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RESEARCH REPORT

Optimum Design of a Hybrid Power Generation System at Air Sena Village

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2015

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CHAPTER 1. INTRODUCTION

1.1. Background and Objectives

Indonesia is by far the largest economy in Southeast Asia. With 13,466 islands (Timnas PNR Report 2010; in GIZ PDP Indonesia 2014) and around 237.64 million population (Statistics Indonesia 2020; in GIZ PDP Indonesia 2014), achieving 100% electrification rate remains one of the biggest challenges faced by the country.

Electricity production for the national grid is predominantly generated through the use of fossil fuels (i.e. coal, natural gas and oil), whilst the remote islands and outer regions are mostly powered through diesel-fired power plants.

As Indonesia provides substantial subsidies for transport and power generation sectors, the high cost of oil has placed a heavy burden on Indonesia's economy. To lessen this burden, the Indonesian Government is looking towards renewable energy (RE) as a complementary energy source for these sectors.

Unfortunately at this stage, developing RE in emerging countries such as Indonesia is not without its own challenges. Business and development policy need to have a common interest in structuring political, economic, legal and social framework conditions which promote RE development. Under the Public-Private-Partnership (PPP) concept, it is hoped that companies and development cooperation organisation can work hand in hand. The target-oriented combination of the different strengths of the two partners creates new possibilities for positive development impulses in the partner countries.

Against this background, the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) is implementing the Project Development Programme in Indonesia (PDP-Indonesia). Funded by the German Federal Ministry of Economics and Energy, the programme's main objective is to help initiate development of RE pilot projects through bridging business partnerships between Indonesian and German companies.

One of the pilot projects pursued is the mini-grid hybrid (solar-wind-diesel) application in the fishing villages, located in one of the islands of Riau Archipelago Province. Air Sena Village has a population of 202 households and the majority of the households are currently served by diesel generator (genset) and grids sufficient for six (6) hours of electricity per day.

Typically, the village is using two 140 kVA gensets working alternately, to power 148 households and 4 public facilities. However, smaller gensets are also used by some households to provide additional power, in which the costs are shared among 5-8 households.

This research is to support for the GIZ PDP-Indonesia in conducting the Technical Data Survey and Energy Audit for Air Sena-Fishing Village Hybrid-PV Project in Sumatra Remote Islands to provide information for the preparation of implementing a pilot project that will serve as a model to showcase possible RE solutions to help improve the livelihoods of the villagers and encourage replication of mini-grid hybrid power plant projects across Indonesia.

The **objectives** of this study are listed as follows:

1. To complete detailed energy audit of the Air Sena fishing village,
2. To collect necessary meteorological data (e.g. solar irradiation, wind speed) at the Air Sena village,
3. To design a hybrid power generation system to meet the load.

1.2. Project Location

This project took place in Air Sena Village - Central Siantan District - Anambas Archipelago Regency of the Riau Island Province. The map location of the Village is shown in Figure 1. The centre of the Village lies on 30 24’ 7” N and 1060 28’ 0” E. Air Sena is located on the Southern part of Matak Island, amid the South China Sea, between Malaysia and Kalimantan-Indonesia. The closest mainland cities to Matak Island are Kuantan-Malaysia (around 177 nautical miles distance), Pontianak-Indonesia (around 273 nautical miles distance), and Singapore, Batam-Indonsia, Tanjung Pinang-Indonesia (around 180 nautical miles distance).

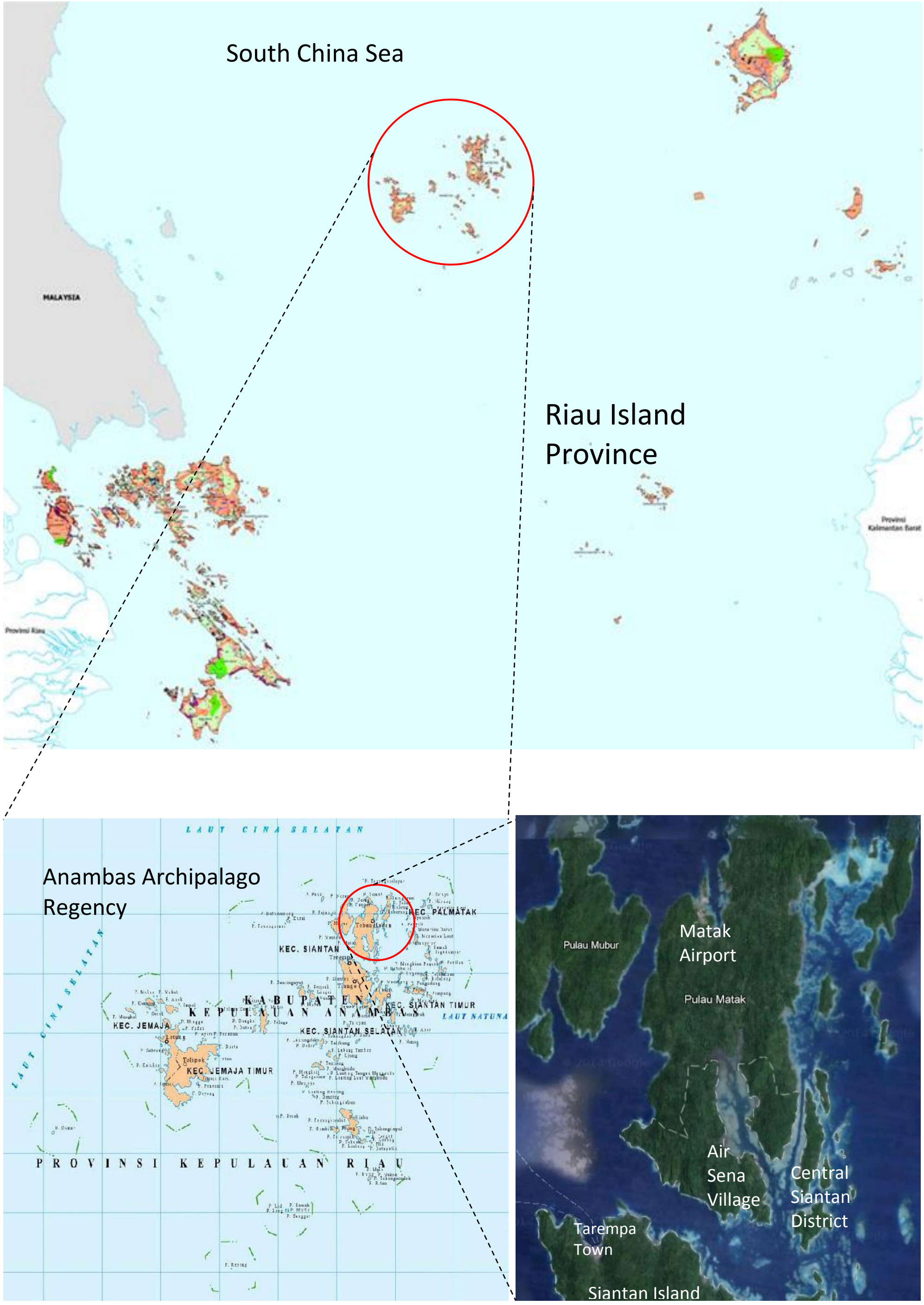

Figure 1. Location of Air Sena Village

Due to its remote location, currently the Air Sena Village can only be reached by using three different types of transportation modes. The first, which is the more secure option in terms of regularity of transportation, is by ferries from Tanjung Pinang to Tarempa Town in Siantan Island (approximately 9 hours), then is continued by small boats from Tarempa to Air Sena that normally takes around 30 minutes. However, during December to February, when the sea wave around Matak is at its highest condition, the ferries are normally not in operation. The second option is by airplanes from Batam or Tanjung Pinang to Matak Airport in Matak Island, then continued by land transport from Matak Airport to Matak Port (approximately 30 minutes), and by boats from Matak Port to Air Sena (Approximately 35 minutes). Unfortunately, the flights to and from Matak are not always available. The flight reschedules or even cancellations are often occurring. At the moment this report is being prepared, all flights to and from Matak are unavailable. The third option is using the Conoco company’s private aircrafts (Matak – Jakarta Halim Perdanakusuma Airport route) that sometime can be shared for non-Conoco staff for free. However, it is considerably difficult to get a seat on the Conoco’s flights because priority is given for the Conoco’s staff, local NAVY’s staff, and local Government staff.

CHAPTER 2. METHODS

2.1. General Methodology

The audit measurements were carried out in Air Sena. The measurements were done on a daily basis to investigate the characteristic of the energy consumption (peak and base loads). To prepare information for setting up a hybrid power generating system (e.g. diesel/pv/wind) in the village, the necessary meteorological data (e.g. solar irradiation, wind speed, etc.) at the village were collected. This information was obtained from the relevant institutions i.e. Badan Meteorologi, Klimatologi dan Geofisika (BMKG), Badan Pusat Statistik (BPS), and Meteonorm. The solar and wind data were also compared to the Surface Meteorology and Solar Energy database of the NASA.

More detailed methodology applied to meet the objectives is as follows:

- **Detailed energy audit of Air Sena Village:**

Energy audits included the current and projected energy need assessments of all consumer groups and the assessment of the current electricity supply system(s) in the village. The energy load assessment is aimed at developing the energy profile and costs include peak loads, base loads, daily energy consumption, daily energy use pattern, seasonal or annual variability, energy costs, and the activities or services provided by the available electricity.

To ensure an acceptable data representative, the energy load assessments were conducted at 30% - 40% of the households connected to the current grid and all public facilities. The energy loads of each consumer group were classified based on the types of loads and their services. A special questionnaire was developed for this assessment purpose and the surveys were conducted through a series of direct interviews. Also, the spatial distribution of the load premises has been observed to mapping the load locations - whether centralized, semi-centralized, or distributed.

The assessment of the current electricity supply system in the village was aimed at providing technical information about what equipment available on the village that might be included in the proposed hybrid power system(s). The assessment involved (but not limited) to the existing diesel and other generating system(s), local minigrid condition, and the condition of corresponding devices and equipment. In order to analyse the current performance of the existing generating systems, some measurements were taken accordingly e.g. output voltage, output current, fuel consumption, frequency, etc.

The assessment also looked at the management aspects of the current and proposed power generating system such as the owner of the current system, the operational practices, etc., as well the respondent preference about the ownership and the operational practices of the proposed system. There was also an observation about the availability of the land to install the hybrid system if the study recommends a centralized system, the owner of the proposed site/land, or how the site could be provided by the villagers. Site visit were undertaken to the potential site location(s) of the proposed hybrid system(s).

- **To collect necessary meteorological data (e.g. solar irradiation, wind speed) at Air Sena Village**

Solar and wind resource are the most important elements in projecting PV array and wind turbine performance at a given site. The best way of knowing the amount of global solar radiation and the wind resource are to install pyranometers or photovoltaic sensors and anemometer at the potential site to undertake measurements at least as long as one year period. However, such a long term measurement is not possible to be conducted as part of this project. It has been assumed that there are no measured solar radiation and wind data of the village. Therefore, the only possible available data came from the nearby meteorological station (BMKG). However, since the nearby meteorological station data is insufficient, another alternative was using the satellite-based wind speed and solar radiation data taken from Meteonorm and later were confirmed with the NASA databases. Information provided by these databases includes global solar radiation and wind speed. This information was used to design an optimum hybrid power system in the village.

- **Design of the Optimum Hybrid Power Generating System**

Beside the above tasks, it is also very important to recommend some scenarios of the proposed hybrid system(s). The design of the hybrid power system(s) in the village considered a mix of conventional generators, wind turbines, solar photovoltaic, and batteries. The software HOMER (developed by the NREL-USA) was used to evaluate the technical and economic feasibility of various hybrid energy alternatives to the village. The economic analysis compares the levelized cost of electricity generation of various options. The levelized cost focusing on the elements causing differences such as fuel price, PV modules, with battery or generator rather than the elements that are similar across the technology choices (distribution, metering, etc.). Due to the geographical nature of the household locations in the village, in order to determine which types of microgrid to be constructed in the village, another software named ViPor was also be used. ViPor (developed by the NREL-USA) determines which load premises should be connected to the microgrid and which premises should be supplied by stand-alone power systems to ensure the most efficient option. The results of the HOMER design recommended the cheapest option of the proposed hybrid system with lowest net present cost and lowest energy price per kWh. While the results of the analysis using ViPOR recommended the most efficient minigrid to be developed considering the distribution of the households in the village.

CHAPTER 3. PROFILE OF AIR SENA VILLAGE

3.1. Area, Geography and Topography

The total area of Air Sena Village is about 10 km^2. It has a peak elevation of 200 m above sea level and the lowest elevation is the sea level. Figure II-1 shows the situation of Air Sena Village. The map of Air Sena Village is shown in Figure II-2 showing entire area of Air Sena that consists of both land and water areas. This map also shows the Village's electrical load which is mainly concentrated on the land area. However, some load premises also exist on the water area. Although the number of households is 202, but some households possess also settlements off-shore (camps). There are seven clusters of camps off-shore where each cluster usually consists of some houses. Therefore, In terms of power connection, we consider the number of premises is 211 instead of 202.

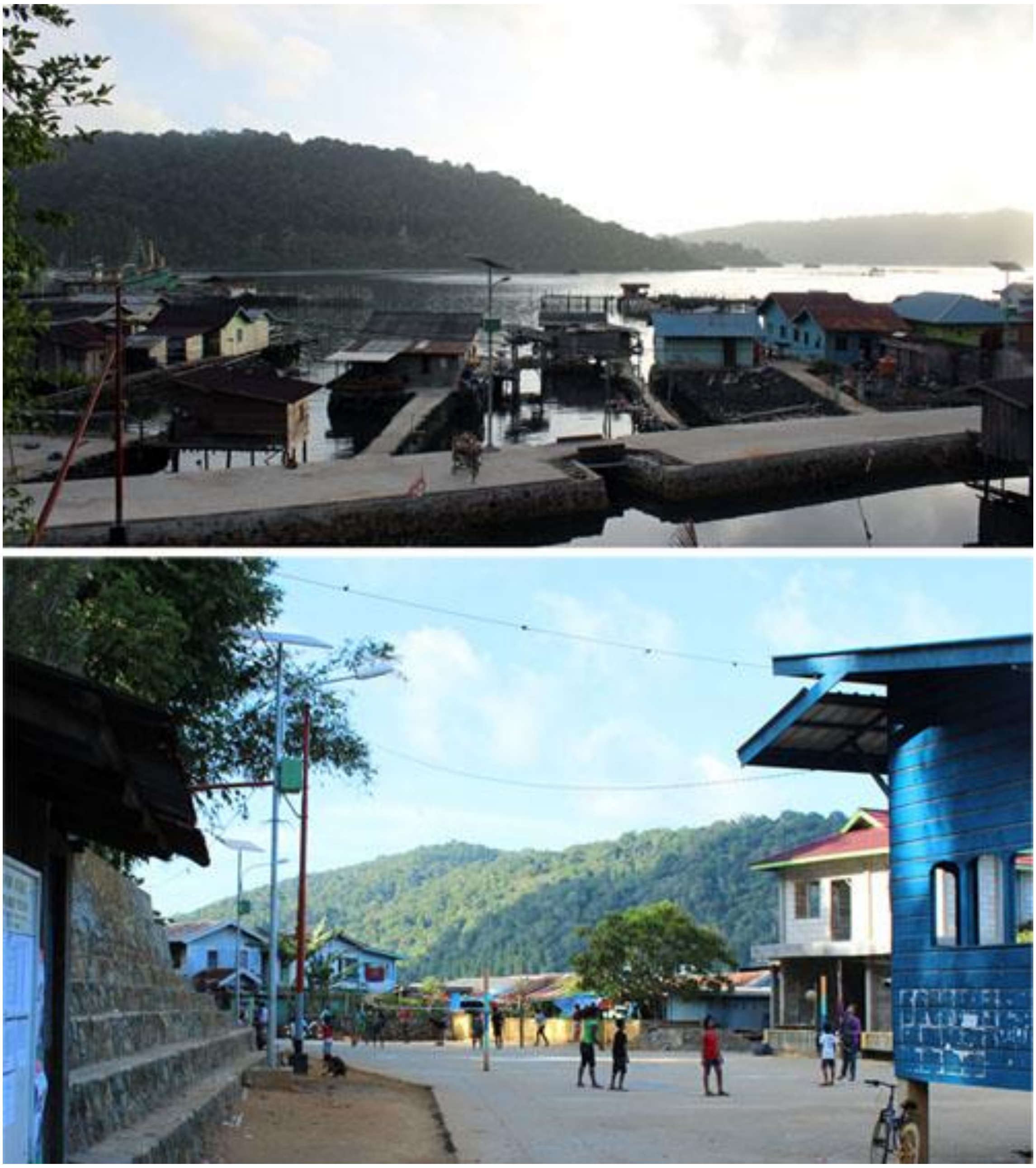

Figure II-1. Situation at the Air Sena Village

Air Sena Village consists of 5 Community Association (RW) and 8 Neighbourhood (RT). In the North, Air Sena is bordered with Air Nangak Village and Teluk Sunting Village, in the South it is bordered with Batu Belah Village and the South China Sea, while in the West it is bordered with Jeruan Village and Tarempa, and in the East it is bordered with Air Asuk Village.

The concentration of residential centre of the villager in Air Sena was located along the coastline, this due to the majority of the villager livelihoods associated with coastal and marine areas. The resident of the villager was concentrated in the northern of Air Sena which bordered to Air Nangak Village. The type of house of Air Sena villager is mostly constructed from wood (70%), some houses can be moved out from one place into another. The detail about the house distribution of the villager of Air Sena can be seen on Figure II-2.

