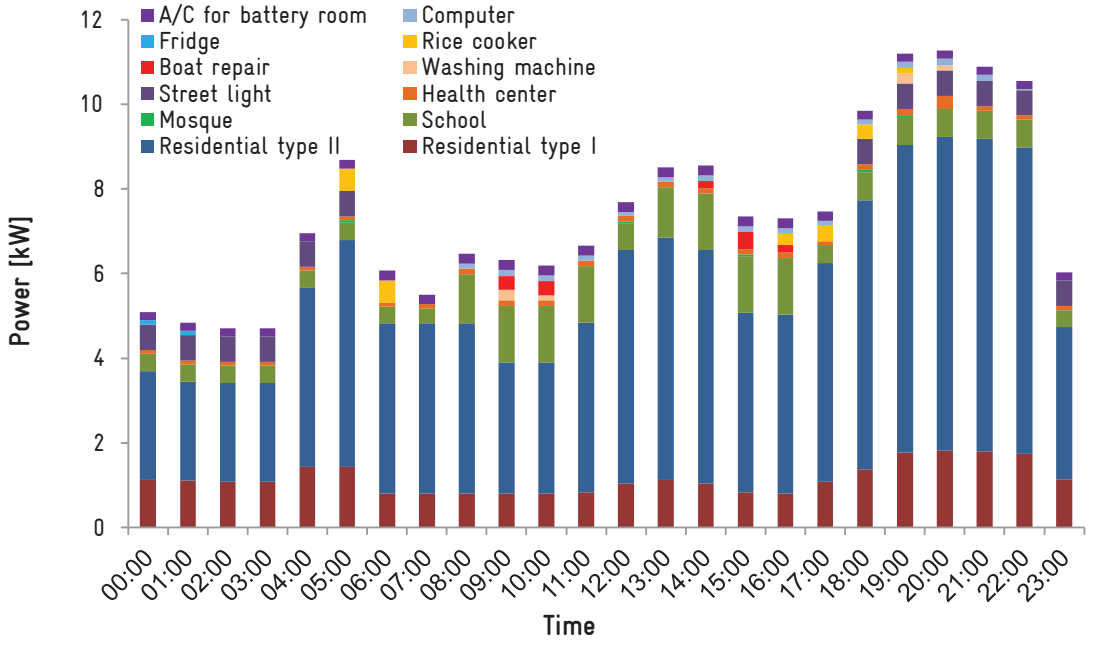


Figure 36: Anticipated 24-hour load profile of Bulon Don Island (in March) [5]

5.2 Renewable Energy Hybrid Grid System

5.2.1 Load Profile and Forecast

Average and Peak Power Forecast

Based on the current load profile as shown Figure 36 the future load profile and peak demands were developed by the technical consultant taking future loads as stated in the survey summaries into consideration and applying common growth rates based on international best-practices in the mini-grid sector.

Table 8 is giving an overview on the peak power forecast in 5 and 10 years from now. Figure 37 visualized the load profile forecast.

Table 8: Peak Power Forecast for the RE Hybrid System on Bulon Don [5]

Data	Average power (P_{avg})[1]	Peak power (P_{max})	P_{avg} / P_{max}	Peak power (used in HOMER simulation)
2018	10.81 kW	17.98 kW	1.66	18.06 kW
2022	15.26 kW	25.39 kW		25.72 kW
2027	17.83 kW	29.67 kW		29.94 kW

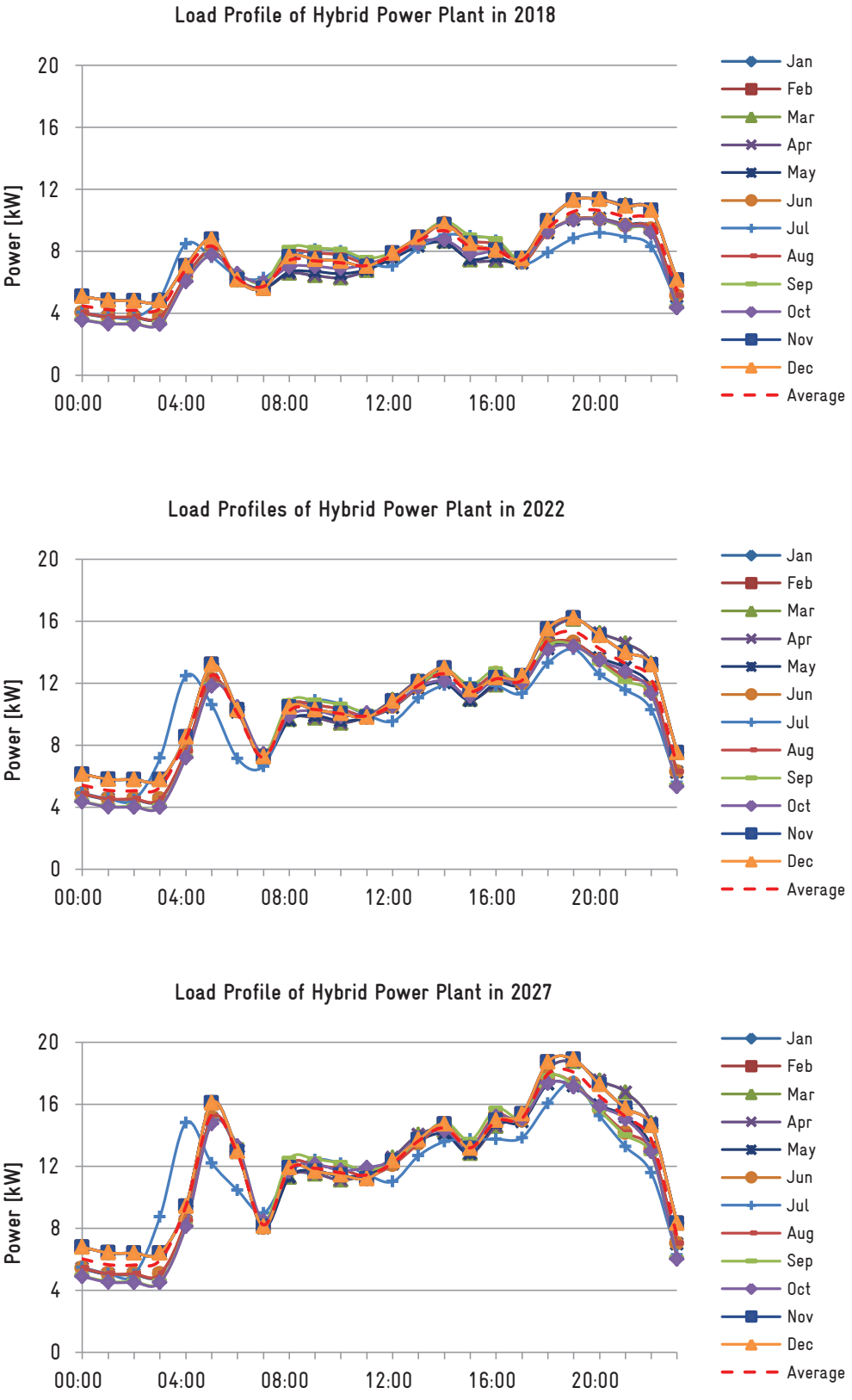


Figure 37: Load profile forecast for Bulon Don in 2018, 2022 and 2027 [5]

Energy Demand Forecast

Figure 38 shows the estimated energy demand in year 1, 5 and 10 after system installation split into consumer categories on Bulon Don.