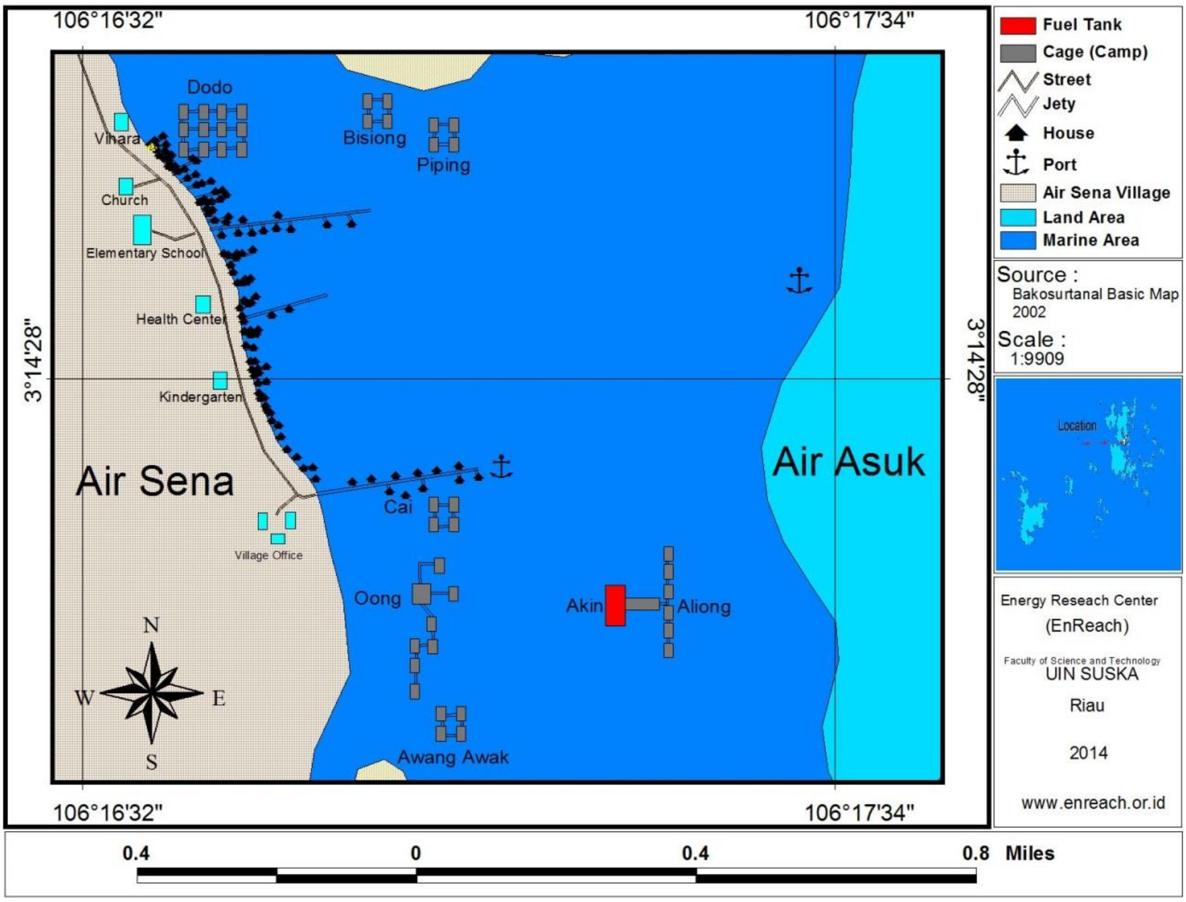

Figure II-2. House Distribution of Air Sena Village

Air Sena Village is a coastal area with hilly topography with the maximum altitudes is 200 meters above sea level. While the concentration of the residential of the population was located along the coastline, this is due to the livelihoods of the majority of the villagers of Air Sena Village associated with coastal and marine areas. The topography of Air Sena can be seen in Figure II-3.

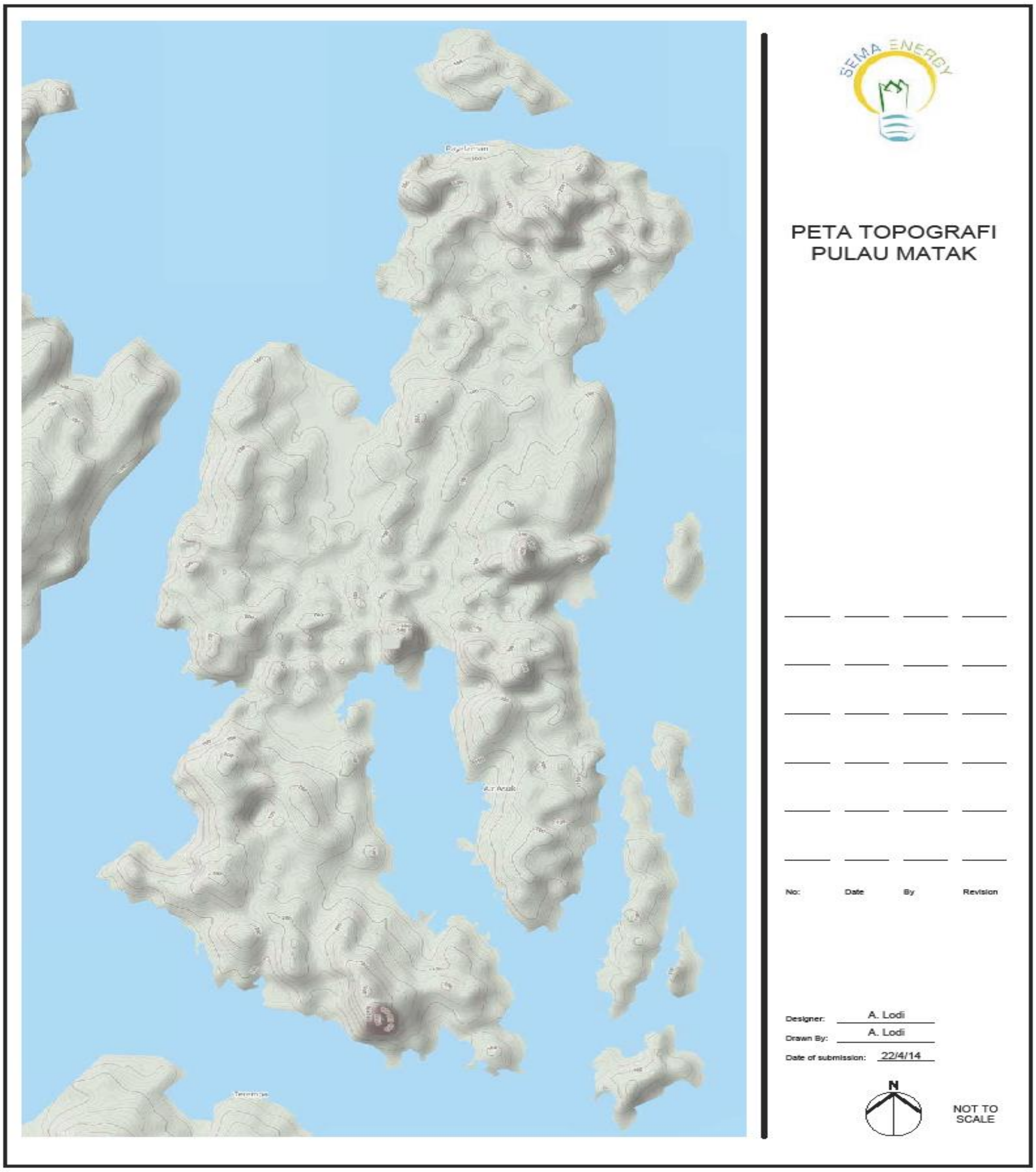

Figure II-3. Topography Maps of Matak Island (Image: PT. Suar Intermuda 2014)

Fisheries sector is main commodity in Air Sena Village, it is proven by the majority of the villager occupation is as a fisherman (84%). For fisheries aquaculture Air Sena has become one of the central in of the fisheries aquaculture sector in Anambas Archipelago Regency. The main commodities of fisheries aquaculture in Air Sena are Napoleon (Cheilinus sp), Kerapu (Epinephelus sp), and Kakap (Lutjanus sp). While the main commodity for the wild fisheries in Air Sena is stare Tongkol (Euthynnus sp), Tenggiri (Scomberromo sp), Selar (Caranx Sp), Teri (Stolephtorus sp), Kembung (Rastrelliger sp).

Figure II-4. One of the Fish Breeding sites at Air Sena Village

Based on information of Fisheries and Marine Department of Anambas Archipelago Regency, there is no specific information about total production of wild and aquaculture fisheries in Air Sena Village. The available information is only about wild fisheries production for Anambas Archipelago with total commodity of 4454.01 Ton per Year. The biggest commodity is Tongkol (Euthynnus sp) with 894.40 ton or up to 20.08% of total production per year. The detail information about wild fishery commodity can be seen in Table II-1 below. Tongkol and Tenggiri are the most common fish commodities available in Anambas Archipelago.

Table II-1. Wild Fishery Main Commodity in Anambas Archipelago

No	**Local Name**	**Latin Name**	**Total Production (T/Y)**	**Percentage (%)**
1	Tongkol	*Euthynnus* sp	894.40	20.08
2	Tenggiri	*Scomberromo* sp	864.30	19.40
3	Selar	*Caranx* Sp	484.40	10.88
4	Teri	*Stolephtorus* sp	286.00	6.42
5	Kembung	*Rastrelliger* sp	264.00	5.93
6	Other	*Other*	1660.91	37.29
	Total		**4454.01**	**100.00**

Source: DKP Provinsi Kepulauan Riau (2014)

Beside fisheries sector, there is also commodity in plantation sectors. The main commodities in plantation sector are coconut, clove, rubber, and palm oil. There is no specific information available about the area of plantation but clove, Air Sena village has 49 ha of clove plantation. In the agriculture sector, there are no routine activities that may due to: land availability, because the majority of land area in Air Sena Village are owned by residents of other villages; the habit of the community, based on ethnic background the villager of Air Sena is accustomed to be a fisherman not to be a farmer and they do not have experience in farming activity; and soil fertility, based on a survey activity stated that the land of Air Sena is not support to agriculture activity. Figure II-5 shows one of the plantation products at Air Sena Village.

Figure II-5. Rubber is one of the plantation products at Air Sena Village

Total population of Air Sena is 714 persons consist of 202 head of family (KK) or households. In general, the differentiation of male and female population is not significant, where 371 (52%) of the population are male and 343 female (48%). The population distribution based on the age showed that the highest percentage is at the age of 0 - 4 years old with a number of 89 persons (12.46%), while the lowest percentage is on the age level 70 - 74 and 75> year old, each of the age group is 4 persons (0.56%). The detail information regarding population distribution based on age and gender can be figured out from Table II-2.

Table II-2. Population distribution Based on Age and Gender

No	Age (Year)	Male (Person)	Female (Person)	Total (Person)	Percentage (%)
1	0 - 4	43	46	89	12.46
2	5 - 9	32	38	70	9.80
3	10 - 14	36	24	60	8.40
4	15 - 19	34	29	63	8.82
5	20 - 24	44	31	75	10.50
6	25 - 29	30	36	66	9.24
7	30 - 34	29	26	55	7.70
8	35 - 39	35	47	82	11.48
9	40 - 44	21	16	37	5.18
10	45 - 49	22	17	39	5.46
11	50 - 54	17	7	24	3.36
12	55 - 59	5	9	14	1.96
13	60 - 64	14	12	26	3.64
14	65 - 69	5	1	6	0.84

15	70 - 74	1	3	4	0.56
16	75>	3	1	4	0.56
Total		**371**	**344**	**714**	**100.00**

Source: Air Sena Village Government (2014)

3.2. Demography

3.2.1. Population Distribution Based on Level of Education

Reviewed from the level of education of Air Sena Village population, the percentage of the population does not/not yet in school is the highest percentage which reached 256 people (38.85%), while the lowest percentage is undergraduate degree which only 1 person (0.14%). The detail information regarding the population distribution based on level of education can be figured out from Table II-3.

Table II-3. Population Distribution Based on Level of Education

No	Education Level	Total (Person)	Percentage (%)
1	Not/Not yet in School	256	35.85
2	Not Graduated from Elementary School	228	31.93
3	Graduated from Elementary School	151	21.15
4	Graduated from Junior High School	40	5.60
5	Graduated from Senior High School	27	3.78
6	Graduated from Diploma (I/II/III)	11	1.54
7	Under Graduate Degree (S1)	1	0.14
Total		**714**	**100.00**

Data Source: Air Sena Village Government (2014)

Families of Air Sena do not consider education beyond elementary school to be important since residents have historically been able to obtain income as fishermen from a young age. Additionally, the two largest income earners of the village (47% of total village income) do not have education beyond elementary school, as described in Section 2.5.4. The decline of the fishing industry may affect this mindset, as described in Section 5.2.

3.2.2. Population distribution based religion

The majority of Air Sena residents are Catholic and Buddhist faiths. Catholic has the highest number as many as 339 people (47.48%), while the number of adherents of Protestant Christianity was the lowest as many as 6 people (0.84%). The detail about Population distribution based religion adherent can be seen in Table II-4 below.

Table II-4. Population distribution based religion adherent

No	Religion	Total	Percentage (%)
1	Islam	38	5.32
2	Protestant	6	0.84
3	Catholic	339	47.48
4	Hindu	-	0.00
5	Buddha	331	46.36
6	Others	-	0.00
Total		**714**	**100.00**

Data Source: Air Sena Village Government (2014)

It is likely that there is no a significant correlation between religion and economic conditions of Air Sena residents. Religion has no rule in defining the economic or income activities. The people in Air Sena live side by side in peace and tolerance.

3.2.3. Population Distribution based on Occupation

Based on the data of Air Sena Village Government In 2014, the majority of the population of Air Sena are fishermen, it is up 84.10% or 201 persons from the total of 239 persons employee of Air Sena Village. The detail about Air Sena Village population distribution based on occupation can be figured out from Table II-5 below.

Table II-5. Population Distribution Based on Occupation

No	Type of Work	Total	Percentage (%)
1	Farmer	4	1.67
2	Fisherman	201	84.10
3	Civil Servant	6	2.51
4	Private Employee	7	2.93
5	Honorary Worker	4	1.67
6	Labour	6	2.51
7	Entrepreneur	11	4.60
Total		**239**	**100.00**

Source: Air Sena Village Government (2014)

3.3. Human Resources

Of 714 population, 67% is categorized to productive age and 33% others are categorized to non-productive age. The calculation of the ratio based on the government legislation No. 13 in 2003 which stated that the productive age is between 15 – 64 years old. The detail about the ratio between productive and non-productive age in Air Sena Village can be seen in Table II-6 and Figure II-6 below.

Table II-6. Productive and Non Productive Age Ratio of Air Sena Villagers Population

No	Category	Total	Percentage (%)
1	Productive Age	481	67
2	Non Productive Age	233	33
	Total	**714**	**100**

Source: Air Sena Village Government (2014)

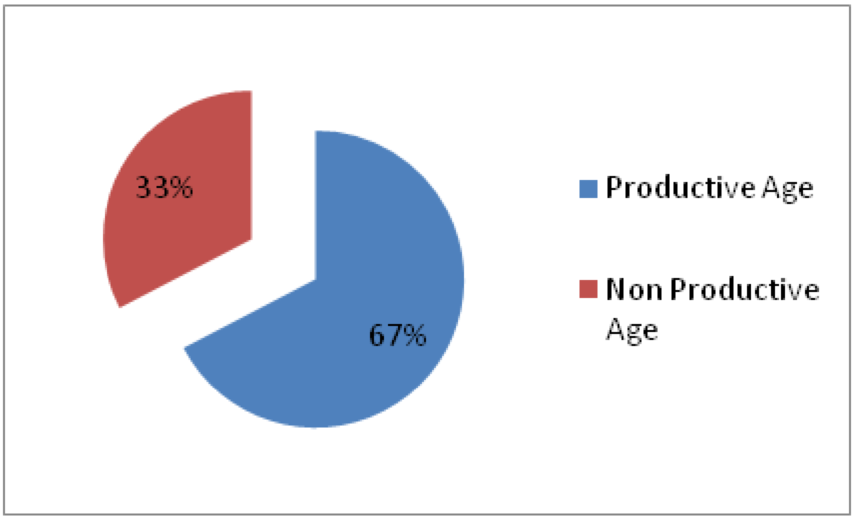

Figure II-6. Productive and Non Productive Ratio in Air Sena Village

From total of 481 productive age in Air Sena Village, only 239 person of them are under employment (49.69%), while 242 others are still unemployment (50.31%). The detail regarding the ratio of employment of the productive age population in Air Sena Village can be seen in Table II-7 below.

Table II-7. Ratio of Employment and Unemployment

No	Category	Total (Persons)	Percentage (%)
1	Employment	239	49.69
2	Un Employment	242	50.31
	Total	**481**	**100.00**

Source: Air Sena Village Government (2014)

3.4. Transportation and Accessibility

The primary access to Air Sena Village is through sea route from Tarempa, the capital city of Kepulauan Anambas Regency. Air Sena Village can be accessed by speed boat about 15 - 20 minutes, or by traditional motorboat (pompong) about 45 – 60 minutes. The secondary access is through the land route from Matak Airport, it only able to be accessed on foot or motorcycle about 1.5 hours due to the bad condition of infrastructure of the land route itself. Transportation infrastructure in Air Sena Village itself from the total of 8.25 km, 6.65 km already paved and the other 1,7 km still unpaved. The means of transportation has been used in Air Sena Village are motorcycle, bicycle, canoe, and motorboat (speed boat and pompong).

Table II-8. Means of Transportation in Air Sena Village

No	Type of Means Transportation	Total Unit	Percentage (%)
1	Motorcycle	64	15.92
2	Bicycle	88	21.89
3	Canoe	138	34.33
4	Motorboat	112	27.86
Total		**402**	**100.00**

Data Source: Air Sena Village Government (2014)

3.5. Socio-economic Condition

3.5.1. Villager Occupations

The majority of Air Sena Villagers are fisherman (fishing and aquaculture). From total of 239 employed villagers, 201 (84%) of them work as fisherman as primary occupation, while the other 16% are farmers, civil servants, private employees, honorary workers, labourers and entrepreneurs. Generally, the rest 16% choose fishing as their secondary occupation. There are two type of fisherman in Air Sena: Fishing and aquaculture, but most of them combine both. The detail about Air Sena villager occupation can be seen in the Figure II-14 below.