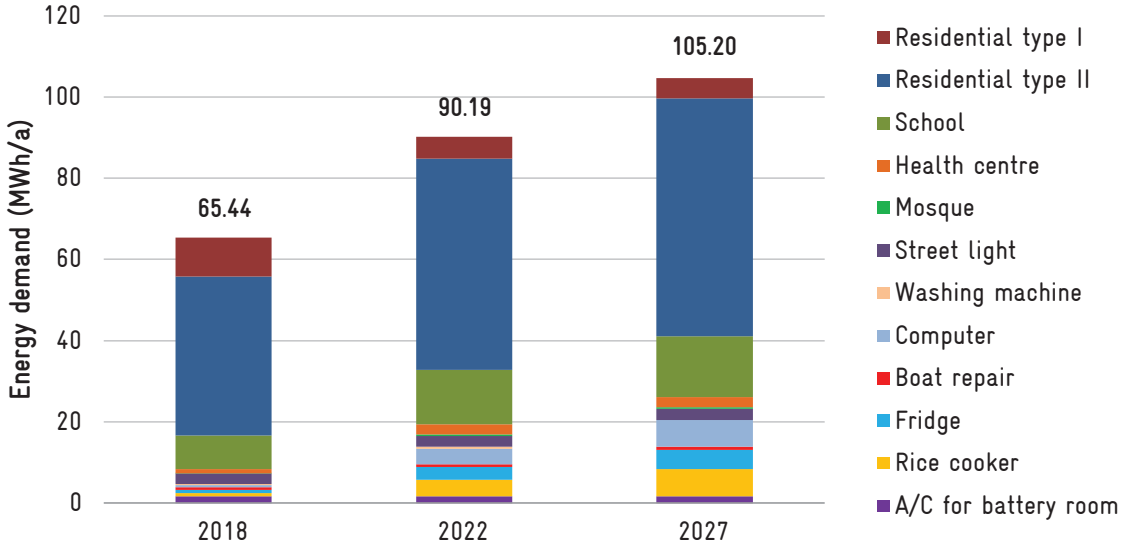


Figure 38: Energy demand forecast for Bulon Don [5]

Taking distribution losses of 1% into account, the future energy generation delivered by the hybrid power plant is summarized Table 9.

Table 9: Future estimated amount of generated energy by hybrid power plant [5]

Data	2018	2022	2027
Gross generation of hybrid power plant	66.10 MWh/a	91.11 MWh/a	106.26 MWh/a

NOTE: For more detailed information and applied methodologies as well as growth factors, please refer to the feasibility study for Bulon Don (Annex 5: Feasibility Studies).

5.2.2 System Design

With the above-mentioned tools and methodology and based on the outlined load projections, ILF optimized the RE hybrid system size for Bulon Don to be:

- Diesel Generator 3 x 15 kW
- Solar PV 52.14 kWp
- Battery Storage 100 kWh

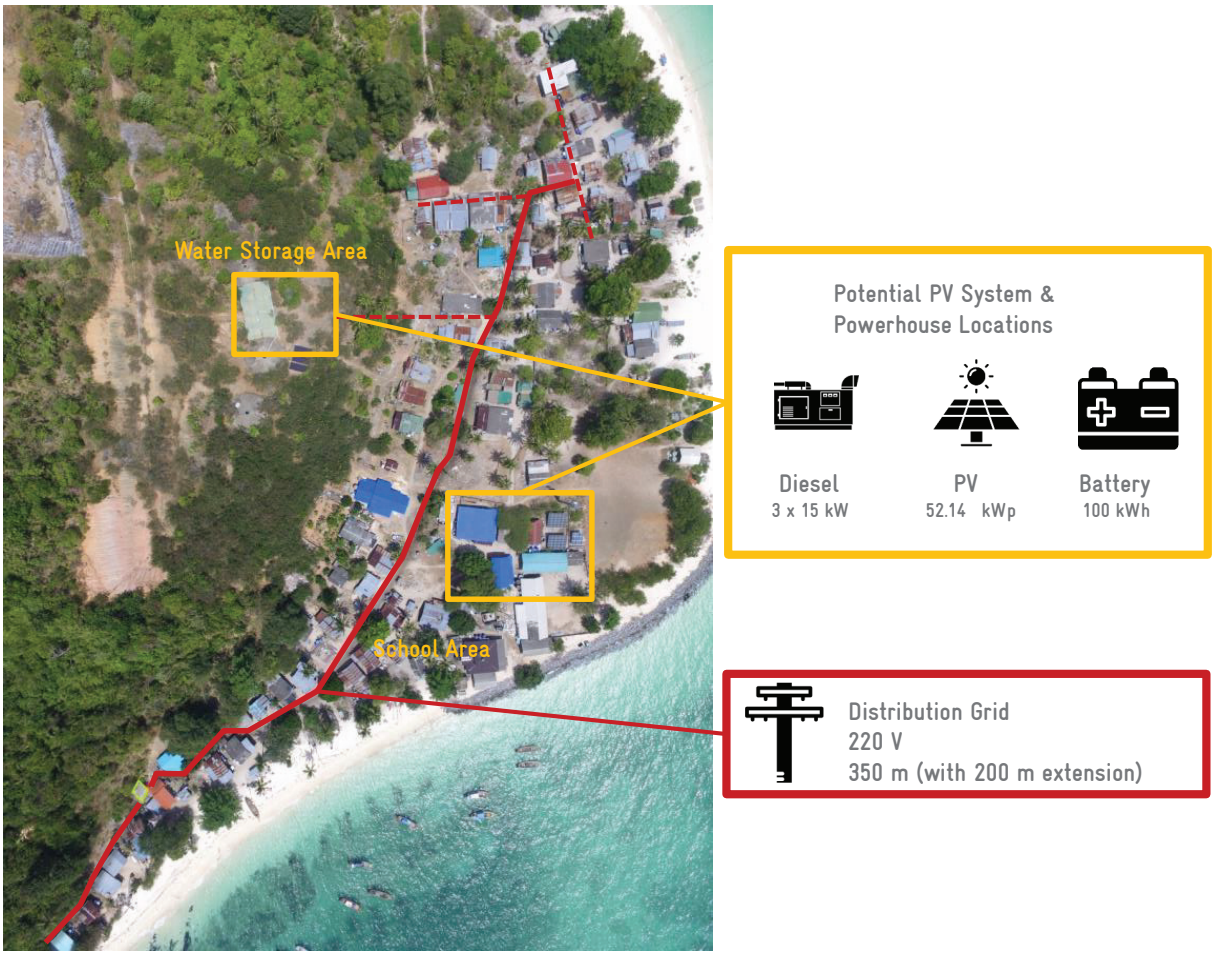


Figure 39: RE hybrid system design and size for Bulon Don Island; [5], Icon Source [2]

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

Table 10: Energetic results of the simulation [5]

PV / Diesel / Battery Hybrid System	Unit	2018	2022	2027
System parameters				
Total capacity diesel generators	kW	45 (3x15 kW)		
Number of diesel generators	Unit	3		
Total PV capacity	kWp	52.14		
Total PV inverter	kWAC	46		
Total battery capacity	kWh	100		
Usable total battery capacity (SOCmin 10%)	kWh	90		
Battery inverter capacity	kW	27.3		

PV / Diesel / Battery Hybrid System	Unit	2018	2022	2027
Homer simulation output				
Total energy production (demand)	kWh/a	66,072	91,067	106,219
Share Diesel	kWh/a	24,940	42,077	55,933
Share PV and battery	kWh/a	41,132	48,990	50,286
Excess PV energy	kWh/a	25,096	14,417	11,250
Total diesel consumption	l/a	9,460	15,795	20,944
Reduction of diesel consumption (compared to diesel reference scenario)	l/a	18,003	20,158	20,672
Specific diesel consumption	l/MWh	379	375	374
Renewable fraction (PV and battery)	%	62	54	47
Excess PV energy	%	37	22	18
Total diesel operating hours	hr/a	2,047	3,193	4,162
Operation hours below 50%	%/a	6.37	0.28	0.04
CO_2 emission	t/a	25	42	55
Reduction of CO_2 emission (compared to diesel reference scenario)	t/a	48	53	55

More details are given in the following chapters. The Single Line Diagram (SLD) is shown in Annex A.4.2 Bulon Don.