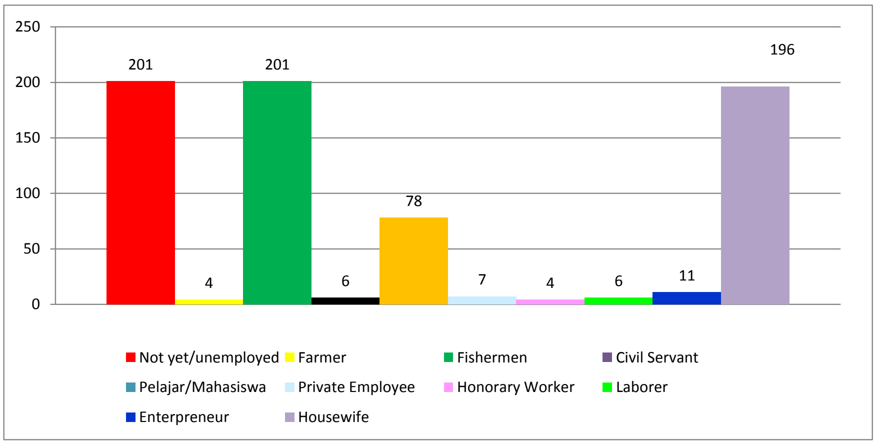

Figure II-14. Distribution of Type Occupation of Air Sena Villagers

3.5.2. Social Institution and Activity

A Kinship among the villager of Air Sena was quite strong and most of them have family ties. Social structures in Air Sena Village was homogeneous, they stick to the leaders, and also have a good awareness. One of program has been initiated by the government to enhance the local social institution and the villager participation is through PNPM Mandiri Pedesaan implementation in Air Sena. PNPM Mandiri Pedesaan has been facilitated several program initiated by the village government such as construction of public clean water supplies, building kindergarten building and facilities and increase men and woman participation in generating household income. In 2011 PNPM Mandiri Pedesaan formed three women's group in Savings and Loans system activities. The program was intended to enhance women participation in household economic management. The program was implemented successfully in Air Sena with the ratio of payback more than 78%.

Beside PNPM Mandiri Pedesaan Program, the local government through it program also enhance the local social institution trough the villager participation in the development program. Some of the local government programs in Air Sena Village are road construction, diesel generator aid (PLTD), and street lights with solar system, which most of the aid is manage and maintain by the local institution. Through the department of fisheries and marine of Anambas Archipelago Regency, the local government also enhance the local institution through fisheries group (Nelayan Teri Group). The fisheries group was formed in 2011, with the total member 0f 10 people, the group is inter village group within Central Siantan District with focus on enhance fisheries activity in Air Sena and Central Siantan District.

Figure II-15. One of the PNPM project at Air Sena, fresh water supply system

Beside of intervention of local government and other institution to enhance the local social institution, the role of Church and the Vihara as the biggest religion based community also play a big role in enhancing the local institution in Air Sena. Each of these group of community also have own program which contribute to the development of Air Sena Village. In Air Sena village, men become the backbone of the family, earning a living for the family meet the needs (food, education, health, etc.). The women usually stay at home, doing domestic activities, such as taking care of the home, child care, preparing meals, washing, etc.). At the Air Sena village, there are two fairly large religious group, characterized by two buildings, namely the Catholic Church and the Buddhist Vihara, which becomes facilities of worship villagers.

3.5.3. Formal and Informal Leader

Historically, local inhabitants of Air Sena came from Taiwan and were families each other. So far, both formal and informal leaders are usually local inhabitants. However a few numbers of local leaders come from outside Air Sena since they work at Air Sena as civil servants (PNS) such as the Principal of the Elementary School.

In the daily life of the community, in the village of Air Sena, there are activities of village government headed by a village chief with his staff (village secretary, village heads, and the heads of the RW and RT). In addition, this village there are institutions Consultative Body (BPD) and the Institute of Rural Community Empowerment (LPMD), are the institutions that comprise elements villagers In addition to the formal figures above, there are also other informal village leaders are the villagers themselves, through religious social activities that interact with the community, recognized and become role model for society. These figures are the heads of the group or organization (fishermen, youth leaders, sports, savings and loans, Posyandu, the monastery and churches, etc.).

Figure II-16. Formal and informal leaders of Air Sena: Head of Village, Mr. Sensen (left), Mr. Acen (right)

3.5.4. Household Income and Outcome

Household Income

Based on data interpolation of the report of Regional Technical Implementation unit (UPTD) of Fisheries and Marine Department of Anambas Archipelago Regency, total Air Sena Village income is IDR. 22,622,825,581. From the total income of Air Sena Village, fisheries and marine sectors contributed about 19,263,000,000 per year (85.15 %). While the rest 14.85% come from entrepreneur, civil servant, farmer, private employee, labour, and honorary worker. Compared to other villages in Anambas Archipelago Regency, Air Sena Village is known as the highest household income.

Based on the observation, this fact is due to the high income of two business household in Air Sena Village (Aken and Dodo). Both households contribute high economic income to Air Sena Village. Aken household is a Pertamina Distributor in Anambas Archipelago in the sector of Fuel Distribution in Anambas Archipelago Regency and also have a business in the sector of fisheries aquaculture. While Dodo is a primer businessman in fisheries aquaculture sector in Anambas Archipelago Regency. The detail about the contribution of Aken and Dodo household income in generating Air Sena Village average income can be seen from Table II-9 and Figure II-15 below (UPTD Perikanan, 2014). It can be seen that the income of these two businessmen is higher than income of all other residents combined. This information is useful when considering the future electricity demand of the Village if these two businessmen are included in the proposed hybrid system.

Table II-9. Comparison of total (Aken and Dodo) household income to others Household Income

#	Household Income	Total per Month (IDR)	Percentage (%)
1	Aken and Dodo Household Income	650,000,000	47
2	Other Household Income (Excluding Aken and Dodo))	726,000,000	53
Total		**1,376,000,000**	**100**

Maximum income of Air Sena Villagers including the Aken and Dodo income is IDR. 425,000,000 per month, the minimum income is IDR. 1,250,000 per month, the average income is IDR. 9,333,849 per month. While the maximum income of Air Sena Villagers excluding Aken and Dodo is IDR. 95,000,000 per month, the minimum is IDR. 1,250,000 per month , and the average is IDR. 5,619,118 per month. The detail can be seen in Table II-10.

Table II-10. Summary Income of Air Sena Villager including and Excluding (Aken and Dodo)

#	**Household Income**	**Amount Include (IDR)**	**Amount Exclude (IDR)**
1	Maximum Income	425,000,000	95,000,000
2	Minimum Income	1,250,000	1,250,000
3	Average Income per household	9,332,849	5,619,118

Villager Expenditures

Maximum expenditures of Air Sena Villagers is IDR. 7,070,000 per month, the minimum is IDR. 110,000 per month, while the average outcome of Air Sena Villagers is IDR. 1,759,216 per month. The highest average outcome is come from Food about 1,948,148 per month and the lowest average outcome is from for clean water as much as 28,909 per month. While the outcome from Aken and dodo cannot be calculated, because they cannot calculate the amount of the outcome. The detail about the outcome of Air Sena Villagers can be seen from Table II-11 below. It can be seen that the share of electricity supply is 12 % in average of the household outcome.

Table II-11. Summary Outcome of Air SenaHousehold excluding Aken and Dodo

Category	Household Expenditures (IDR)						
	Food	**Education**	**Electricity**	**Energy**	**Clean Water**	**Others**	**Total**
Maximum	3,500,000	2,000,000	1,000,000	3,000,000	100,000	3,800,000	13,400,000
Minimum	300,000	350,000	80,000	28,000	20,000	75,000	853,000
Average	1,900,000	1,175,000	540,000	1,514,000	60,000	1,937,500	7,126,500

Note: - Energy includes kerosene, LPG, and firewoods.
- * The Total above is an overall value of household expenditures without split into food, education, etc

The medium to high income households appear to spend less than half of their income for essential services. Low income households spend mostly for food and education.

3.6. Energy Stakeholders and Local Capacity

There are 2 x 140 kVA diesel generators (PLTD) in the village of Air Sena, the diesel generator operating for 6 hours each day (17:30 to 23:30) for 30 days per month, and also every Sunday between 7:00 a.m. to 12:00 a.m. The consumers of the PLTD are household and public facilities and infrastructures (government office, worship center, schools, health centre, etc.). The village street lighting uses electricity from solar PV systems developed by the ESDM with installed capacity of 40 x 40 Wp. There are only few business activity which associated with the household being consumer of the PLTD supplies, and there no consumer from industrial group. The detail about the consumer group of PLTD Air Sena can be seen in Table 12 below.

3.7. Energy Overview in Air Sena

3.7.1. Existing Energy situation

Sea transportation and power generation dominate energy use in the Air Sena Village. Business is mostly limited to small private shops owned by some households and fuel distribution facility owned by one of the villagers. Industry on the other hand, is mostly limited to a large scale fish breeding and fish processing facilities on the Village which rely directly on electricity. Traditional biomass use for cooking – although rapidly declining at the moment in favour of kerosene and later LPG – still accounts for the significant share of overall energy use in the Village. With the exception of some contributions from the PV street lighting system, energy use in the Air Sena Village is dominated by fossil fuels; diesel fuel and kerosene in particular. Despite that Anambas Archipelago Regency possesses one of the important national oil exploration fields operated by the Conoco Phillips, the absence of local oil refining facility in Anambas area means that the crude oil is exported for refining and then the refined oil products must be re-imported over great distances at high and volatile costs.

Electricity production in the Air Sena Village uses diesel fuel to operate the Village's generators and smaller diesel generators owned by some household or groups of several households.

From the monthly electricity bill data prepared by the LPMD, in February 2014, there are 148 households and 4 public facilities connected to the PLTD grid. In terms of the installed power capacity on the consumer premises, they are divided into five groups. There are 127 premises with 4 Ampere electrical system that consume 66.37% of the power produced that make this group as the largest consumer group.

The average of electricity bill in Air Sena Village is IDR. 231.000. Reviewed from the amount of average income of the villager of Air Sena as much as IDR. 5,619,118. The percentage of electricity bill from the average income is 4.11%.

Table II-12. Existing Electricity situation

#	**Ampere**	**Total**	**Consumption (kWh/month)**		**Payment (IDR/month)**		**Electricity Cost**
	(A)	Consumers	Average	Total	Average	Total	*(IDR/kWh)*
1	2	2	11	22	62,000	124,000	5,636
2	4	127	44	5588	125,000	15,875,000	2,841
3	6	17	105	1785	269,000	4,573,000	2,562
4	10	5	184	920	468,000	2,340,000	2,543
5	20	1		0	-		
Total		**152**	**86**	**8,315**	**231,000**	**22,912,000**	**3,396**

Source: LPMD (2014)

From the above Table II-12, the 4 A, 6 A, and 10 A consumers have large potential to utilize electricity for income generating activities when the proposed hybrid system implemented, particularly those with 4A connection. The customer/household paid IDR 2,815 per kWh in average for electricity supply.

3.7.2. Energy Challenges and Opportunities for Renewables in the Air Sena Village

Islands present unique challenges and opportunities for the deployment of renewable energy (RE). Air Sena Village and all other islands in Anambas Archipelago Regency are located far from major oil distribution hubs and depend on complex and lengthy fuel supply chains. Fuel delivery logistics are often further complicated by lack of modern port facilities, requiring the use of smaller, specialized boats. The small population sizes of many islands limit the level of fuel demand while the small geographic size constrains fuel storage. Both of these factors reduce the purchasing power of such island communities.

As a result, Air Sena Village faces some of the Indonesia's highest fuel costs and has greater exposure to price volatility and supply disruptions. In 2014 the consumer electricity tariffs produced by the local (non-PLN) diesel generation is averaged at IDR 2,000/kWh with 6 hours power supply per day, which is much higher than those in the cities of between IDR 275 and IDR 495 per kWh for comparable tariff group with mostly 24 hours power supply per day. High energy costs, price volatility and risks to fuel supply are of particular concern because most households in the Air Sena Village have small economies.

Figure II-17. Fuel supply is one of big issua in Air Sena

Figure II-18. The only one fuel station at Anambas Archipelago owned by Mr. Akin

In addition, climate change effects associated with oil consumption in the local diesel generators are major concerns for the Village. Anambas Archipelago Regency in general faces a significant threat from rising ocean levels, with some islands having a maximum elevation of less than 5 meters above sea level. Increased storm activity and weather disruptions associated with climate change threaten the many islands that are in the path of seasonal cyclones and typhoons.

Against this background, the provision of renewable-based power generation could be a good option for Air Sena Village as an effort to improve the electricity supply for the village. The improvement might be through longer electricity supply e.g. 12 hours or even 24 hours per day, cheaper per kWh tariff, more secure supply, and more environmentally friendly power generation system.

CHAPTER 4. EXISTING POWER SYSTEMAND LOADS

4.1. Generation System

4.1.1. Diesel Generators

Diesel generators are the most common generation technology used for power systems in remote areas such as Anambas and often provide isolated communities with their first access to electricity. A number of factors make diesel generators well suited for island power generation. Diesel fuel has a high energy density which greatly reduces fuel storage requirements compared to other fossil fuels such as coal. The generators are relatively compact and available in a wide range of capacities. These are meant for power plants to closely match the community's demand. The majority of power plants in the Anambas use several diesel generators running in parallel. This gives operational flexibility as individual generators can be started up or shut down when demand changes. Multiple small generators also increase efficiency and security of supply versus a single large generator. Diesel generators have relatively quick start times and good flexibility in meeting daily and seasonal variations in demand. They provide fast response times and good power quality and are relatively simple to operate and maintain. The technology is robust and has a long track record of successful deployment.

Since September2012, the Air Sena Village has a Diesel Power Plant (Pembangkit Listrik Tenaga Diesel / PLTD) received from the rural electricity development program by the Government of Riau Islands through the Energy and Mineral Resource Office of the Anambas Archipelago Regency (Dinas Pertambangan dan Energi / ESDM) and is operated by the Lembaga Pemberdayaan Masyarakat Desa (LPMD) of Air Sena Village. The PLTD consists of **two 140 kVA identical diesel gensets**. By 12 March 2014, the operational hours of each genset are 1,990 hours and 2,031 hours during the period of 558 days, or equal to 4,021 hours for the two gensets. Therefore, it can be calculated that the annual average operation hour of each genset is 2,630 hours. It also can be calculated that the daily average operation hour of the genset are 3.57 hours to 3.64 hours.

Some 148 households are currently supplied by two identical 140 kVA diesel generators that typically run alternately on a daily basis from 17:30 pm until 23:30 pm and additional operating hours on Sunday from 07:00 am until 12:00 pm and special national holidays. The power house (7m L x 5m W x 4.5m H) of the PLTD is positioned at the centre of the village on the hill slope facing east toward the bay. Figure III-1 shows the front view of the diesel power plant.

Figure III-1. The front view of the Diesel Power Plant

Each generator includes a 12 Volt battery with 100 Ah capacity and manually-operated electrical starter motor to bring the main engine online. Once the engine is running a small amount of power is used to keep the starter battery charged and to power some lamps in the power house. The generators produce three-phase alternating current (AC) electricity, the same type of power generated by traditional mainland power plants. They are also equipped with active power and frequency control to match the power generation with the demand from customer loads and therefore minimize the sudden spikes and drops when the demand change rapidly. FigureIII-2 shows the diesel generator at Air Sena Village.

Figure III-2. Diesel Power Plant at Air Sena Village

Generators are designed to run at certain speed of rotation (rpm) regardless of their level of power output. A generator’s alternator is designed such that this rpm is directly proportional to the frequency of the AC power being produced. The generators have also the active voltage regulators (AVR) that play a key role in maintaining a constant voltage on the grid. Table III-1 shows the specification of both generators.

Table III-1. Specification of diesel generators at Air Sena Village

Producer	**Perkins**
kVA Base Rate	140 kVA
kW Base Rate	112 kW
Frequency	50 Hz
rpm	1500
Output Voltage	380 Volts
Phase	3
Amps Base Rate	212.7 Ampere
Power Factor	0.8

Engine Fuel Type	Diesel
Operational lifetime	10,000 hours

4.1.2. Operational Time

From the energy bill data of the LPMD, the average energy production is 7,500 kWh per month. Based on this information and of the above Table II-12, it can be estimated that only around 35% of the generator capacity is used by the load. Therefore, the average energy produced by the Air Sena Village's PLTD is equal to the 0.35 x kW base rate of the generator times the number of online hours. Table III-2 shows the estimation of the energy production of the Air Sena Village's PLTD. The average daily energy production is 235.2 kWh per day (Sunday and special events are excluded); 1,824 kWh per week (special events are excluded); 7,500 kWh per month; and 100,901 kWh per year (all included) or similar to 100.9 MWh per annum for two gensets. Therefore it can be estimated that the Capacity Factor of each genset is 5.14% only. Such a low Capacity Factor is due to the generators are oversized due to the procurement standard applied by the Dinas ESDM.

TableIII-2. Energy Production of the Air Sena Village's PLTD

#	**Day/Event**	**Diesel Online**	**Number**	**Number**	**Total**	**Average Energy Production (kWh)**		
		(Time of day)	of hours per day	of days / year	online hour / year	Daily	Weekly	Annually
1	Monday - Sunday	17:30 – 23:30	6	365	2190	235.2	1646.4	85,848
2	Sunday	07:00 – 12:00	5	52	260		196	10,192
3	Chinese New Year	06:00 – 17:30 23:30 – 24:00	12	7	84			3,293
4	Vesak	07:00 – 15:00	8	1	8			314
5	Ester	07:00 – 15:00	8	1	8			314
6	Christmas	07:00 – 15:00	8	2	16			627
7	Volley ball competition	07:00 – 15:00	8	1	8			314
Total					**2574**	**235.2**	**1842.4**	**100,901**

4.1.3. Energy Production/Demand and Efficiency

A series of measurement have been conducted to generate important information from the PLTD. The measurement used the Hioki 3196 Power Quality Analyser (see FigureIII-3) that automatically collected data with the intervals every 10 minutes and 15 minutes. Three measurements of the generator output voltage and frequency were conducted on Friday 14 March 2014 from 18:12:17 PM to 23:27:17 PM; Saturday 15 March 2014 from 17:38:38 PM to 23:38:38 PM; and Sunday 16 March 2014 from 07:41:08 AM to 12:11:08 AM.

Figure III-3. Hioki 3196 Power Quality Analyser

The frequency of the output voltage when no load connected to the generator is 50 Hz. However, as anticipated, the frequency slightly down when the generator start supplying power to the load. As shown by Table III-3 the maximum and minimum frequencies during the tests were 49.87 Hz and 49.16 Hz, respectively. The average frequency was 49.58 Hz. The frequency deviation was 0.42 Hz, which is lower than the maximum allowable frequency deviation for Jawa-Bali power system of 0.5 Hz and outside Jawa-Bali system of 1.5 Hz.

The quality of the output voltage of the Air Sena Village's PLTD is slightly beyond (does not meet) the PLN standard for voltage variation i.e. (+5%) and (–10%). As shown in Table III-4, the maximum voltage was 400.56 Volts which is 5.4% higher than the normal voltage or 0.4% higher than the highest allowable voltage. Similarly, the minimum voltage was 334.14 Volts which 12.07% lower than the normal voltage or 2.07% lower than the allowable minimum voltage. However, in average, the rms values of output voltage are 1.2% - 2.3% lower than the normal voltage.

Table III-3. Electrical measurement result of the Air Sena Village's PLTD

Date of Measurement	Time of Measurement	Measurement Interval (minutes)	Voltage Out (Volts)			Frequency (Hz)		
			Max	Min	rms	Max	Min	Ave
3/14/2014 - Fri	18:12:17 - 23:27:17	15	380.76	368.58	375.38	49.73	49.20	49.45
3/15/2014 - Sat	17:38:38 - 23:38:38	10	400.56	341.11	375.18	49.75	49.16	49.47
3/16/2014 - Sun	07:41:08 - 12:11:08	15	387.06	334.14	371.19	49.87	49.80	49.82
Average								49.58

In order to estimate the efficiency of the diesel generator, some information needed such as - the amount of energy contained in the fuel used to produce a given amount of electrical energy and the amount of energy produced. The type of diesel fuel in Indonesia's market is Diesel Fuel Number 48 with flash point 52^0 C. This type of fuel has the density of 847.5 kg/m^3 and heating value of 44.23 MJ/kg (Yuliarita 2011). The average fuel consumption, based on information from the genset operator and management, is 2.6 ton per month. By converting both monthly input and output energies into megajoule and divide monthly energy output by monthly energy input, it is estimated the efficiency of the Air Sena Village's PLTD is 23.07% (Table III-4).

Table III-4. Efficiency of the Air Sena Village's PLTD

Energy Input		**Energy Output**		**Efficiency (%)**
Monthly fuel consumption (kg)	Energy input (MJ)	Monthly Electricity Produced (kWh)	Energy Output (MJ)	
2,600	114,998	7,370	26,532	23.07

Diesel generators operate most efficiently at a certain load, generally 65-80% of the maximum rated capacity. Island power plants are generally designed to meet varying demand while keeping generators as close to this load as possible. This delivers higher efficiency and provides spinning reserves to meet demand increases. Operating below this load reduces generator efficiency, limiting the desired fuel savings. Operation below 30- 40% of the rated load can result in engine over-fuelling, which carbonises injection tips and disrupts the fuel spray pattern. The resulting poor combustion leads to soot formation and un-burnt fuel residue which clogs and gums piston rings (Source: Generator Solution). As a result prolonged low load operation has numerous cost impacts. It further decreases generator efficiency, increases maintenance requirements and reduces a generator's lifespan.

4.1.4. Operational Management

In 2014 Air Sena consists of 202 households and 7 camp clusters. However, only 148 households (73%) are currently connected to the PLTD grid and the number of grid-connected households is rising. All of the connected households are located on the land area while none of the camps are connected due to the distance.

The operational and maintenance of the PLTD is managed by the LPMD. There are seven people involved in the PLTD management. Below is the organisation of the PLTD.

- Chairman : Mr. F. X. Celi
- Secretary : Mr. Yulius
- Bill Collector : Mr. Yeremias Hartono
- Operator Coordinator : Mr. Belon
- Operator Team Member : Mr. Sontet, Mr. Gegen, and Mr. Suhar.

All of the PLTD team members are paid by the LPMD using the money collected monthly from the consumers, except Mr. Belon, the Operator Coordinator who get monthly paid from the ESDM. In case the expenditure (O&M) of a certain month is larger than the income of that month, the difference is normally paid by the Village Management using the Village's money. Before 2012 the price of diesel fuel was IDR 4,500/litre, but since 2012 becomes IDR 6,000/litre.

There appears to be an increasing trend in diesel fuel price in the future due to the increasing price of crude oil in international markets and the government plan to reduce oil subsidy. Although the crude oil prices in international markets are often predictable, the national oil subsidy reduction is often a political preference of the government and therefore it is not predictable. Information about the future diesel fuel price is not available either in the 2012-2031 National General Plan on the Electrical Energy or in the draft National General Plan of Energy, or in the BPPT's Indonesian Energy Outlooks, or in the Anambas Archipelago's Electrical Energy General Plan.

Table III-5. O&M cost of the PLTD and responsible institution.

Cost	Frequency	Average Value (IDR)	Responsible Institution
Diesel Fuel	1 x 1 month	15,600,000	LPMD
Lubricant Oil	1 x 180 hours of diesel operation	1.400.000	LPMD
Lubricant Oil Filter	1 x 180 hours of diesel operation	Unknown	ESDM
Diesel Fuel Filter	1 x 6 months	Unknown	ESDM
Operator Coordinator salaries	1 x 1 month	Unknown	ESDM
Operator member salaries	1 x 1 month	3,200,000	LPMD
Electricity Bill Collector Salary	1 x 1 month	1,000,000	LPMD

As the Coordinator of the PLTD operator, Mr. Belon was trained for 12 days in Jakarta and Bandung prior to the PLTD installation to operate and maintain the PLTD. The training was financed by the ESDM. In addition, Mr. Belon then conducted trainings for other two operators who assist Him to operate and maintain the generator.

The current LPMD started to manage the PLTD since January 2014. Before this time, the previous management applied different system. The electricity bill to be paid by the consumers was based on the installed power capacity (VA) and appliances used. For example, for a refrigerator the consumer paid IDR 25,000 per month while for television and lighting the consumers paid IDR 150,000 despite the number of lamps and television in a household.

The current billing system adopts parts of the system applied in areas connected to the PLN grid. Each premise pay for both installed power capacity (VA) and energy consumed. The price of the installed power capacity is flat while the price of energy consumption depends on the amount of kWh used. A 4A, 6 A, and 10 A premise pay for IDR 40,000; IDR 60,000; IDR 100,000; per month. The price of consumed energy is IDR 2,000 per kWh. This cost is applied for household only, while public facilities such as school, health clinic, and worship centre do not pay for the electricity bill.For comparison, the following Table III.6 shows the current elecricity tariff for households connected to the PLN, whic is much cheaper than the current electrical energy price applied in Air Sena.

Table III-6. Electricity tariff for households connected to the PLN.

No	Tariff group	Power Limit (VA)	Regular Connection		Pre-Paid Connection
			Load Cost (IDR/kVA/month)	Consumption Cost (IDR/kWH)	
1	R1-TR	up to 450	11,000	Block I : 0 – 30 kWH: 169 Block II : above 30 kWH – 60 kWh: 360 Block III : above 60 kWh: 495	415
2	R1-TR	900	20,000	Block I : 0 – 20 kWH: 275 Block II : above 20 kWH – 60 kWh: 445 Block III : above 60 kWh: 495	605
3	R1-TR	1,300	*	979	979
4	R1-TR	2,200	*	1,004	1,004
5	R2-TR	3,500 – 5,500	*	1,145	1,145
6	R3-TR	6,500 above	*	1,352	1,352

Note:
* Minimum Account (RM) applied. RM = 40 (number of active hours) x connected power (kVA) x Consumption cost.

Source: ESDM (2014)

The PLTD has a 5 ton fuel tank mounted on the side of the power house. However, the tank is not used to anticipate the unwanted fuel loss due to thief. Instead, the fuel is stored inside the power house in 62 gallons. Figure III-1 above shows the fuel tank next to the power house and Figure III-4 shows the fuel gallons.

Figure III-4. Gallons used for fuel storage at the PLTD Air Sena Village

4.2. Local Grid

The electric power system on Air Sena Village does not have any high voltage transmission lines. It is a small distribution system with nominal voltages of 380 Volts to bring electricity to customers. Electricity grids have three wires. Household loads such as lights and appliances use only one phase. The AC frequency is 50Hz. The transmission line use metal posts with twisted cables. In general, the grid is in a good condition. However, in some locations the cables touch the trees or the metal roof of houses. Figure III-4 shows the grid on Air Sena Village.

Beside the PLTD grid, there is also a solar photovoltaic street lighting system connected at the Air Sena. The system works properly and provides necessary lighting for the village during the nights. Figure III-5 shows some of the solar photovoltaic street lighting systems.

Figure III-4. Grid condition at Air Sena Village

Figure III-5. Solar photovoltaic street lighting system at Air Sena

4.3. Existing Electricity Load Profile

The consumers of the PLTD are households and public facilities (village government office, worship centre, schools, health centre, etc.). The gensets do not serve the street lighting because the village street lighting is supplied by solar energy. There are only few business activities that associated with the household consumers of the PLTD, and there are no industrial consumers in the village. The detail of the consumer group and their averaged monthly power consumption can be seen in Table III-7. Households dominate the power consumption. Nearly all electricity produced by the PLTD (97.74%) goes the households. This indicates that there is an opportunity to change the people's habit from consumptive way of utilizing electricity in to income generating activities. Very small fraction of energy produced is consumed by public facilities because they are normally operated during the day when the gensets are off-line. Although the Kantor Desa is not connected to the PLTD grid, it consumes a very small electricity during the nightime, but some electrical appliances are operated during the work hours using a 5.5 kW genset. Other premises currently not connected to the grid have but not used electrical appliances and are expected to have more appliances when they are connected to the grid in the future.

Table III-7. Electricity Consumption of the PLTD Air Sena Based on Consumer Group

No	Category	Monthly Energy Consumption (kWh)	Percentage (%)	Note
1	Household	7,500	97.74	
2	Government Offices:			
	- Office of Village Govt (Kantor Desa)	99	1.29	
	- Village Activity Centre (Balai Desa)		0	Not connected to the grid
	- Village Representative Office (BPD)		0	Not connected to the grid
3	Schools:			
	- Kindergarten (TK)		0	Not connected to the grid
	- Elementary School (SD No 03)		0	Not connected to the grid
4	Worship Centres:			
	- Church (Gereja Katolik Santa Martha)	50	0.65	
	- Vihara	22	0.28	
5	Health Clinics:			
	Polindes		0	Not connected to the grid
	Puskesmas Pembantu	4	0.05	
	Total	**7,674**	**100**	

Figure III-6 shows the households daily load profile of the Air Sena during weekdays (148 households currently connected to the PLTD) based on the energy audit activities. The loads were measured at 0.5 hour interval. It starts at 17:30 PM when the PLTD starts and goes up to the peak power of 62.5 kW at 19:00 in the evening. The load constantly reduces after 19:00 PM until the PLTD shut down at 23:30 PM. The daily energy consumption based on the energy audit is around 265.75 kWh which matches the information generated from the diesel energy production calculation (around 235 kWh/day).

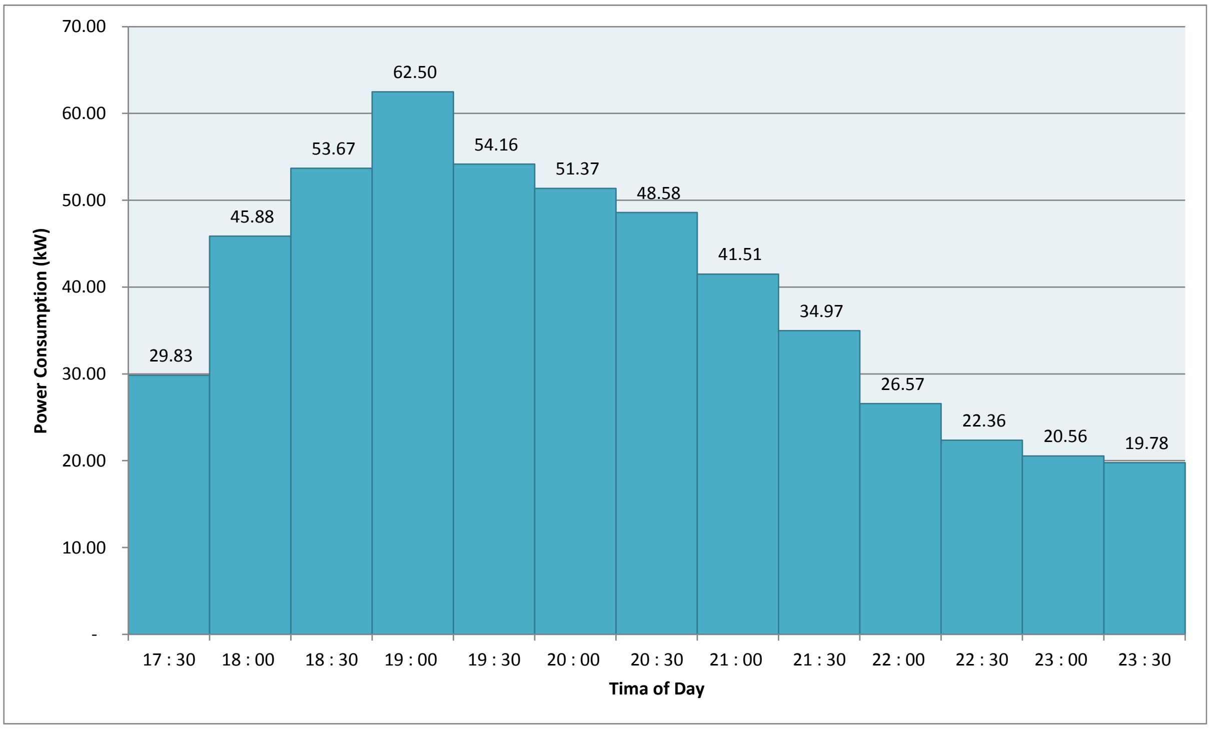

Figure III-6. Households weekday electrical load profile of the Air Sena Village, weekdays

Figure III-7 shows the households daily load profile of the Air Sena on Sunday (148 households currently connected to the PLTD) based on the energy audit. The load starts at 07:00 AM when the PLTD starts and ends at 12:00 PM when the PLTD shut down. The load is relatively constant with small fluctuation where the peak power of around 38.1 kW occurs around 9 AM. The daily energy consumption based on the energy audit is around 207 kWh which matches the information generated from the diesel energy production calculation (around 196 kWh).

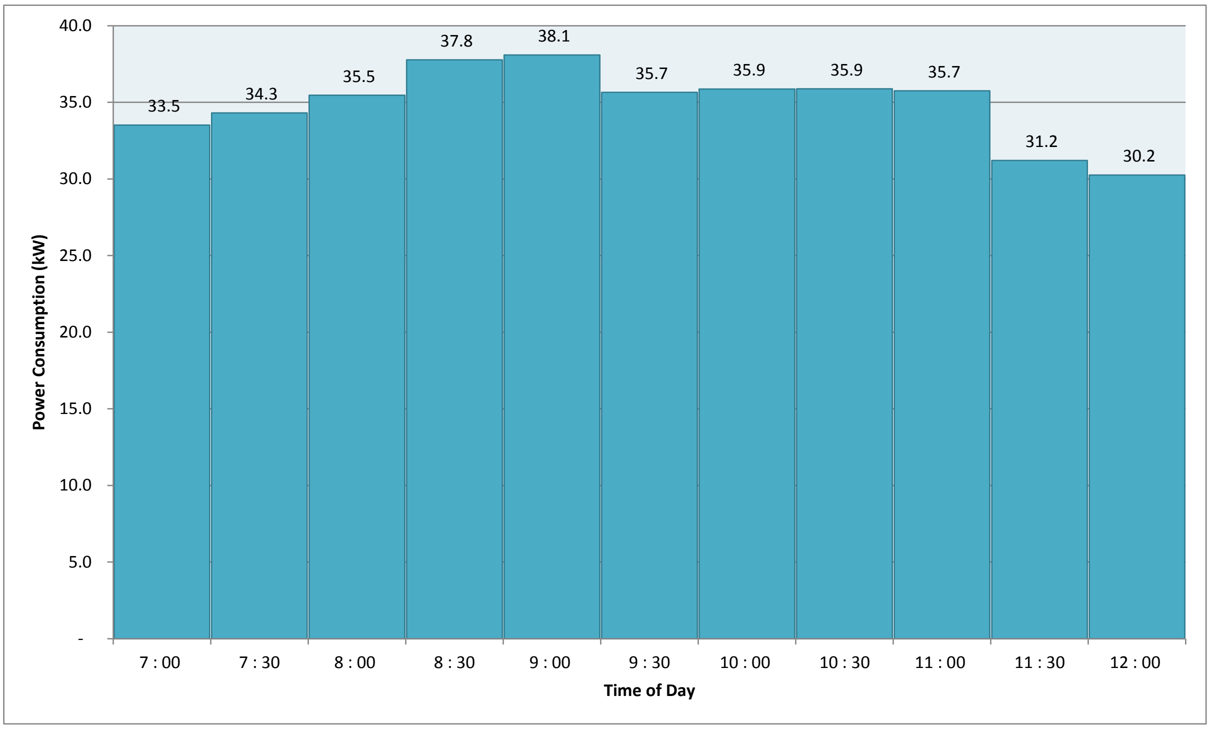

Figure III-7. Households Sunday electrical load profile of the Air Sena Village

Figure III-8 shows the public facilities daily load profile of the Air Sena on weekdays based on the energy audit. The loads consist of Head of Village Office, the Church, the Vihara, and the small health clinic currently connected to the PLTD grid. The load starts at 17:30PM when the PLTD starts and ends at 23:30 PM when the PLTD shut down. The only load comes from the lightings in those premises with the total amount of 0.12 kW. The daily energy consumption based on the energy audit is around 1.56 kWh.