5.2.2.1 Diesel Generator

The optimized diesel generator capacity, for the case of the island has been identified to be 3 x 15 kW 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 no longer be 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. 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.

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

The main characteristics are summarized in Table 11. 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 11: Main characteristics of the diesel generators [5]

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	15 kW (18.75 kVA)

Parameter	Value
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
CO2 emission (diesel fuel)	2.64 kg/l

5.2.2.2 PV and Battery Storage

To achieve the above criteria (2.3.5) the PV capacity was optimized to be 52.14 kWp and the battery capacity 100 kWh. More details are given in the following two tables.

Table 12: Main characteristics of PV power plant [5]

Parameter	Value
Total PV capacity (DC, STC)	52.14 kWp
Total inverter capacity (AC)	46 kWAC
DC/AC ratio	1.13
Power factor (cosφ)	0.8

Table 13: Main characteristics of battery storage system [5]

Parameter	Value
Technology	Li-ion
Total battery capacity	100 kWh
Battery inverter capacity	27.3 kW
Roundtrip efficiency	~90%
Maximum C-Rate (charge/discharge)	1.0C / 1.0C
Maximum DOD (SOCmin)	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
Estimated lifetime throughput	~600,000 kWh
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.

Figure 22 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.

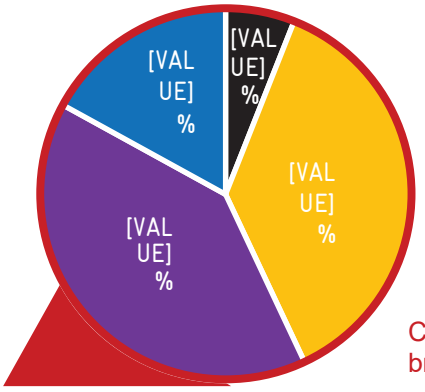
5.2.2.3 Electricity Grid

To implement the hybrid system on the island, the existing grid transmission line shall be upgraded and extended as mentioned in Chapter 4.1.3.1. The cables of the central grid line are still in good condition. In addition to the transmission line all connections to households have to be redone as the current connections are not in line with common safety standards.

5.2.3 Financial Analysis

The approach was to compare different electrification scenarios for Bulon Don Island as mentioned above (Chapter 3.5). Table 14 gives an overview of all CAPEX and OPEX cost. The CAPEX is covering all expenditures to implement the RE hybrid 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 14: CAPEX and OPEX for the RE hybrid system on Bulon Don [5]



	CAPEX	OPEX	No. REPLACEMENT
Diesel generator	373,950 THB	3.74 THB/kWh (e.g. 2018: 93,276 THB)	5
PV	2,253,073 THB	34,662 THB/a	1
Battery	2,393,280 THB	40,686 THB/a	Battery: 3 Battery Inverter: 1
Other	1,028,778 THB	3,324 THB/a	-
Total	6,049,081 THB	e.g. 2018: 171,948 THB	

To get a better understanding on the unit cost and to compare the two different electrification scenarios (RE hybrid system vs. 100 % diesel system), the levelized cost of electricity (LCOE) were calculated for both scenarios as well as for the decentralized micro-grid setups applying to the island over the past 1.5 years.

- Decentralized Micro Grids
  2-6 hours of electricity supply
  decentralized diesel generators
  here calculated for K. Jaesen's grid — 63.69 THB/kWh

- 100 % Diesel Scenario
  24/7 electricity supply
  30-years project lifetime — 22.53 THB/kWh

- RE Hybrid System
  24/7 electricity supply
  30-years project lifetime — 16.44 THB/kWh

The figures show that an RE hybrid system would be the most economic option to electrify Bulon Don Island. All technical and financial in- and output is summarized in a separate file, see Annex A.3.2 Bulon Don.

5.2.4 Regulatory Framework

As mentioned earlier, Bulon Don lay within the area of Mu Ko Phetra National Park. Therefore, implementing construction and infrastructure projects is very limited and needs approval of the regional and central National Park Offices. Therefore, the project needs to be proposed to the central National Park Office in Bangkok and the local National Park Office in Pak Bara encouraging the community benefits and the containerized "non-permanent" system design approach.

There are two options to get approval:

- Option A: Joint Project with Mu Ko Phetra National Park (Co-Project) In this case the project needs to be proposed to the regional office in Pak Bara first. As they are supporting the project for its community purpose and environmental friendliness, they agreed to add supporting notes to the proposal before sending it to the central office for approval. This option is easier to get approval for system implementation, but the RE hybrid system ownership would need to be transcribed to the Mu Ko Phetra National Park.
  With private sector involvement as planned for Bulon Don, this is a major barrier.

- Option B: Own-Project Implemented by Private Sector In this case all coordination between the private company and the National Park goes through the central office in Bangkok. Approval might become harder, but is not impossible. Currently, GIZ together with the private company are clarifying the proposal and approval process with the central National Park Office in Bangkok.

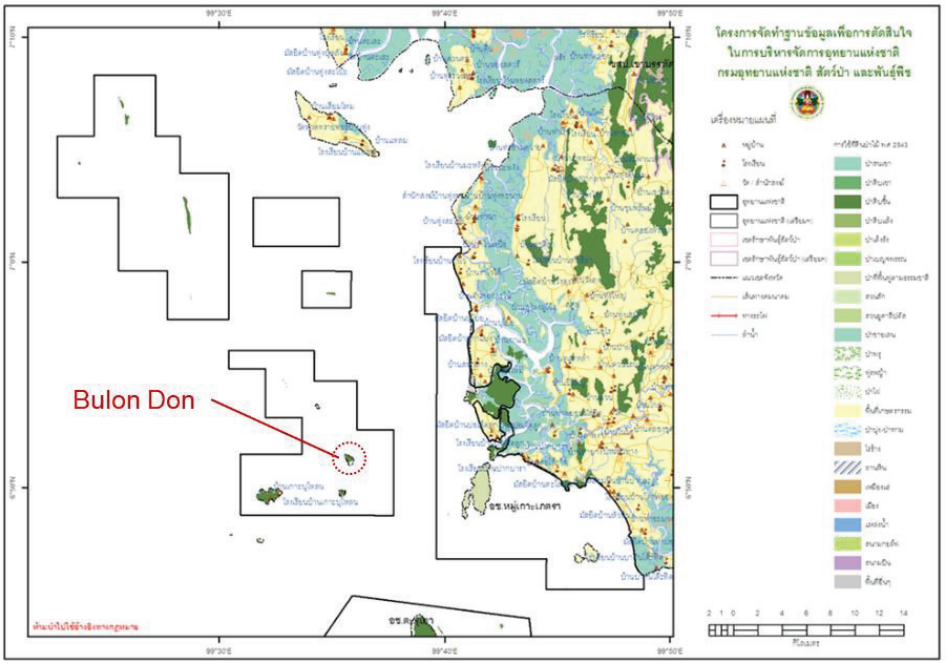


Figure 40: Mo Ku Phetra National Park area map indicating different conservation zones [9]

NOTE: It has to be mentioned, that the system as it is planned at the moment took the rules and regulations of the National Park already under consideration. No additional buildings are needed or extra land needs to be acquired. The PV system shall be built next to the water storage area and replace the currently broken water collection roof next to the tank. For the battery and diesel generator housing a containerized solution under the PV system/water collection roof shall be considered. The space is currently not utilized and no building has been constructed. The system shall make use of already installed concrete poles to bear the new roof consisting of solar PV panels. In addition to the roof area, the abandoned and broken PV system next to the water tanks shall be replaced.