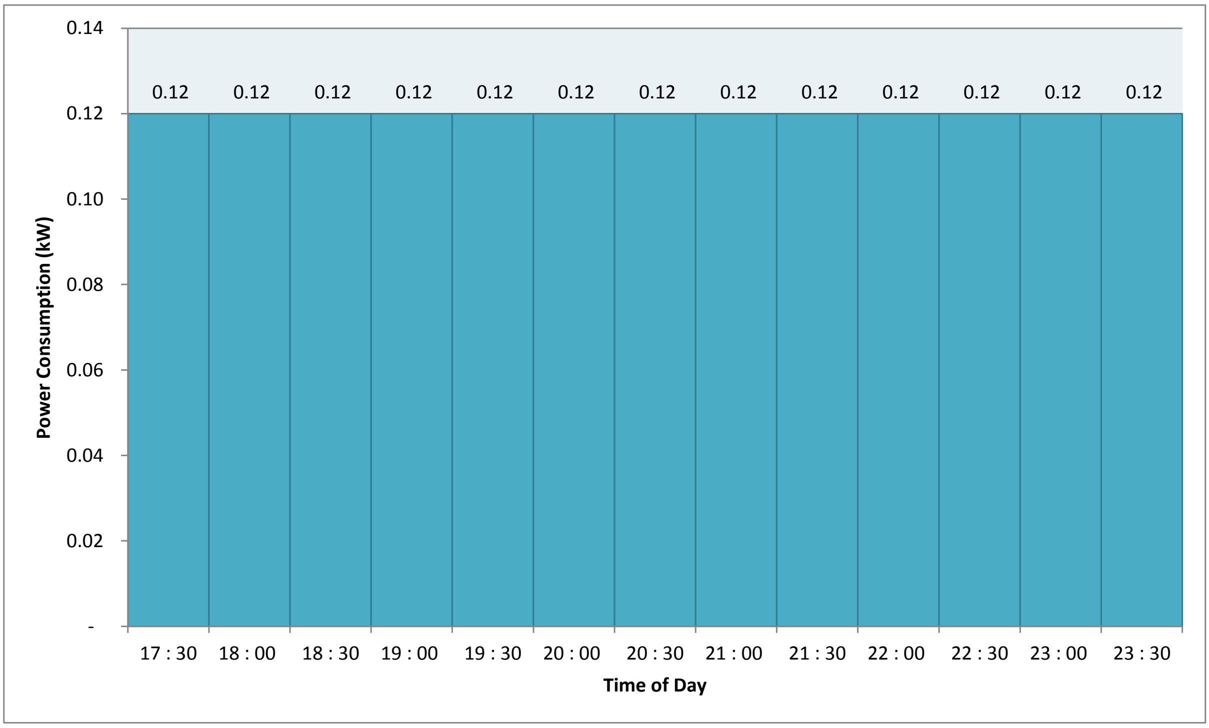

Figure III-8. Public facilities weekdays electrical load profile of the Air Sena Village

Figure III-9 shows the public facilities daily load profile of the Air Sena on Sunday based on the energy audit. The small load starts at 07:00 AM when the PLTD starts and ends at 12:00 PM when the PLTD shut down. The peak power of around 0.3 kW occurs from 9 AM to 12 AM due to Sunday service at the Church.

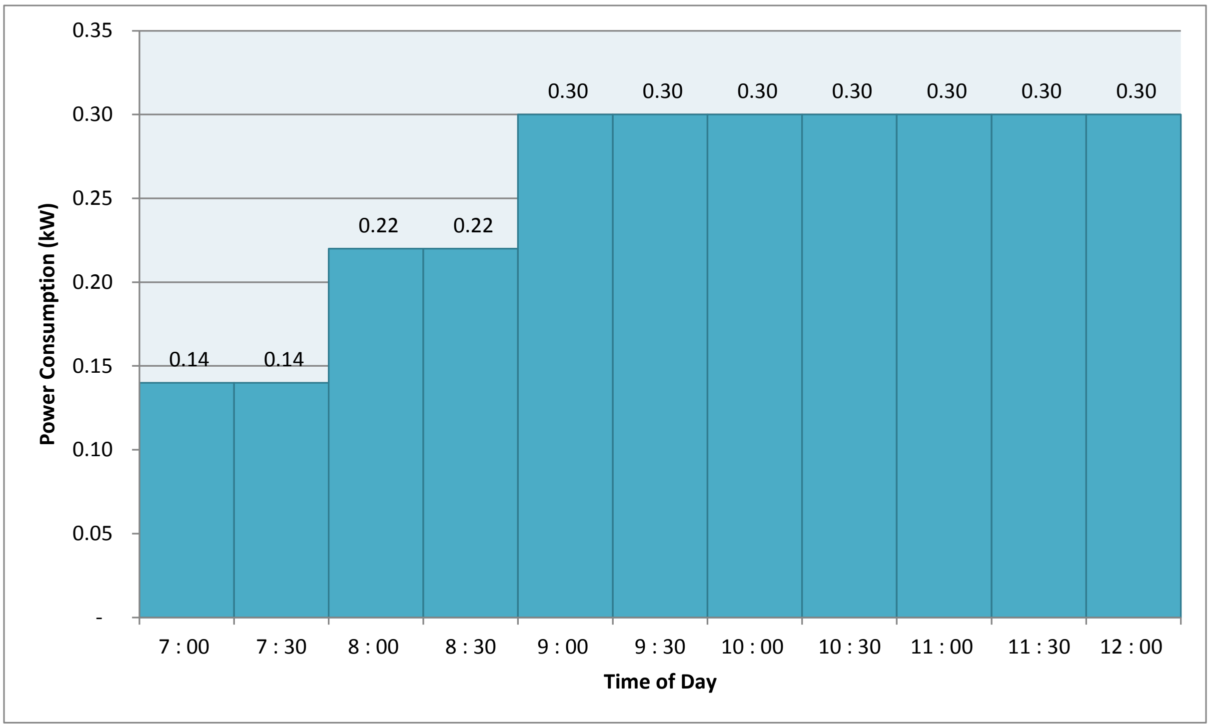

Figure III-9. Public facilities Sunday electrical load profile of the Air Sena Village

4.4. Grid integration of renewable power and its impacts

The primary goal of RE integration in Air Sena power generating system is decreasing power output from diesel generators to fuel consumption and extending the power supply hours to more than 6 hours a day. High level RE integration can cause generator to run at low load and could even allow the generator to be shut down. Low generator loading and frequent stops, however, have important performance and safety implications.

Low load operation is also a concern for power quality. Many RE assets are capable of providing frequency and voltage control. However, their control systems are normally designed to monitor the frequency and voltage produced by the diesel generator and links their output to these “master control” levels. Below 30-40% of rated load most generators cannot support power quality on the grid. Technologies exist that will allow some RE resources to support power quality on the grid.

The deployment of technologies such as centralised inverters will allow RE generation systems to supply the power quality needed to support grid stability. This will allow generators to be shut down permitting the grid to run on 100% RE and greatly increasing fuel savings. However, if RE production suddenly drop, generators would need to quickly be restarted. Frequent stop-start operation reduces efficiency, increases wear and tear and reduces the useful lifespan of the system. Systems will need to be designed to limit start/stop operation.

Low load and start-stop operations are of particular concern for power systems in Islands regions. Many of these generators have already exceeded the OEMs recommend running hours and as such non-standard operation could severely impact efficiency, maintenance costs and increases the risk of generator failures. Older control systems may simply not allow for prolonged low load operation or rapid shutdown and startup. There are low load generators that can operate safely and efficiently below 10% of rated load. In this context it is essential for islands considering high RE penetration to perform a detail inventory of their diesel generator assets and factor possible replacement of current diesel assets into the budgets for RE programs.

The variability of RE output is a challenge but it is not an insurmountable one. Modern generator control systems provide a great deal of operational flexibility and control systems on older generators can be upgraded. Advanced power electronics and supervisory control systems can greatly reduce the impacts of RE variability on diesel grids.

CHAPTER 5. OPTMUM DESIGN OF A HYBRID POWER GENERATING SYSTEM

4.1. Design Goals and Parameters

4.1.1. Design Goals

The primary goals of RE integration in Air Sena power generating system are to the most extend possible to extend electricity supply to all residents, extend the power supply service period from part-time to full-time, and optimize the use of all power sources, including diesel generators, to reduce fossil fuel consumption.

The designed systems are meant to be modular and scalable in that it is meant to first meet the current load profile and upgrade to meet the expected increase in electricity demand.

The design is aimed at finding some optimum hybrid generating system options using the NREL's HOMER optimization model to analyze the technical and economic feasibility of adding wind, PV and battery to reduce diesel fuel use of the current PLTD system on the Air Sena Village. The design also analyses the wind, PV and batteries sizes that could meet the entire load for the designated service hours.

4.1.2. Project Lifetime

The system is expected to start online on 1 January 2015. The intended lifetime of this hybrid power system project is 15 years until 31 December 2029.

4.1.3. Diesel Fuel Properties

The diesel fuel properties used in the design:

- Lower heating value : 43.2 MJ/kg
- Density : 820 kg/m^3
- Carbon content : 88%
- Sulphur Content : 0.33%

4.1.4. Annual Interest rate

The annual real interest rate[1] used in this design is 6.5%, based on the historical average annual interest rate from 2010 to 2015 (OECD 2013).

4.1.5. Battery Charging Strategy

The battery charging will mostly be done by the genset(s). The proposed hybrid system will apply cycle charging method with set point state of charge is 80%. With this method, the genset(s) will run at full power to meet the load and charge the battery until reaching the specified battery's set point state of charge. The diesel generator is also used to fulfil the full charge requirements of the battery manufacturer and to equalize the lead acid battery cells.

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[1] annual real interest rate is the discount rate used to convert between one-time costs and annualized costs.

4.1.6. General System Configuration

Stand-alone power systems are generally differentiated according to their type of voltage DC or AC. In DC coupled systems, the PV generator is connected via a special DC/DC charge controller. In AC coupled systems, a conventional PV inverter is used for feeding power into the grid. That allows a distribute energy feeding of PV power on site. The stand-alone battery inverter is the heart of an AC coupled system. It ensures that generated and load power are balanced at all times. The connection of the PV generators on the AC-side offers a decisive advantage: it enables systems to be built up or expanded with standardized components on a flexible, modular basis.

Parallel hybrid configuration allows the system to decide which component(s) to operate under a specific load demand. During a low load period, the inverter takes power from the PV array and wind turbines and converts it to alternating current (AC) before it is supplied to the load. During the low load situation, when the load is lower than the power produced by the PV array, the excess power from the PV array will be charged into the battery bank. As load exceeds the actual power produced by the PV array and wind turbine, a synchronised control system in the inverter activates the diesel generator, which takes over the load, and exports excess power to the battery bank. In this instance, the inverter changes its function to become a battery charger. As the load increases continually and exceeds the diesel capacity, the diesel remains active, and the inverter returns to its genuine function to draw power from the battery bank to 'help' the diesel generator to meet the load.

The function of a PV inverter basically consists of converting the direct current provided by the solar modules into sinusoidal AC current. In this process, the device has the task of synchronizing the waveform of the available current and voltage to the frequency of the stand---alone power grid.

The Figure 41 shows a typical structure for a **parallel hybrid configuration** system with mixed DC/AC sources and one central battery inverter has been considered to meet the load. The system consists of two busses i.e. AC and DC busses. A parallel hybrid configuration has been chosen due to its ability in meeting the load optimally, to promote high diesel generator efficiency and therefore minimise the diesel generator maintenance, and reduce the rated capacity of both diesel and renewable generators to minimize the investment costs.

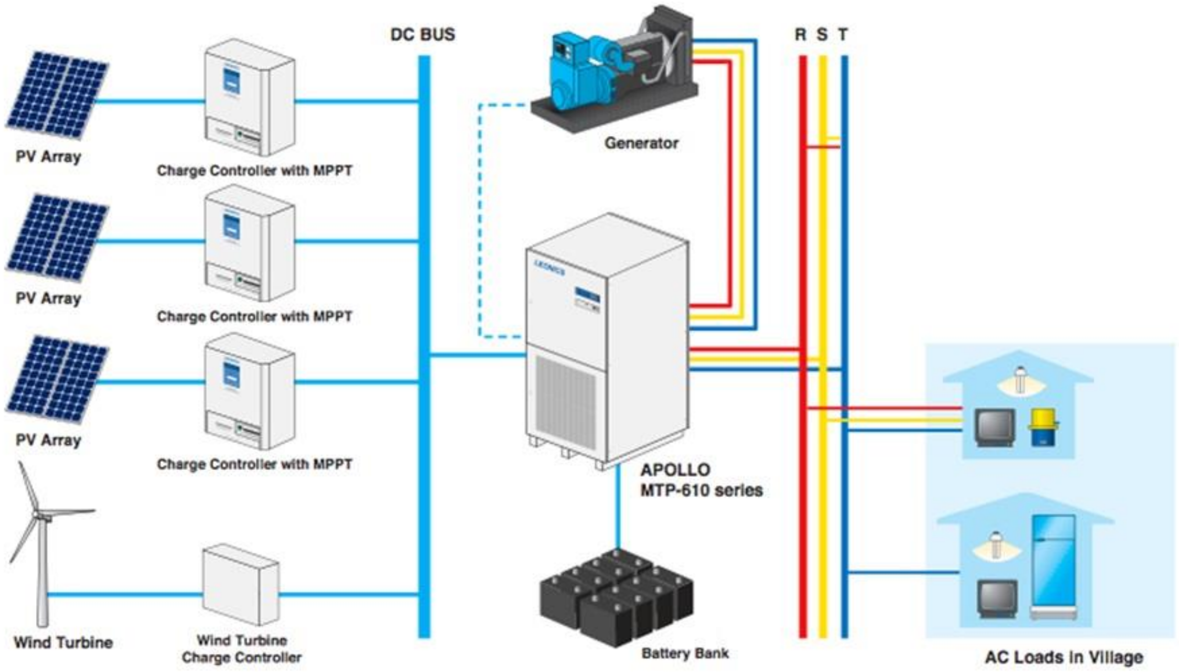

Figure 1. Hybrid system configuration and equipment (modified from Wollny Consulting 2014)

4.1.7. Constraints

Constraints are conditions which systems must satisfy. This design discards systems that do not satisfy the specified constraints, so they do not appear in the optimization results or sensitivity results.

Maximum annual capacity shortage, is the maximum allowable value of the capacity shortage fraction, which is the total capacity shortage divided by the total annual electric load. It has been used maximum annual capacity shortage in this design of 75% with a sensitivity value of 60%.

Regarding the load profile, it has been assumed that the weekdays and weekends profiles of the electrical consumption at Cluster 1 are similar for every month. This assumption was taken because the annual variability of the load due to special events are relatively insignificant compared to the total consumption.

Due to geographical condition of the Air Sena where loads are situated both on and off shore, the system will consist of three separated systems each for Cluster 1, 2, and 3.

4.2. Resource Data Collection

4.2.1. Solar Resource

The solar resource in this project uses the Meteonorm data for 2005 (http://meteonorm.com) for Anambas region (3”6’ N and 106”25’ E) with the timezone GMT +7. The data delivers in resolution of hourly values. To compare the Meteonorm solar resource data to other source, Table 21 presents the solar data at Anambas from the Meteonorm and NASA and the sky clearness index from NASA. These data had been confirmed valid though the actual measurements every 30 minutes for two days at Air Sena during the survey period using an Environdata (model SR10/11) pyranometer (Figure 42).

Month	Monthly Averaged Solar Irradiation (kWh/m^2/day)		Clearness Index[3]
	Meteonorm[2]	NASA[3]	
Jan	4.76	4.84	0.490
Feb	5.55	5.62	0.546
Mar	5.77	6.24	0.552
Apr	5.72	6.27	0.554
May	5.26	5.69	0.530
Jun	4.61	5.21	0.479
Jul	5.00	5.08	0.514
Aug	5.08	5.21	0.503
Sep	4.88	5.30	0.472
Oct	4.34	4.88	0.426
Nov	4.52	4.59	0.462
Dec	4.11	4.42	0.431
Ave.	**4.97**	**5.28**	**0.50**

Table 1. Solar data and Sky Clearness Index at Anambas region (Source: EnReach, 2014)

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[2] The Meteonorm solar data is the averaged monthly values of 2005. They are based on long term averages (1991-2010 for sites available); hourly values are based on stochastic generation to obtain a typical year.

[3] The NASA solar data is based on 10 years averages. The data is presented in the averaged monthly values.

Figure 2. Measurements of solar irradiation at Air Sena using Environdata (model SR10/11) pyranometer (EnReach 2014)

Considering the solar resource at the project location, it has a great potential for PV system application. Figure 43 shows the global horizontal radiation (kWh/m^2/day) at Air Sena being used in this design.

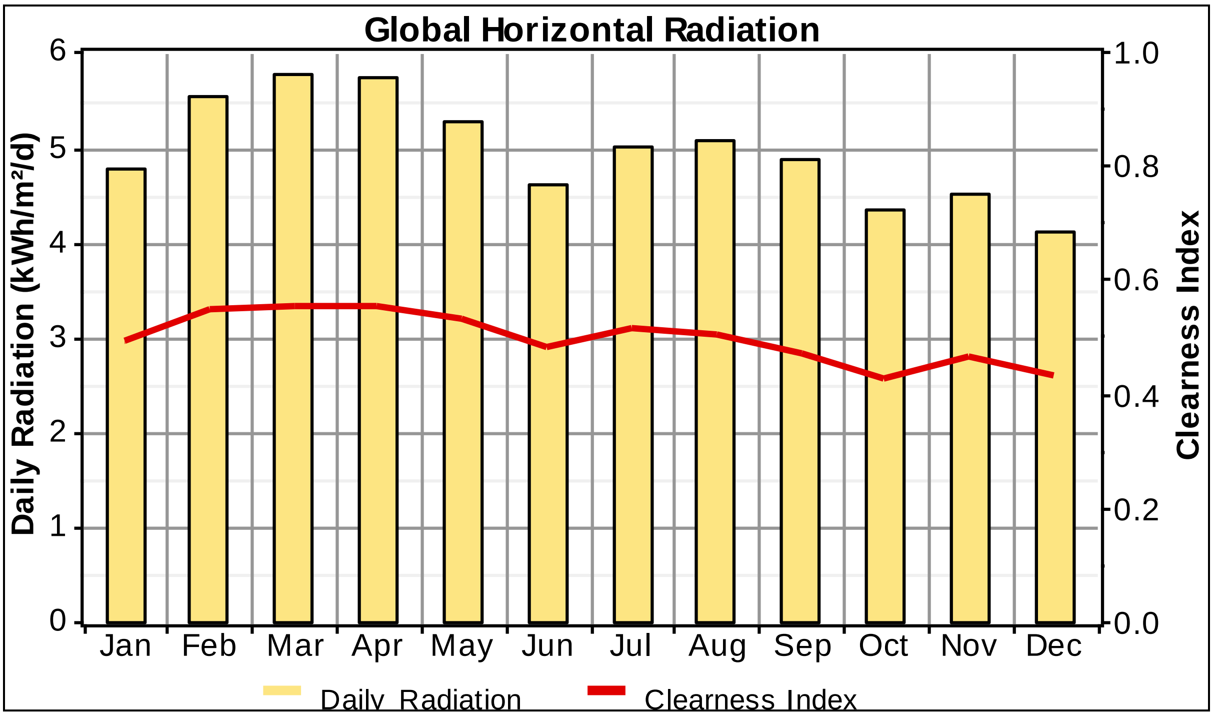

Figure 3. Global horizontal radiation at Air Sena (EnReach 2014)

4.2.2. Wind Resource

There were three sets of wind data obtained for Anambas region. They come from the BMKG Tarempa, Meteonorm, and NASA. However, they are extracted from measurements or calculation at 10 m altitude (BMKG Tarempa and Meteonorm) and at 50 m (NASA), whereas the proposed hub height of the wind turbine is 30 m.

Selection to use altitude of 30 m is made since wind speed increases with the height in algorithmic pattern. The instantaneous increase in wind speed with elevation depends on a number of meteorological factors, e.g., temperature layering and humidity. These largely determine the atmospheric stability. However, the mean value to be expected statistically over a long term at a particular height is largely determined by the roughness of the earth's surface (Hau 2006). The roughness of the earth's surface is defined by the so-called roughness length Z_0 that is specified in metres (Table 22).

Types of terrain surfaces	Z_o (m)
City	1.00
Forest	0.80
Suburbs	0.50
Built up Terrain	0.30
Many Tress and/or Bushes	0.20
Agricultural terrain with a closed appearance	0.10
Agricultural terrain with an open appearance	0.05
Agricultural terrain with very few buildings, trees, etc.	0.03
Airports with buildings and trees	0.02
Airports, runway	0.01
Bare earth (smooth)	5×10^{-3}
Snow surfaces (smooth growth)	10^{-3}
Sand surfaces (smooth)	3×10^{-4}
Water surfaces (lakes, fjords and the sea)	10^{-4}

Table 2. Roughness lengths and roughness classes for various surface characteristics (Source: Hau, 2006)

A conventional approach for describing the increase in wind speed with height is logarithmic height formula:

$$\tilde{V}_H = \tilde{V}_{ref} \cdot \frac{ln \frac{H}{Z_0}}{ln \frac{H_{ref}}{Z_0}}$$

where:

$\tilde{V}_H$ = mean wind velocity at elevation H (m/s)

$\tilde{V}_{ref}$ = mean wind speed at reference elevation Href (m/s)
H = height (m)

H_{ref} = reference elevation (measuring elevation) (m)
In = natural logarithm

Z_0 = roughness length (m)

Table 23 summarizes the wind speed data from the three sources for Anambas region. It shows the original data at 10 m or 50 m altitudes then are converted into 30 m altitudes wind data using the above equation.

Month	Monthly Averaged Wind Speed (m/s)					
	BMKG Tarempa[4]		Meteonorm[5]		NASA[6]	
	10 m alt	30 m alt	10 m alt	30 m alt	50 m alt	30 m alt
Jan	3.4	4.35	2.2	2.82	4.2	3.81
Feb	2.5	3.20	2.3	2.95	3.4	3.09
Mar	2	2.56	1.8	2.31	2.9	2.63
Apr	1.8	2.31	1.4	1.79	1.7	1.54
May	2.1	2.69	1.5	1.92	1.8	1.63
Jun	2.2	2.82	1.6	2.05	2.6	2.36
Jul	2.6	3.33	1.8	2.31	2.6	2.36
Aug	2.5	3.20	1.9	2.43	2.9	2.63
Sep	2.6	3.33	1.7	2.18	2.3	2.09
Oct	2.2	2.82	1.5	1.92	2	1.81
Nov	1.5	1.92	1.4	1.79	2.4	2.18
Dec	2.2	2.82	1.8	2.31	3.8	3.45
Ave.	2.3	2.9	1.7	2.2	2.7	2.5

Table 3. Wind speed data from various sources for Anambas region (Source: EnReach, 2014)

In this instance, the most reliable wind speed data comes from the BMKG Tarempa because it is a result of direct measurement. This project uses the BMKG wind data at 30 m height (highlighted in green in Table 23). The Meteonorm and NASA data – although previously considered - are not used. Based on email conversation with the Meteonorm, the Meteonorm wind speed data is not very accurate and should not be used for wind energy simulation. The NASA data – even sometime used for wind turbine design purposes – is also not used because a more reliable data available.

The Meteonorm and NASA data were mainly used to estimate the time of day when the highest wind speeds occur. Based on the Meteonorm data and is confirmed with the NASA data, the highest wind speeds occur from 14:00 PM to 17:00 PM with the peak wind speed at 16:00 PM.

Considering the wind speed at the project location, it will only be possible to install small wind turbine with the size of 500 – 1,000 watt. However, one may expect to have a better wind resource for wind turbine application at Air Sena if the turbines are sited on the best available locations where local topography would increase the wind speed across the wind turbines (please see Section 4.5.2. Potential Sites for Wind Turbines). Figure 44 shows the wind resource (m/s) at Air Sena being used in this design.

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[4] The BMKG Tarempa wind speed data is the averaged monthly values of 2012 and 2013. This is a direct measured data using Anemometer RM Young 26700 at the location 3.6 °N and 106.25 °E at 10 heights above the ground.

[5] The Meteonorm wind speed data is the averaged monthly values of 2005. They are based on long term averages (1991-2010 for sites available); hourly values are based on stochastic generation to obtain a typical year.

[6] The NASA wind speed data is based on 10 years averages at 10 m height. The data is presented in the averaged monthly values.

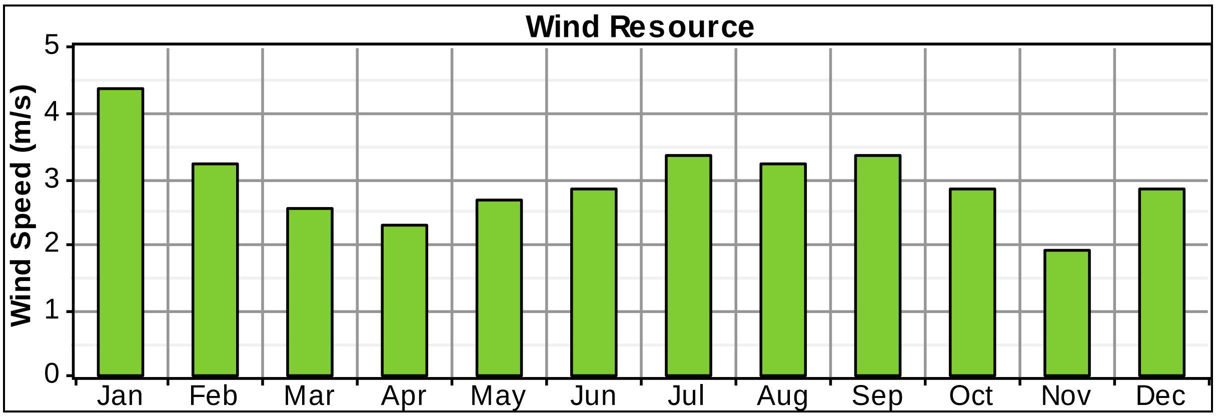

Figure 4. Monthly averaged wind resource at Air Sena (EnReach 2014)

4.3. Cost Input

The costs input to the model are summarized below. Except where indicated, these cost assumptions were developed at the time of study in 2014 and include increased estimated cost for installation on an island. The exchange rate is assumed that USD 1 = IDR 11,000.

4.3.1. Diesel fuel cost

The price of diesel fuel used in the design is the average cost of diesel in 2014 at Air Sena Village i.e. USD 0.545/litre. A sensitivity analysis was performed determining the system effects if diesel costs USD 1.10/litre to anticipate the likely impact of diesel fuel subsidy removal and international crude oil price. The nowaday's news trend shows that the next government of Indonesia is likely to reduce the oil subsidy.

4.3.2. Diesel Generators

There are four diesel genrators to be considered for the system design i.e. two 140 kVA generators for Cluster 1 and two 5 kVA generators for Cluster 2 and 3.

Two 140 KWA generators

Capital cost: $0 (the equipment is already purchased and installed at the Village).

- Replacement cost of each genset: USD 40,000 (the equipment will be replaced when the generator has run for 10,000 hours),
- Operation and Maintenance cost of each genset: USD 4.48/operating hour (Source: Homer Energy 2014).[7]

As has been estimated, the annual averaged operational hour of each genset is 1,315 hours. With the maximum of oprational hours of 10,000 hours, the remining operational hour of each genset is 7,990 hours. Therefore the gensets should be replaced in 73 months started from mid of March 2014 until April 2020.

Two 5 KWA generators

Capital and replacement costs: $1,250 each.

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[7] HOMER Energy recommends O&M cost of 2 US cents per kWh at rated output. However, in this design has been used 4 US cents per kWh at rated output to allow for unforseen cost factors.

- The generator will be replaced after it has run for 10,000 hours,
- Operation and Maintenance cost of each genset: USD 0.2/operating hour (uses the same calculation with those large gensets above).

4.3.3. Photovoltaic Panels (PV)

The PV panel cost per kWp used in this study is USD 2,520 (Raharjo and Fitriana n.d), including panel distribution boxes, cabelling the maximum power point (MPP) controller, and lightning protection system. A sensitivity was performed determining the system effects if PV cost decline to USD 1,300/kWp. Operation and Maintenance cost: USD 25/kWp/year.

4.3.4. Wind Turbine

- Capital cost: USD 2,500/kW.
- Replacement cost: USD 1,875/kW (the turbine will be replaced after 15 years of service)
- Operation and Maintenance cost: USD 15/kW/yr

4.3.5. Energy Storage System

- Cell stacks (OPzS Cell 2V 12 OPzS 3000)
  - Capital cost: USD 1,080 for a cell stack
  - Replacement cost: USD 1,080 (the cell stack will be replaced after 15 years of service)
  - Variable O&M cost: USD 0.005/kWh throughput.
- Lithium Battery (24V cells)
  - Capital cost: USD 500/kWh
  - Replacement cost: USD 350/kWh (the cells will be replaced after 10 years of service)
- VRLA (12V, 1335Ah)
  - Capital cost: USD 350/kWh (the units will be replaced after 4 years of service)
  - Replacement cost: USD 350/kWh.

4.3.6. Converter (inverter/rectifier)

- Capital cost: USD 800/kW
- Replacement cost: USD 800/kW (the equipment will be replaced after 15 years of service)
- O&M cost: USD 100/year.

4.3.7. Costs not included

The design of this hybrid system considers the costs directly related to the system equipment. So the design does not include the following costs:

- cost related to construction of such as power house building and cost for distribution lines and poles,
- office and staff costs after the project commissioning.

4.4. Hybrid System Design Results

4.4.1. Design criteria

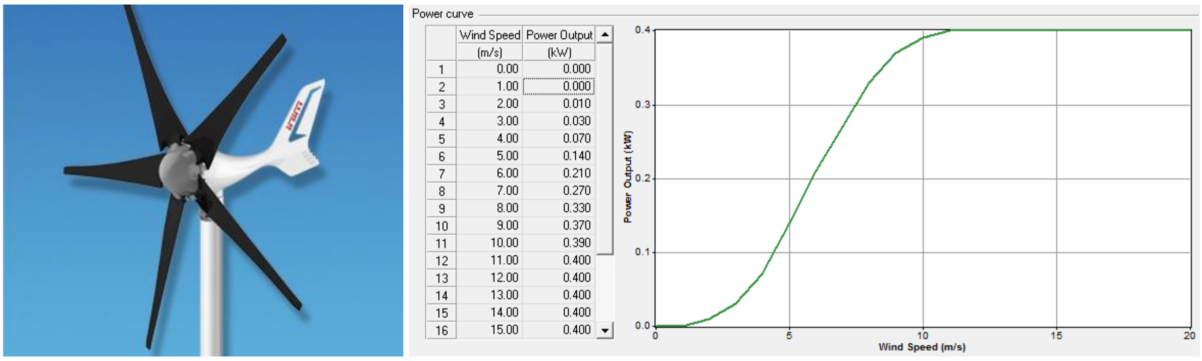
The following equipment has been considered in designing the hybrid systems for Air Sena Village (Table 24). The final utilisation of equipment is based on the most optimum system configuration to meet the load and therefore perhaps not all equipment will be used for each design. The main consideration in determining the winning system is based on the lowest net present cost (NPC).

No	Equipment	General Specification
1	**Diesel Generator 1 and 2**	Existing diesel generators. Please see Table 13
2	**PV module**	Lifetime: 25 years; derating factor: 80%; slope degree: 5^0 due South; ground reflectance: 20%; temperature coefficient of power: -0.5%; nominal operating temperature: 47^{0}C; efficiency at standard test condition: 10%; no tracking system
3	**Wind turbine**	Sunning Wind Power turbine or those with similar specification; lifetime: 15 years; hub height: 30 m; other specifications please see Figure 45.
4	**Battery**	Nominal capacity at C$_{10}$: 3000 Ah; nominal voltage: 2 volts; round trip efficiency: 86%; minimum state of charge: 50%; minimum battery lifetime: 7.5 years: lifetime throughput: 19,196 kWh; max. charge rate: 1A/Ah; max charge current: 510 A; number of battery per string: 24 (Cluster 1) and 12 (Cluster 2 and 3).
5	**Converter**	Inverter & Rectifier unit; inverter lifetime: 15 years; inverter efficiency: 90%; inverter can operate simultaneously with diesel generators; rectifier efficiency: 80%

Table 4. Equipment considered in the design of hybrid system

Figure 45 shows an example of small wind turbine available on the market and its power curve. This example was given because wind turbines for low wind speed are not always available. It is produced by Sunning Wind Generator with a model name Mini 5 Plus Small Wind Turbine. From the manufacturer’s website, the specification of the turbine is as follows:

▪ Rated Capacity	: 400 watts at 28 mph (12.5 m/s)
▪ Max Capacity	: 450 watts
▪ Rotor Diameter	: 1.21m
▪ Weight	: 7.1 kg
▪ Shipping Dimensions	: 770 x 410 x 200 mm (9 kg)
▪ Start-Up Wind Speed	: 1.5 (m/s)
▪ Cut-In Wind Speed	: 2.0 (m/s)
▪ Voltage	: 12, 24 VDC
▪ Turbine Controller	: Microprocessor-based smart internal regulator with Maximum Power Point Tracking
▪ Body	: Cast aluminium
▪ Blades	: 5 PC Nylon Fibre
▪ Over speed Protection	: Electronic torque control
▪ Kilowatt Hours per Month	: 42 kWh/mo at 3.2 m/s
▪ Survival Wind Speed	: 50 m/s



Power curve

	Wind Speed (m/s)	Power Output (kW)
1	0.00	0.000
2	1.00	0.000
3	2.00	0.010
4	3.00	0.030
5	4.00	0.070
6	5.00	0.140
7	6.00	0.210
8	7.00	0.270
9	8.00	0.330
10	9.00	0.370
11	10.00	0.390
12	11.00	0.400
13	12.00	0.400
14	13.00	0.400
15	14.00	0.400
16	15.00	0.400

Figure 5. Example of Small wind turbine (Source: www.sunningpower.com, accessed 2 April 2014)

4.4.2. Cluster 1

Configuration

In order to meet the load of Cluster 1 for 24 hours a day for Air Sena, the following system equipment has been considered (Table 25).

PV Array (kWp)	Wind Turbine (Quantity)	Diesel Genset 1 (kW)	Diesel Genset 2 (kW)	Battery Bank (Strings)	Converter (kW)
0	0	0.00	0.00	0	0.00
700	5	112.00	112.00	15	200.00
800	10			20	
900	15			25	
1,000	20			30	
1,100				35	
1,200					

Note: number of battery per string: 24

Table 5. Equipment considered for the design of hybrid system, Cluster 1

There are 3,360 possible configurations and 4 sensitivities considered in the design to meet the Cluster 1 scenario. With the diesel price of USD 0.545/litre and maximum annual capacity shortage of 5%, the winning system, which is the most optimum system with the lowest NPV would consist of the following components. The dispatch strategy is load following.