5.3 Implementation Plan

5.3.1 Proposed Project Setup: Public Private Partnership

For the case of Bulon Don Island, a private solar company showed interested to implement this pilot site as one of the first commercially driven RE hybrid system projects in Thailand. They take this pilot with a view to rolling-out further projects based on the lessons-learnt and reference case to upscale their activities in the mini-grid sector. The company is planning to hire 2-3 staff as local operators living on the island.

The local government (SAO) installed an electricity grid app. 2.5 years ago which was used to supply the island via a centralized diesel generator (also procured by SAO). This generator broke down and the grid got abandoned. Even though it needs extension, the grid may partly be used for the RE hybrid system. A grid usage agreement will be set up between the local government and the company.

GIZ is facilitating required meetings between all involved stakeholders. The results of the feasibility study conducted by GIZ served as a basis for further calculations of the implementing company and raised their initial interest.

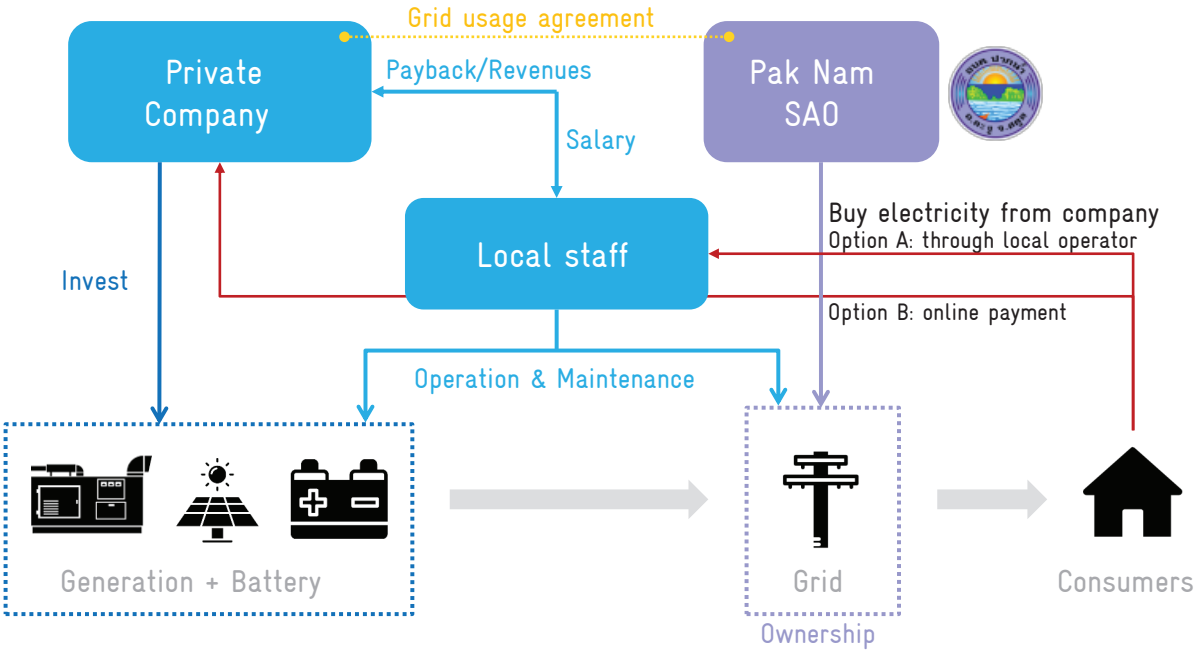


Figure 41 Foreseen business model: Public Private Partnership - Bulon Don Island; Icon Source [1]:

Motivation:
After several meetings and talks with private companies, one of them showed higher interest in developing the system on Bulon Don. The solar company is usually focusing on large scale solar projects, but is looking into new business models and segments. Their vision is to develop this very first mini-grid project and build upon lessons learnt while rolling-out their approach to other islands and thus tap the full market potential in Thailand's mini-grid sector and support the local communities in their socio-economic development.

Investment:
They are willing to invest in the generation assets and grid infrastructure in order to install the RE hybrid system on Bulon Don. Parts of the existing grid infrastructure shall be integrated into the new system setup. A grid usage agreement shall be signed between the company and the local government (SAO).

Project Duration:
The solar company plans to install the RE hybrid system and operate it over a project duration of 10 years. After this time the initial investment shall be paid back and sufficient revenues shall be gained to ensure long-term operation of the system (replacement cost). After 10 years, the company is planning to hand the system over to the community. The community shall be enabled to run and manage the system over the course of the first 10 years through capacity building measures.

Tariff Structure:
The tariff needs to be agreed upon between the company and the community. It needs to be designed in a way that it is affordable for the local community and still covers operation and maintenance as well as payback of the investment cost. Negotiations are ongoing and GIZ ensures close alignment between both parties. The current proposal foresees a tariff of 22 THB/kWh, but is not yet final.

Payment System:
The payment system shall ideally be realized via mobile payment. The company will further assess the feasibility of this approach in the next site visit. If some villagers do not have access to mobile payment channels, an alternative payment system via local accountants in cash is considered.

Operation & Maintenance:
The company plans to hire at least two local people and train them to take care of basic operation and maintenance on the island. Their experts are backstopping in case of major technical obstacles.

Monitoring:
It is crucial to install smart meters for remote monitoring and part of the risk management of the company. It also serves the community to balance and control their consumption and thus regulate their electricity cost to be in line with their ability to pay. Through the installation of smart meters, the demand and consumption of electricity is transparent to both parties (company and community) and triggers a trustworthy relationship.

5.3.2 Next Steps

1) National Park: Project Proposal and Approval
As a very important next step the proposal and approval process with the central National Park Office needs to be outlined and clarified. Therefore, GIZ will arrange a joint meeting between the central office and the solar company in order to present and discuss the project and define concrete next steps.
The next trip to the South to meet the island community and local stakeholders (SAO, PEnO, National Park) is planned for March 2018. This serves as an opportunity for further relation ship management and to progress on the issues described below.

2) SAO: Grid Usage Agreement & Tariff Design Transparency
In the next meeting with the local government, GIZ and the private company are aiming to receive an official document from SAO who agreed to give the grid utilization rights to the project. From SAO side, no official grid usage agreement is needed. However, the company prefers to get an official document in order to manage their risks.
In addition to this, the company promised to provide more transparency on their tariff deter mination. Different tariffs for several off-grid communities under the jurisdiction of Pak Nam SAO (mainly 100 % supplied by diesel generators) were discussed and evaluated in a latest meeting. In order to make the determined tariff transparent and comparable to the previously discussed cases, more detailed information was requested by SAO.

3) Bulon Don Community: Stakeholder Management; Tariff Design Transparency; Local Operator and Accountant Selection
The objectives of the next meeting with the communities are twofold:
First the tariff needs to be discussed and agreed upon. Therefore, it would be highly relevant to understand past tariff agreement processes conducted by the community in depth to understand how the community works and makes decisions which are valid for everyone on the island.
Secondly feedback and availabilities from the pre-screened candidates to take over the role as local operators and who will become the company's staff has to be gathered in casual talks and interviews in order to select the most suitable candidates. These need to have a basic technical understanding and high backing in the local community.