- 700 kWp PV array,
- 1 x 112 kW diesel gensets,
- 480 batteries, and
- 200 kW inverter,
- 200 kW rectifier.

Economic Analysis

Table 26 below summarises the cost of the hybrid system for Cluster 1 scenario. The total NPC is USD 2,937,768 with the annual Operating cost of USD 55,688/year. The levelised cost of energy is $ 0.356/kWh.

No	Cost Component	Cost (USD)
1	**Total net present cost (NPC)**	USD 2,937,768
2	**Levelized cost of energy**	USD 0.356/kWh = IDR 3,850

3	**Annual Operating cost**	USD 55,688/yr

Note: current price of electricity at Air Sena is IDR 2,000/kWh; 6 hours of operation/day.

Table 6. Cost summary of the hybrid system, Cluster 1

Table 27 shows the NPC of each system component based on the cost types. As shown in Figure 46, the capital cost constituted the largest portion of the total NPC at 81.6%, followed by O&M cost (14.8%), replacement cost (10. 8%) and fuel costs (7.4%).

Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)	%
PV	1,729,050	0	169,964	0	-288,589	1,610,426	54.82
Generator 1	0	46,947	69,182	218,830	-10,265	324,694	11.05
Hopecke 24 OPzS 3000	507,862	270,441	0	0	-129,900	648,403	22.07
Converter	160,000	0	194,245	0	0	354,245	12.06
System	2,396,912	317,388	433,392	218,830	-428,754	2,937,768	100.00
%	81.59	10.80	14.75	7.45	-14.59	100.00	

Table 7. Net Present Costs of system components based on the cost types, Cluster 1

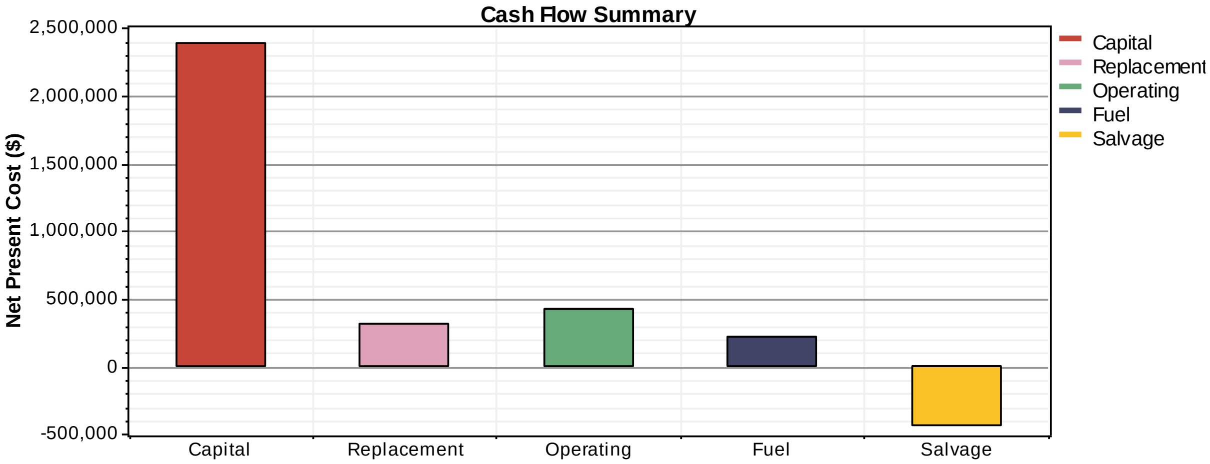


Figure 6. Net Present Costs based on the cost types, Cluster 1 (EnReach 2014)

From Figure 47, the component incurring the largest cost is the PV array (54.8%) followed by the battery bank (22.1%), converter (12.1%), and genset (11.1%).

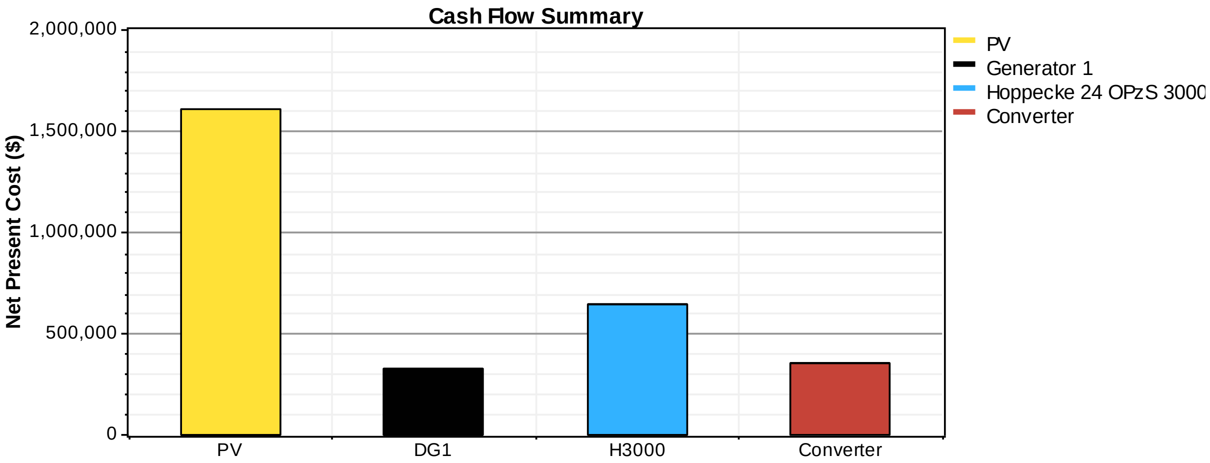


Figure 7. Net Present Costs based on the system components, Cluster 1 scenario (EnReach 2014)

Table 28 shows an overview of the annualised cost of the system. It is estimated that the average annual cost is USD 302,481 where the largest annualised cost of 54.8% will be spent for the PV array.

Component	**Capital (USD)**	**Replacement (USD)**	**O&M**	**Fuel**	**Salvage (USD)**	**Total (USD**	**%**
PV	178,028	0	17,500	0	-29,714	165,814	54.82
Generator 1	0	4,834	7,123	22,531	-1,057	33,431	11.05
Hopecke 24 OPzS 3000	52,291	27,845	0	0	-13,375	66,761	22.07
Converter	16,474	0	20,000	0	0	36,474	12.06
System	246,793	32,679	44,623	22,531	-44,146	302,481	100.00
%	81.59	10.80	14.75	7.45	-14.59	100.00	

Table 8. Net Present Costs of annualised cost of the system, Cluster 1

Technical Performance Analysis

Table 29 summarises the annual energy production of the system. Renewables produces 90% of the total output. The total production is 1,121,866 kWh year. Figure 48 shows the monthly electrical energy production of the system.

Component	**Production (kWh/yr)**	**Fraction**
PV array	1,013,485	90%
Generator 1	108,381	10%
Total	1,121,866	100%

Table 9. Energy production of the hybrid system, Cluster 1

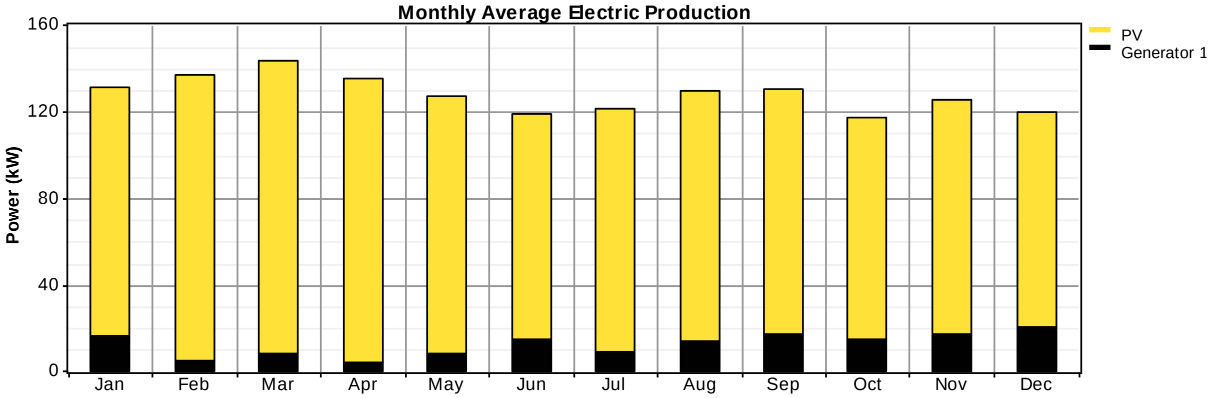


Figure 8. Monthly energy production, Cluster 1 (EnReach 2014)

The load would consume 848,495 kWh electrical energy per annum. Therefore, the system would produce excess electricity of 123,332 kWh per year (11.0%), 0.7% of unmet electric load, and 1.2% of capacity shortage. This is an optimum condition under the Cluster 1.

Emissions

Table 30 shows the environmental performance of the system in terms of the greenhouse gas emission from the operation of the diesel genset.

Pollutant	Emissions (kg/yr)
Carbon dioxide	108,867
Carbon monoxide	269
Unburned hydrocarbons	29.8
Particulate matter	20.3
Sulfur dioxide	219
Nitrogen oxides	2,398

Table 10. Greenhouse gas emission, Cluster 1

Sensitivity Analysis

All of the above analyses were based on the diesel price of USD 0.545/litre and maximum annual capacity shortage of 5%. However, it has been set two other values that might affect the system design and performances i.e. diesel price of USD 1.10/litre and maximum annual capacity shortage of 10%. Table 31 shows the effect of applying sensitivity values on the system configuration, economic analysis, performance analysis, and environmental analysis.

Items	Diesel Fuel (unsubsidised) USD 1.1/l	Max. annual capacity shortage of 10%	Both of the Besides applied
System configuration	▪ 700 kWp PV array, ▪ 1 x 112 kW diesel genset, ▪ 720 batteries, and ▪ 200 kW inverter, ▪ 200 kW rectifier.	▪ 700 kWp PV array, ▪ 15 wind turbines ▪ 840 batteries, and ▪ 200 kW inverter, ▪ 200 kW rectifier.	▪ 700 kWp PV array, ▪ 15 wind turbines ▪ 840 batteries, and ▪ 200 kW inverter, ▪ 200 kW rectifier.
Total NPC (USD)	3,137,387	2,820,147	2,820,147
Annual operating cost (USD/year)	50,097	2,817	2,817

Annualised cost (USD/yr.)	323,034	290,370	290,370
LCOE (USD/kWh)	0.380	0.370	0.370
RE fraction (%)	93	100	100
Annual energy production (kWh/yr.)	1,095,432	1,017,971	1,017,971
Annual energy consumption (kWh/yr.)	850,809	783,963	783,963
CO2 emission (kg/yr.)	83,112	0	0

Table 11. Effects of sensitivity values, Cluster 1

4.4.3. Cluster 2

Configuration

In order to meet the Cluster 2 load for 24 hours a day for Air Sena, the following system equipment has been considered (Table 32).

PV Array (kWp)	Wind Turbine (Quantity)	Diesel Genset (kW)	Battery Bank (Strings)	Converter (kW)
5.000	0	0.00	0	0.00
6.000	1	5.00	1	5.00
7.000	2			
8.000	3			
9.000	4			
10.000				
11.000				
12.000				
13.000				
14.000				
15.000				

Note: number of battery per string: 12

Table 12. Equipment considered for the design of hybrid system, Cluster 2

There were 880 possible configurations and 4 sensitivities considered in the design to meet the Cluster 2 load. With the diesel price of USD 0.545/litre and maximum annual capacity shortage of 5%, the winning system, which is the most optimum system with the lowest NPV would consist of the following components:

- 9 kWp PV array,
- 1 x 5 kW diesel genset,
- 12 batteries, and
- 5 kW inverter,
- 5 kW rectifier.

Economic Analysis

Table 33 summarise the cost of the system. The total NPC is USD 71,243 with the annual Operating cost of USD 3,191/year. The levelised cost of energy is USD 0.386/kWh.

No	Cost Component	Cost (USD)
1	**Total net present cost (NPC)**	USD 71,243

2	**Levelized cost of energy**	USD 0.386/kWh = IDR 4,235
3	**Annual Operating cost**	USD 3,191/yr

Note: current price of electricity at Air Sena is IDR 2,000/kWh; 6 hours operation/day

Table 13. Cost summary of the hybrid system, Cluster 2

Table 34 shows the NPC of each system component based on the cost types. As shown in Figure 49, the capital cost constituted the largest portion of the total NPC at 56.5%, followed by fuel cost (26.1%), operating cost (15.7%) and replacement costs (12.4%).

Component	**Capital ($/yr)**	**Replacement ($/yr)**	**O&M ($/yr)**	**Fuel ($/yr)**	**Salvage ($/yr)**	**Total ($/yr)**	**%**
PV	22,280	0	2,185	0	-3,719	20,747	29.12
Generator 1	1,250	2,229	4,157	18,622	-412	25,846	36.28
Hopecke 24 OPzS 3000	12,718	6,607	0	0	-3,531	15,794	22.17
Converter	4,000	0	4,856	0	0	8,856	12.43
System	40,248	8,837	11,198	18,622	-7,661	71,243	100.00
%	56.49	12.40	15.72	26.14	-10.75	100.00	

Table 14. Net Present Costs of system components based on the cost types, Cluster 2

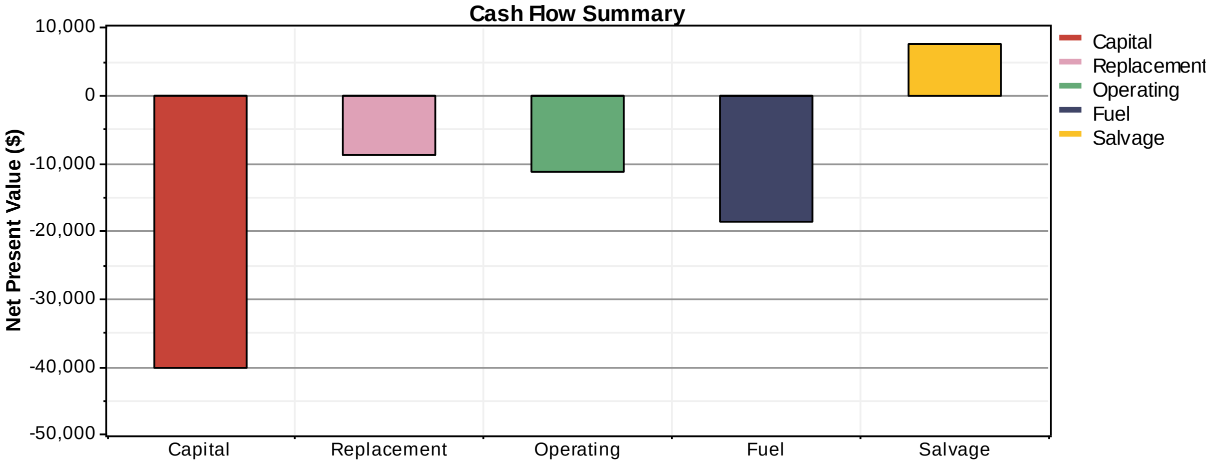


Figure 9. Net Present Costs based on the cost types, Cluster 2 (EnReach 2014)

From Figure 50, the component incurring the largest cost is the diesel genset (36.3%) followed by the PV array (29.1%), battery (22.2%), and converter (12.4%).

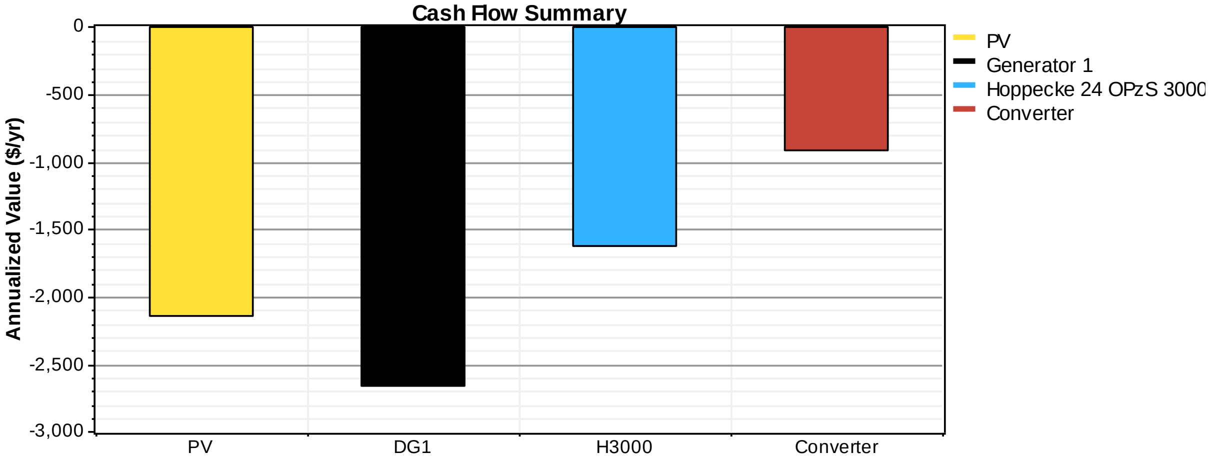


Figure 10. Net Present Costs based on the system components, Cluster 2 (EnReach 2014)

Table 35 shows an overview of the annualised cost of the system. It is estimated that the average annual cost is USD 7,335 where the largest cost of 56.5% will be spent for capital cost.

Component	Capital ($/yr)	Replacement ($/yr)	O&M ($/yr)	Fuel ($/yr)	Salvage ($/yr)	Total ($/yr)	%
PV	2,294	0	225	0	-383	2,136	29.12
Generator 1	129	230	428	1,917	-42	2,661	36.28
Hopecke 24 OPzS 3000	1,309	680	0	0	-364	1,626	22.17
Converter	412	0	500	0	0	912	12.43
System	4,144	910	1,153	1,917	-789	7,335	100.00
%	56.50	12.41	15.72	26.13	-10.76	100.00	

Table 15. Net Present Costs of annualised cost of the system, Cluster 2

Technical Performance Analysis

Table 36 summarises the annual energy production of the system. Renewables produces 55% of the total output. The total production is 23,679 kWh year. Figure 51 shows the monthly electrical energy production of the system.

Component	Production (kWh/yr)	Fraction
PV array	13,031	55%
Generator 1	10,649	45%
Total	23,679	100%

Table 16. Energy production of the hybrid system, Cluster 2

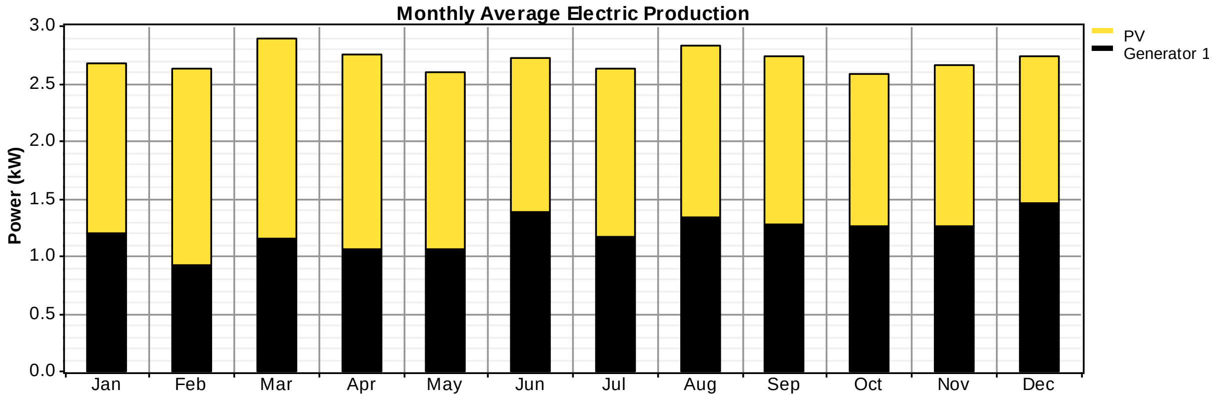


Figure 11. Monthly energy production, Cluster 2 (EnReach 2014)

The load would consume 19,017 kWh electrical energy per annum. Therefore, the system would produce excess electricity of 776 per year (3.28%), 0.00% of unmet electric load, and 0.00% of capacity shortage.

Emissions

Table 37 shows the environmental performance of the system in terms of the greenhouse gas emission from the operation of the diesel genset.

Pollutant	**Emissions (kg/yr)**
Carbon dioxide	9,264
Carbon monoxide	22.9
Unburned hydrocarbons	2.53
Particulate matter	1.72
Sulfur dioxide	18.6
Nitrogen oxides	204

Table 17. Greenhouse gas emission, Cluster 2

Sensitivity Analysis

Table 38 shows the effect of applying sensitivity values on the system configuration, economic analysis, performance analysis, and environmental analysis.

Items	**Diesel Fuel (UNSUBSIDISED) USD 1.1/l**	**Max. annual capacity shortage of 10%**	**Both of the Besides applied**
System configuration	▪ 14 kWp PV array, ▪ 1 x 5 kW diesel genset, ▪ 12 batteries, and ▪ 5 kW inverter, ▪ 5 kW rectifier.	▪ 9 kWp PV array, ▪ 1 x 5 kW diesel genset, ▪ 12 batteries, and ▪ 5 kW inverter, ▪ 5 kW rectifier.	▪ 14 kWp PV array, ▪ 1 x 5 kW diesel genset, ▪ 12 batteries, and ▪ 5 kW inverter, ▪ 5 kW rectifier.
Total NPC (USD)	81,292	71,243	81,292
Annual Operating cost (USD/year)	2,954	3,191	2,954
Annualised cost (USD/yr.)	8,370	7,335	8,370
LCOE (USD/kWh)	0.441	0.386	0.441
RE fraction (%)	84	55	84
Annual energy	24,087	23,679	24,087

production (kWh/yr.)			
Annual energy consumption (kWh/yr.)	18,999	19,017	18,999
CO2 emission (kg/yr.)	4,275	9,264	4,275

Table 18. Effects of sensitivity values, Cluster 2

4.4.4. Cluster 3

Configuration

In order to meet the Cluster 3 load for 24 hours a day for Air Sena, the following system equipment has been considered (Table 39).

PV Array (kWp)	Wind Turbine (Quantity)	Diesel Genset (kW)	Battery Bank (Strings)	Converter (kW)
0.000	0	0.00	0	0.00
5.000	1	5.00	1	5.00
10.000	2		2	10.00
15.000	3		3	
20.000	4			

Note: number of battery per string: 12

Table 19. Equipment considered for the design of hybrid system, Cluster 3

There were 600 possible configurations and 4 sensitivities considered in the design to meet the Cluster 3 scenario. With the diesel price of USD 0.545/litre and maximum annual capacity shortage of 5%, the winning system, which is the most optimum system with the lowest NPV would consist of the following components:

- 10 kWp PV array,
- 1 x 5 kW diesel genset,
- 12 batteries, and
- 5 kW inverter,
- 5 kW rectifier.

Economic Analysis

Table 40 summarise the cost of the system. The total NPC is USD 60,351 with the annual Operating cost of USD 1,816/year. The levelised cost of energy is USD 0.410/kWh.

No	Cost Component	Cost (USD)
1	**Total net present cost (NPC)**	USD 60,351
2	**Levelized cost of energy**	USD 0.410/kWh = IDR 4,510
3	**Annual Operating cost**	USD 1,816/yr

Note: current price of electricity at Air Sena is IDR 2,000/kWh; 6 hours operation/day

Table 20. Cost summary of the hybrid system, Cluster 3

Table 41 shows the NPC of each system component based on the cost types. As shown in Figure 52, the capital cost constituted the largest portion of the total NPC at 70.8%, followed by fuel cost (15.8%), operating cost (15.6%), and replacement costs (11.6%).

Component	Capital (USD)	Replacement (USD)	O&M	Fuel	Salvage (USD)	Total (USD	%
PV	24,750	0	2,428	0	-4,131	23,047	38.19
Generator 1	1,250	735	2,133	9,533	-184	13,467	22.31
Hopecke 24 OPzS 3000	12,718	6,289	0	0	-4,026	14,981	24.82
Converter	4,000	0	4,856	0	0	8,856	14.67
System	42,718	7,025	9,417	9,533	-8,342	60,351	100.00
%	70.78	11.64	15.60	15.80	-13.82	100.00	

Table 21. Net Present Costs of system components based on the cost types, Cluster 3

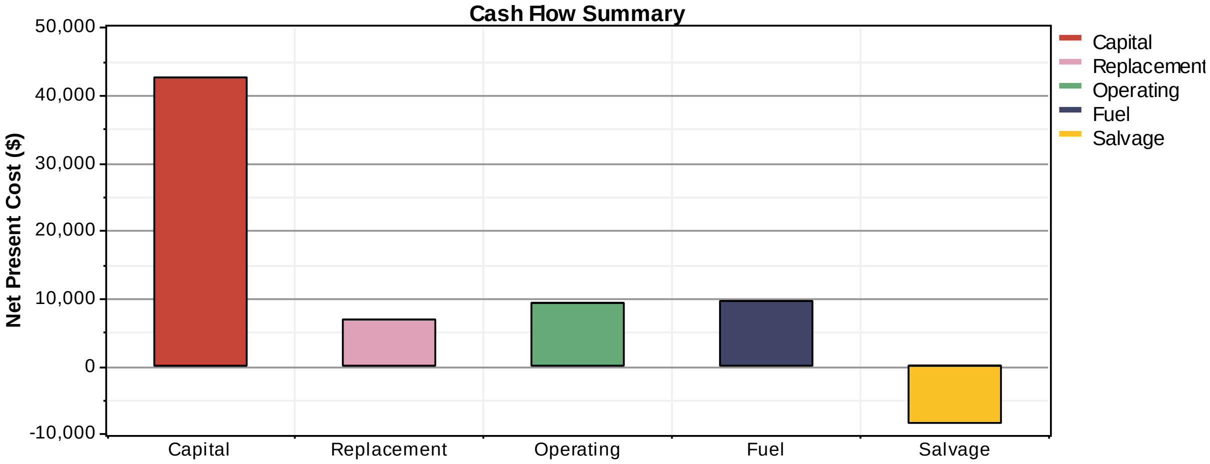


Figure 12. Net Present Costs based on the cost types, Cluster 3 (EnReach 2014)

From Figure 53, the component incurring the largest cost is the PV array (38.2%) followed by the battery bank (24.8%), genset (22.3%), and converter (14.7%).

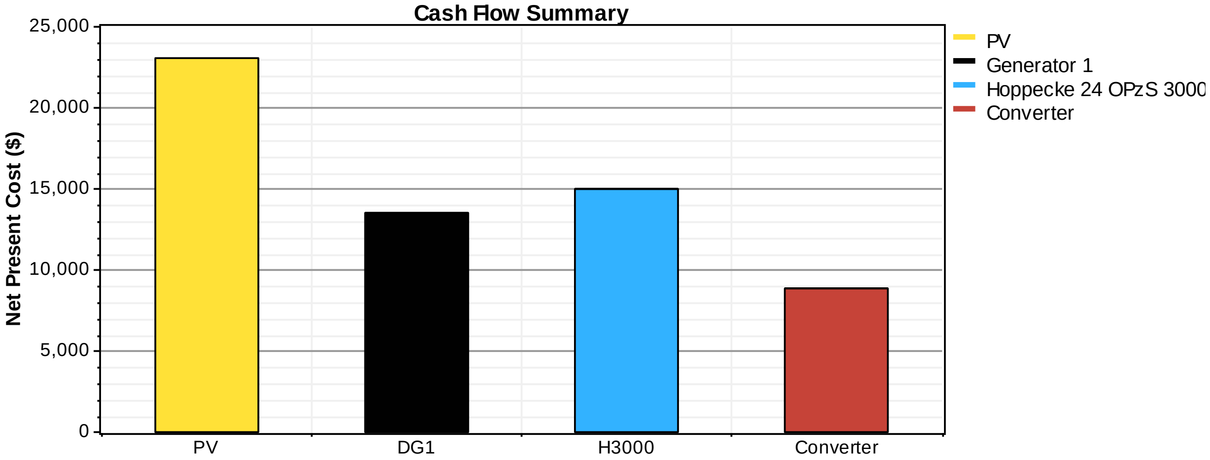


Figure 13. Net Present Costs based on the system components, Cluster 3 (EnReach 2014)

Table 42 shows an overview of the annualised cost of the system. It is estimated that the average annual cost is USD 6,214 where the largest cost of 70.8% will be spent for capital cost.

Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)	%
PV	2,548	0	250	0	-425	2,373	38.19
Generator 1	129	76	220	982	-19	1,387	22.32
Hopecke 24 OPzS 3000	1,309	648	0	0	-415	1,542	24.81
Converter	412	0	500	0	0	912	14.68
System	4,398	723	970	982	-859	6,214	100.00
%	70.78	11.64	15.61	15.80	-13.82	100.00	

Table 22. Net Present Costs of annualised cost of the system, Cluster 3

Technical Performance Analysis

Table 43 summarises the annual energy production of the system. Renewables produces 73% of the total output. The total production is 19,926 kWh year. Figure 54 shows the monthly electrical energy production of the system.

Production	kWh/yr	%
PV array	14,478	73
Generator 1	5,447	27
Total	**19,926**	**100**

Table 23. Energy production of the hybrid system, Cluster 3

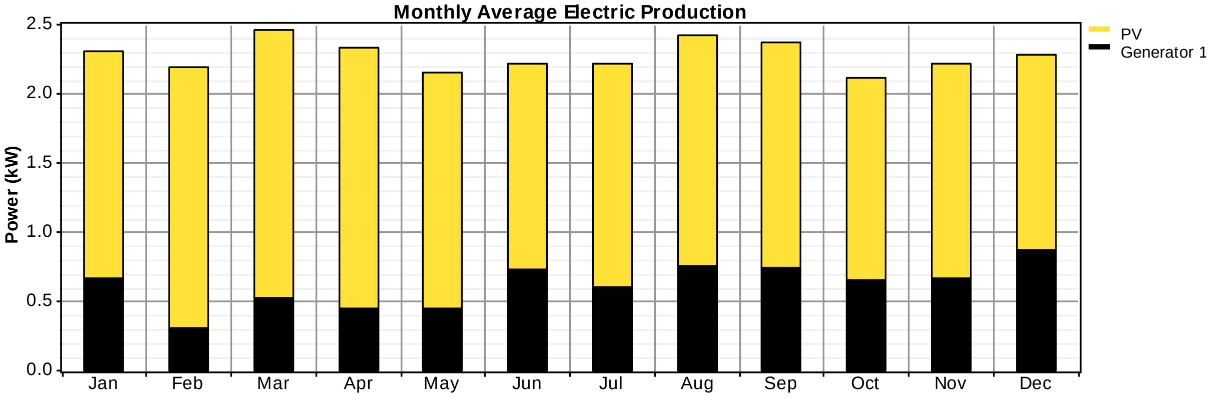


Figure 14. Monthly energy production, Cluster 3 (EnReach 2014)

The load would consume 15,147 kWh electrical energy per annum. Therefore, the system would produce excess electricity of 1,384 per year (6.95%), 0% of unmet electric load, and 0% of capacity shortage.

Emissions

Table 44 shows the environmental performance of the system in terms of the greenhouse gas emission from the operation of the diesel genset.

Pollutant	Emissions (kg/yr)
Carbon dioxide	4,743
Carbon monoxide	11.7
Unburned hydrocarbons	1.3
Particulate matter	0.882
Sulfur dioxide	9.52

Nitrogen oxides	104

Table 24. Greenhouse gas emission, Cluster 3

Sensitivity Analysis

Table 45 shows the effect of applying sensitivity values on the system configuration, economic analysis, performance analysis, and environmental analysis.

Items	Diesel Fuel USD 1.1/l	Max. annual capacity shortage of 10%	Both of the Besides applied
System configuration	▪ 15 kWp PV array, ▪ 24 batteries, and ▪ 5 kW inverter, ▪ 5 kW rectifier.	▪ 15 kWp PV array, ▪ 12 batteries, and ▪ 5 kW inverter, ▪ 5 kW rectifier.	▪ 15 kWp PV array, ▪ 12 batteries, and ▪ 5 kW inverter, ▪ 5 kW rectifier.
Total NPC (USD)	66,169	59,191	59,191
Annual Operating cost (USD/year)	-35.5	553	553
Annualised cost (USD/yr.)	6,813	6,094	6,094
LCOE (USD/kWh)	0.457	0.433	0.433
RE fraction (%)	100	100	
Annual energy production (kWh/yr.)	21,718	21,718	21,718
Annual energy consumption (kWh/yr.)	14,911	14,067	14,067
CO2 emission (kg/yr.)	0	0	0

Table 25. Effects of sensitivity values, Cluster 3

4.4.5. Design Conclusion

Table 46 shows the summary of the system designs, the economic analysis, technical analysis, and GHG emission of the loads Cluster 1, 2, and 3. The summary was based on the diesel fuel price of USD 0.545/litre and maximum annual capacity shortage of 5%.

Items	Cluster 1	Cluster 2	Cluster 3
System configuration	▪ 700 kWp PV array, ▪ 1 x 112 kW diesel gensets, ▪ 480 batteries, and ▪ 200 kW inverter, ▪ 200 kW rectifier.	▪ 9 kWp PV array, ▪ 1 x 5 kW diesel genset, ▪ 12 batteries, and ▪ 5 kW inverter, ▪ 5 kW rectifier.	▪ 10 kWp PV array, ▪ 1 x 5 kW diesel genset, ▪ 12 batteries, and ▪ 5 kW inverter, ▪ 5 kW rectifier.
Dispatch strategy	Load following	Cycle Charging	Cycle Charging
Total NPC (USD)	2,937,768	71,243	60,351
Annual Operating cost (USD/year)	55,688	3,191	1,816
Annualised cost (USD/yr.)	302,481	7,335	6,214
LCOE (USD/kWh)	0.356	0.386	0.410
RE fraction (%)	90	55	73
Annual energy production (kWh/yr.)	1,121,866	23,679	19,926
Annual energy	848,495	19,017	15,147

consumption (kWh/yr.)			
CO2 emission (kg/yr.)	108,867	9,264	4,743

Table 26. Summary of the hybrid system designs at Air Sena.

CHAPTER 5. CONCLUSION

- Three separated hybrid system designs have been considered to serve load Cluster 1, 2, and 3. Each system consists of different configuration and it would have its own local grid. The LCOE of the Cluster 1, 2, and 3 systems are USD 0.356, USD 0.386, and USD 0.410, respectively. Since the current electrify price applied at Air Sena is USD 0.18/kWh only, it can be concluded that the proposed hybrid systems are not economically viable for Air Sena Village, particularly if the project would be purely private investment. But, when there are supports from other institution(s) to cover at least 50% of the capital costs, it can be expected that the LCOE would go down to USD 0.18/kWh.
- The power generation expansion plan is not only aimed at providing electricity access for all consumer groups toward 100% electrification ratio, but is also to increase the length of daily power supply from 6 hours/day up to 24 hours/day.
- Since the wind speed at Air Sena area is low, none of the system design recommended the inclusion of the wind turbines in the hybrid systems.
- If the project is to be implemented, it would be required to install the PV systems on some different locations on shore for Cluster 1 system due to unavailability of large area to sitting the PV system in a site. While the sites for Cluster 2 and 3 systems would be off-shore near the load using common practice of off-shore construction at Air Sena. However, the latter options would consider environment due to utilisation of coral reefs.
- Since developing large hybrid systems are cost and time intensive, some alternative designs that look at smaller load fractions e.g. individual households, public facilities and camps have been proposed. These options would allow the investor to prioritize which loads to be met first and witch load to be supplied in the next phases. These options include some solar home systems and smaller grids system.

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