Once the National Park approves the project and details about the tariff and project setup are agreed upon with the community, the system can be implemented within app. 7 month.

5.4 Sensitivity Analysis

In order to evaluate the influence of different parameters set in the simulation of the system on the LCOE, the technical consultant provided a sensitivity analysis (10- and 30-year project duration). The aim was to get an idea to what extent 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. Sensitivity was analyzed for the following parameters:

- CAPEX: ±30%)
- Energy Demand: ±20%
- Fuel Price: ±10%

10-years project lifetime period scenario

Figure 42 presents the results of the sensitivity analysis on LCOE/LCOEestimated for the variation of CAPEX, energy demand and fuel price.

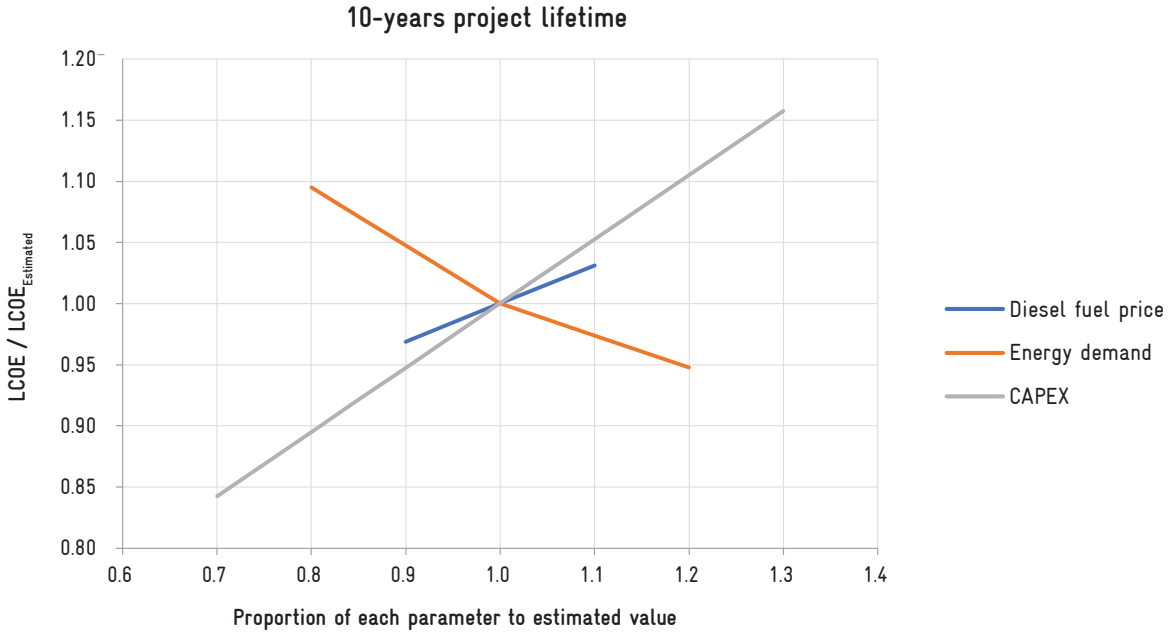


Figure 42: Sensitivity analysis results of 10-years project lifetime scenario – Bulon Don [5]

Meaning that:

- CAPEX ± 30% variation in CAPEX leads to a ± 15.76% variation in LCOE
- Energy Demand + 20% variation in energy demand leads to a – 5.22% variation in LCOE
  - 20% variation in energy demand leads to a + 9.49% variation in LCOE
- Fuel Price ± 10% variation in fuel price leads to a ± 3.10% 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).

30-years project lifetime period scenario

Figure 43 presents the results of the sensitivity analysis on LCOE/LCOEestimated for the variation of CAPEX, energy demand and fuel price.

Figure 44: Sensitivity analysis results of 30-years project lifetime scenario – Bulon Don [5]

Meaning that:

- CAPEX ± 30% variation in CAPEX leads to a ± 8.74% variation in LCOE
- Energy Demand + 20% variation in energy demand leads to a – 0.54% variation in LCOE
  – 20% variation in energy demand leads to a + 0.51% variation in LCOE
- Fuel Price ± 10% variation in fuel price leads to a ± 5.27% variation in LCOE

Again, the variation of CAPEX has the biggest impact on the economics of the project. The hybrid system is most sensitive to CAPEX in the short term, with demand and fuel consumption following. As the project lifetime is increased, the sensitivity to CAPEX decreases and sensitivity to energy demand almost diminishes to zero. The systems sensitivity on fuel cost increases on the long term, as the system uses increased amounts of fuel from year to year.

The project developer is responsible for the procurement of system components and has a direct influence on the CAPEX. Thus, it is an easy to control risk.

The energy demand cannot directly be controlled, but 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. Additionally, a lower energy demand than expected is not affecting overall system stability and thus the company's reputation as reliable electricity supplier. It will only affect the system's economics which can be regulated through innovative tariff structures.

5.5 Impact Assessment

The following analysis will evaluate the impact of RE hybrid system development on the involved stakeholders.

5.5.1 Local Community

For the local community the establishment of a centralized reliable 24/7 electricity supply means a lot. Currently they have limited supply hours and are facing frequent black- and brownouts which is not only difficult to handle for the people but also affecting the lifetime of the electronic devices connected to the grids.

With grid reliability and expected cheaper rates then they are currently using, productive use of electricity on the island will be triggered and economic growth is enabled as well as alternative income sources are generated. Existing businesses such as restaurants, repair shops and grocery shops can expand and new businesses will appear enabled by reliable electricity supply.

The kids suffer from over-heated classrooms and a missing access to modern teaching methods. It is difficult for them to compete with onshore students in regards to higher education. The implementation of a RE-diesel hybrid system will help to tackle these challenges.

> "Curing some minor diseases would be so easy with stable access to electricity. Medicine could be stored in fridges and freezers and given when people get sick. At the moment, we don't have the opportunity to store the medicine in a cool place and are dependent on onshore health centres or the medicine boats that pass the islands from time to time."
>
> Old man living on Bulon Don during the community meeting on 24th August 2017

As stated by this man, the local health care will also improve as medicine can be chilled and stored over long periods of time, curing basic diseases promptly will no longer be an issue. The currently closed health center can re-open and extend their services to the community.

> "Babies and children as well as their families will enjoy better sleep with access to 24/7 electricity - children often wake up in the middle of the night because they are too hot. Family members have to fan them manually to cool them down. The possibility of running electric fans will improve the quality of life a lot."
>
> Mother of a 2-year-old child living on Bulon Don during the community meeting on 24th August 2017

The implementation of a RE hybrid system will have overall positive impacts on livelihood on the island. They will, for example, feel safer and find better sleep as stated by these two women (quote above and below) during a community meeting.

"It gets really dark on the island especially during the monsoon season. Some people are very scared by the darkness. With continuous electricity supply, we would be able to install street lights. People will feel safer and tripping hazards will reduce."

Elderly woman living on Koh Bulon Don during the community meeting on 24th August 2017

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 the implementation of additional renewable energy technologies on the island. Bulon Don Community could be a role model for other island communities especially neighboring Bulon Lae.

5.5.2 Private Company – Project Implementer

The company has interest to develop further island projects after this pilot project and create a pipeline of further mini-grid projects. They will have major market benefits from being one of the first companies to develop these systems in Thailand. With this activity the company is tapping new business models and segments. The up-scaling potential is high and significant lessons- learnt can be taken from this pilot.

"The impact of a reliable electricity supply goes beyond entertainment: It has fundamental impacts to the local health and education systems and safety. App. 1 Mio. of people are still without electricity supply, we need to change that. If one model works, it can serve as prototype and encourage the others to work on this model together for the community"

Chayasak Itthisiri, Head of Business Development, Symbior Solar on the panel at the 3rd Community-based Renewable Energy Conference, February 2018

Other private companies also showed interest in further mini-grid projects on bigger scale (pipeline of projects or bigger project size). This will have a major impact on rural electrification approaches of the country and might trigger fast implementation and connection of the remaining off-grid communities.

5.5.3 Local Government – SAO

The local government plays a major role in project implementation and is able to claim the success in the case of RE hybrid system implementation. They are getting the opportunity to electrify two islands at the same time as they are planning to ship the new 50 kW generator from Bulon Don to neighboring Bulon Lae after successful implementation. They may benefit from the green and innovative image of this project and their pioneering role.

5.5.4 National Park Office

In case of a positive decision towards the implementation of a RE hybrid system on Bulon Don Island, the National Park may also benefit from the green image of the project. They are actually fulfilling their mandate to preserve the area under the National Park as fuel consumption will be reduced and thus environmental pollution and CO2 emissions are decreased. A co-benefit for the local National Par Office in Pak Nam could also be the better relationship to the villagers on Bulon Don. Since the area was declared National Park, there are ongoing conflicts between the villagers who were living there for generations and the Park Administration, as infrastructure and construction projects are very limited.

6. Outlook – Reaching the Last Mile...

GIZ will continue to support the implementation of RE hybrid systems on these two very different islands in two exciting project constellations. As Dumrong Sinto is stating below, the remote off-grid islands of Thailand deserve attention and support towards their sustainable development.

> "Koh Mak Noi is one of the most forgotten islands [in Southern Thailand] and deserves attention and support towards its sustainable development."
>
> Dumrong Sinto, Chief Executive of the regional Subdistrict Administrative Organization responsible for Koh Mak Noi

This project served as a pilot for GIZ to identify the potential and suitable partners as well as to develop effective approaches to support rural electrification in Thailand. The need is identified, the methodology developed and scalability is proven.

We are aiming to scale this project up and implement a follow-up project together with several implementing partners. The project is currently under development and stakeholder consultations are ongoing. The aim is to build upon lessons learnt from this project and together with strong strategic partners reach the last mile of Thailand's remote communities with sustainable and reliable electricity supply.

Sources...

[1] International Energy Agency: Southeast Asia Energy Outlook 2017. World Energy Outlook Special Report. IEA 2017.

[2] Icons [Creative Commons Right]:
- Generator by Jon Trillana from the Noun Project
- Solar panel by Saeful Muslim from the Noun Project
- Battery by Ben Davis from the Noun Project
- Electricity Pole by Ben Davis from the Noun Project
- House by Aimeê Ferreira from the Noun Project

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[6] Google.Maps
Map data ©2018 Google

[7] Information provided by the Provincial Electricity Authority of Thailand

[8] Ministry Regulation Thailand: Enforcement of urban planning in Phang-nga province B.E. 2560.

[9] Mo Ku Phetra National Park, Zoning Map
Department of National Parks, Wildlife and Plant Conservation, Thailand.

Annex 1: Site Selection Criteria Catalogue

See separate PDF file:

"170131_Island Selection Criteria"

General Data of the Consumer

Island/Village:			
Date:	Interviewer:	Location Data (generator serial number, picture of house etc.)	Questionnaire No.:
Type of Electricity Consumer	( ) Household ( ) Public Building (please specify) ( ) Business (please specify) ( ) Hotel/Resort (please specify seasonality)	( ) Temple/Mosque ( ) Health Centre ( ) Infrastructure (please specify) ( ) Others (please specify)	In case of non-household, specify working hours/days

Respondence Data:

Name	Street	Building No.	Phone Number
No. of persons living in the premise	Specify age of the persons living in the premise	describe the building material (wood, masonry, concrete, etc.)	Current source of electricity (please specify model, capacity, age etc. if possible)

Economic Situation of the Consumer

Income Source and Expenses [month]		
Income Source	Amount (low season)	Amount (high season)
1		
2		
3		
4		
Overall Expenses		

Stated Ability to Pay for Electricity [month]	
Amount Low Season	Amount High Season

Current Energy Expenses [month]	
Fuel/Type	expenses
Diesel/fuel	
Kerosene	
Candles	
Batteries	
Battery charging	
Mobile phone charging	
Firewood	
Others (please specify)	
Operation Cost	expenses
Maintenance Cost	
Replacement Cost	

Electricity Needs of the Consumer

Appliances and their Operation

Appliance	Power [W]	No. of Appliances	Daily Use [h]	Range Used [from-to]	Future Plans [additional No. of Appl.]	App. Time of Investment
Light Bulbs (8-20)						( ) immediately ( ) within one year ( ) later
TV (45-120)						( ) immediately ( ) within one year ( ) later
Radio (20-60)						( ) immediately ( ) within one year ( ) later
Phone (2-5)						( ) immediately ( ) within one year ( ) later
Fan (45-60)						( ) immediately ( ) within one year ( ) later
Fridge (80-200)						( ) immediately ( ) within one year ( ) later
Computer (45-200)						( ) immediately ( ) within one year ( ) later
Pump/Weldering						( ) immediately ( ) within one year ( ) later
AC (1500-2200)						( ) immediately ( ) within one year ( ) later
Washing Machine						( ) immediately ( ) within one year ( ) later
Iron (1000-1500)						( ) immediately ( ) within one year ( ) later
Others (please specify)						( ) immediately ( ) within one year ( ) later

Are there fluctuations in the overall energy consumption? (summer/winter, holidays, weekdays/weekend,...)
please specify

Willingness to Pay

How happy are you with your current electricity supply?	( ) Very happy	( ) Not happy	( ) Can live with it
What is important to you?	( ) Cost of Electricity	( ) Quality of Electricity	( ) Duration of Supply
What will drive you to connect?	( ) Neighbors connected	( ) Need for electricity (HH level)	( ) Need for Electricity (business)
Will and electricity mini-grid improve your life or business somehow?	( ) Yes	( ) No	( ) Don't know
On what basis should the electricity tariff be calculated?	( ) Covering GC	( ) Covering GC and O&M	( ) Covering GC, O&M, RC
Are you willing to provide man/ woman-power to reduce costs?	( ) Yes	( ) No	( ) Don't know
Do you have a Solar Home System (SHS)?	( ) Yes	( ) No	( ) Under consideration
If yes: Is the SHS working?	( ) Yes	( ) No (why? Which equipment is installed?)	
If yes: Does it cover your current electricity demand?	( ) Yes	( ) No	Percentage (if assessable)

GC= Generation Cost; O&M = Operation and Maintenance; RC = Replacement Cost

Notes/Comments/Impression _

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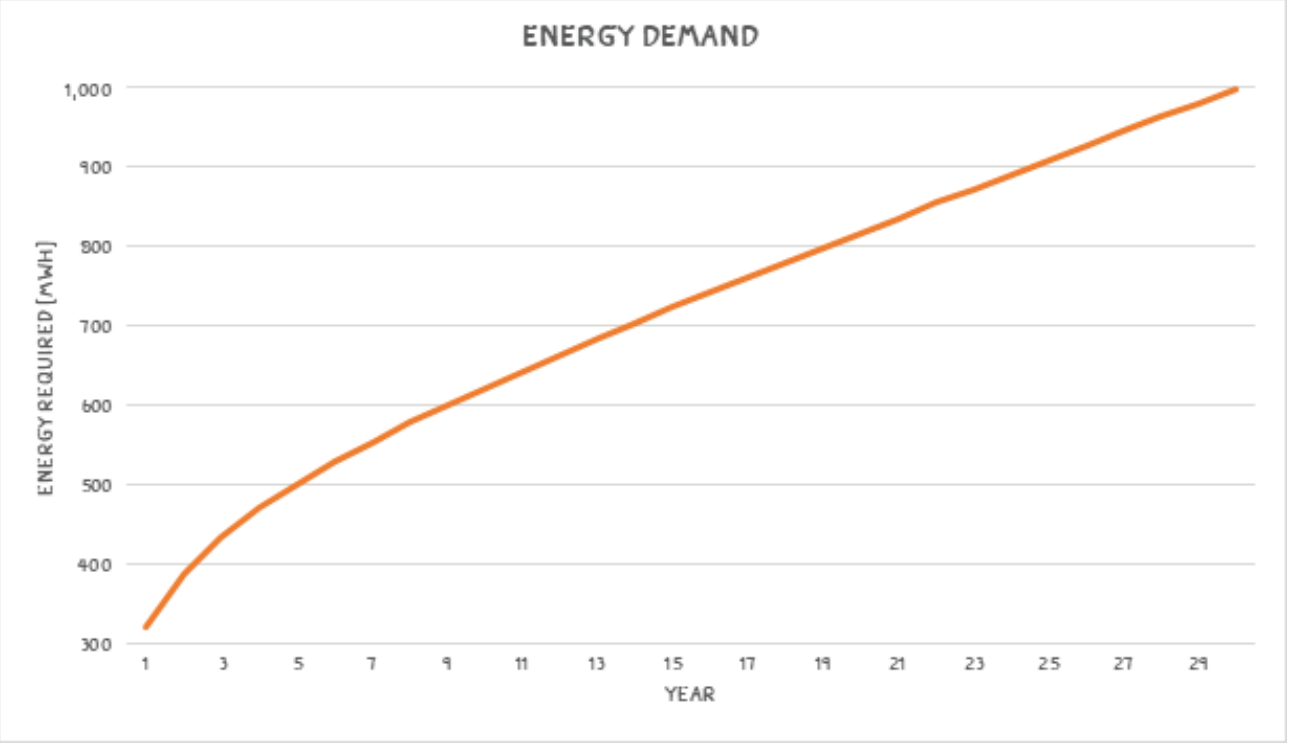
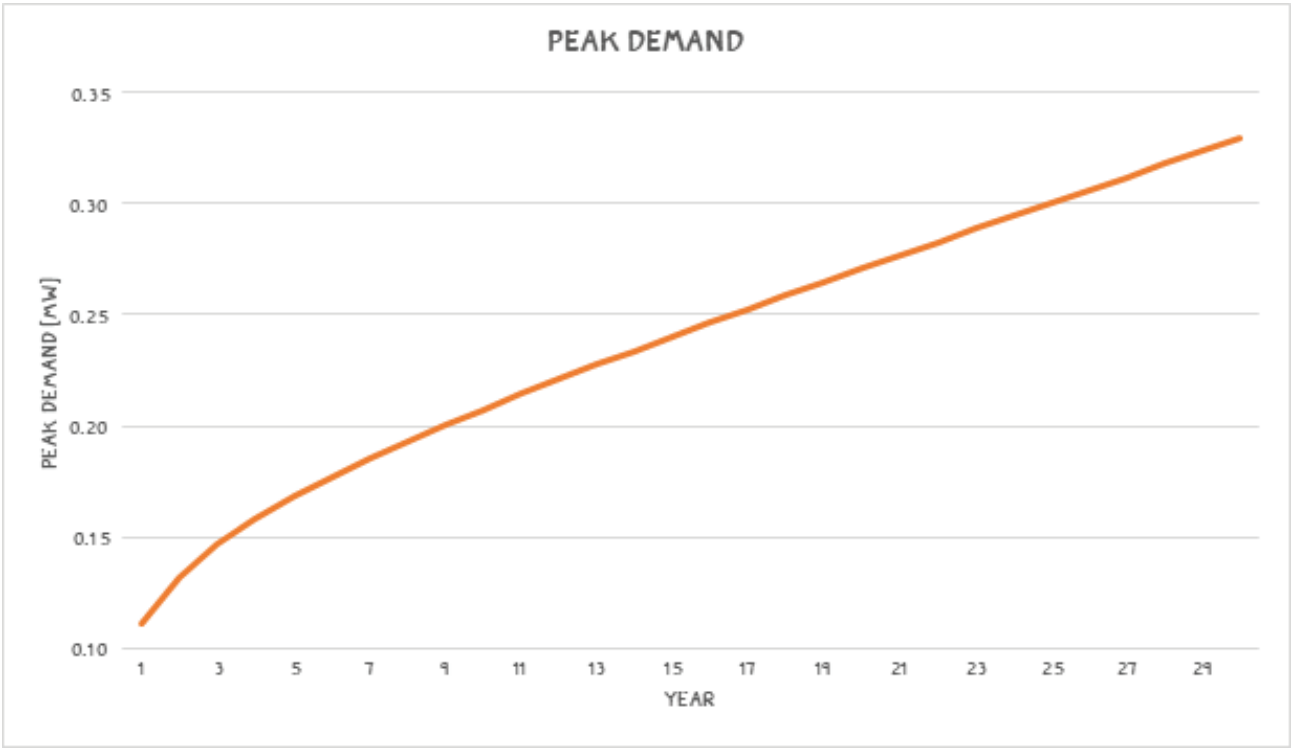
A.2.2 Survey Results

See separate Excel files; provided on request as they contain sensitive data
(write a mail to: thachatat.kuvarakul@giz.de)

A.2.3 Site Assessment Reports

See separate Pdf files:
"170501_Site Visit Report_Mak Noi"
"170501_Site Visit Report_Bulon Don"
"170518_Site Visit Report_Bulon Lae"




PEAK DEMAND
0.35
0.30
0.25
0.20
0.15
0.10
PEAK DEMAND [MW]
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
YEAR

Annex 3: Simulation Inputs and Outputs

A.3.1 Mak Noi

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		

For more details, see separate Excel files; provided on request
(write an Email to: thachatat.kuvarakul@giz.de)
"N048_Hybrid System_MakNoi_(For GIZ)"

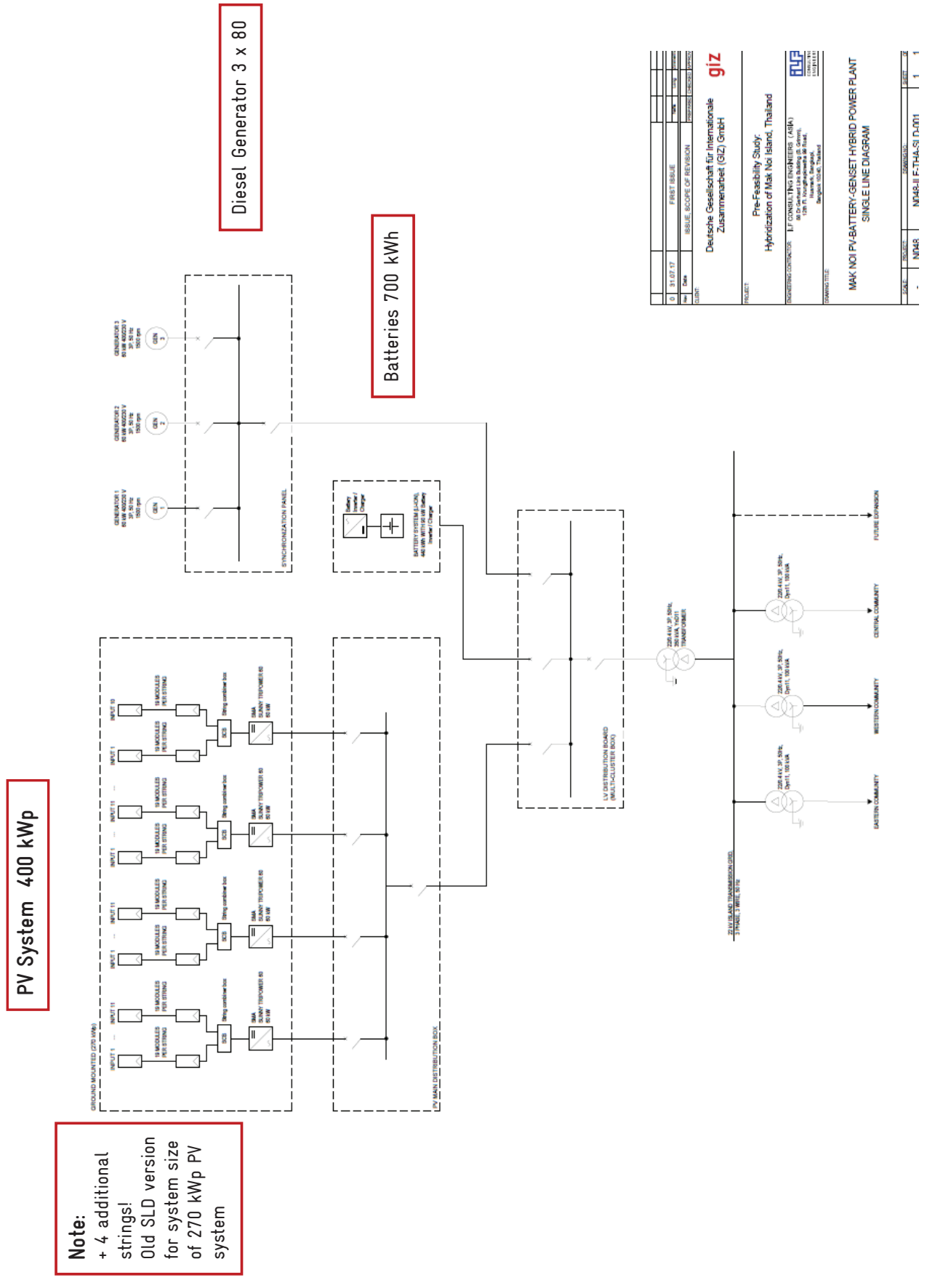
A.3.2 Bulon Don

Parameters	Values	Parameters	Values
Diesel generator		Battery & inverter	
Brand/model	Generac Protector	Battery Technology	Li-ion
Rated power	15 kW x 3 (Total 45 kW)	Battery capacity	100 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: 0.635 l/hr Slope: 0.327 l/hr/kW	Battery Minimum SOC	20%
Total Capital	11,250 USD	Inverter capacity	27.3 kW
Replacement / generator	1,125 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	52.14 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	46 kW		
Efficiency	98%		
Lifetime	15 years		
Capital	included in PV costs		
Replacement	120 USD/kW		

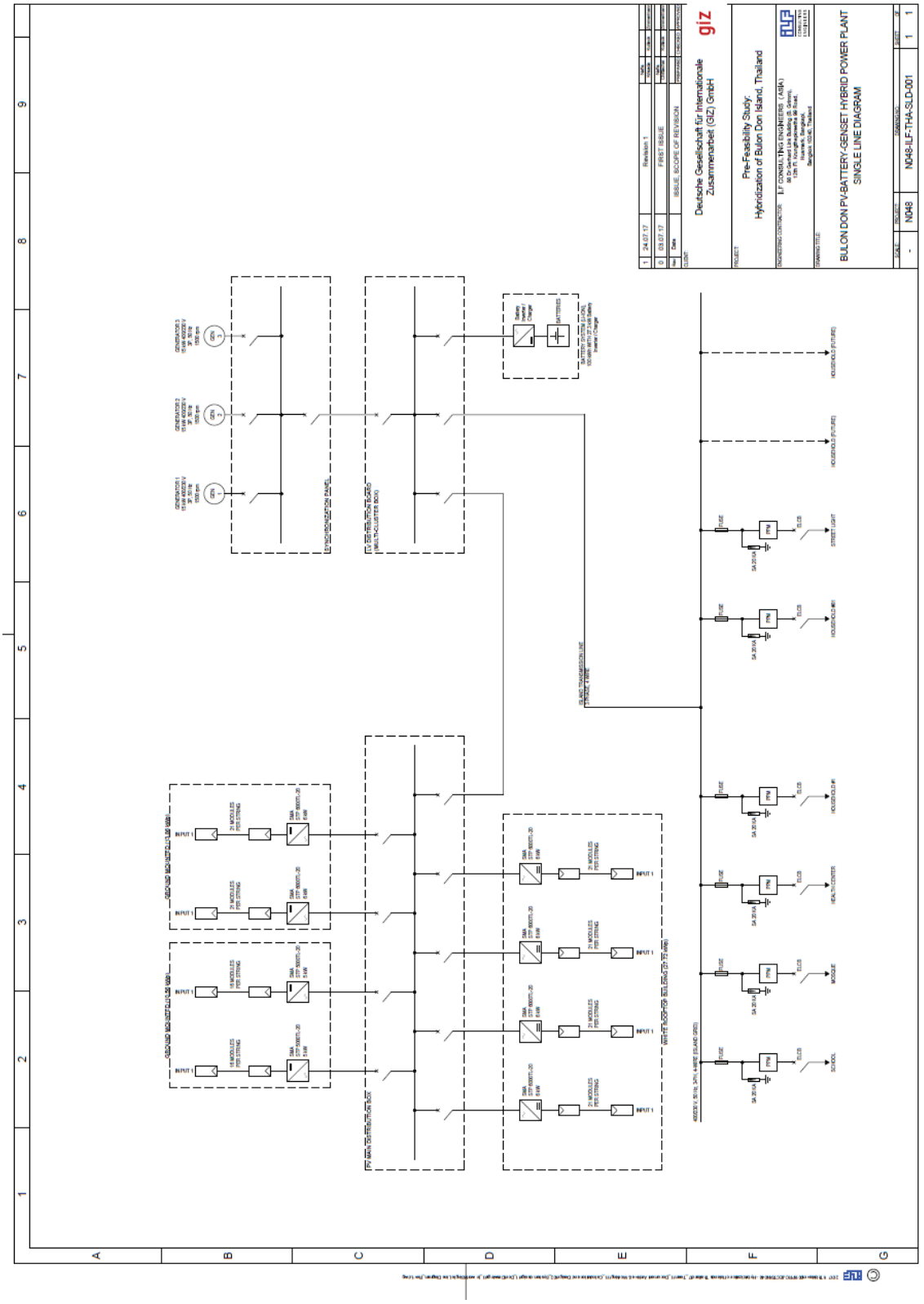
For more details see separate Excel files; provided on request
(write an Email to: thachatat.kuvarakul@giz.de)
"N048_Hybrid System_Don_(For GIZ)"

Annex 4: Single Line Diagram

A.4.1 Mak Noi



A.4.2 Bulon Don



Annex 5: Feasibility Studies

See separate Pdf files:

"170807_Feasibility Study_Mak Noi"

"170809_Feasibility Study_Bulon Don"

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