PV-Mini Hydro-Diesel Hybrid System in a Village

Faiz Arith[1], S. Anis[2], M.Idzdihar.Idris[1], M. M. Yunus[1]
[1] Faculty of Electronic and Computer Engineering Universiti Teknikal Malaysia Melaka,
Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia
[2] Faculty of Science and Technology, Universiti Kebangsaan Malaysia,
43600 Bangi, Malaysia

***Abstract*— Nowadays, renewable energy becomes more demanding because of its advantages which are abundant, untapped and environmental friendly. Due to this fact, it is important to have a lot of research to enhance the performance of the renewable energy system. This paper will discuss on design, analysis and performance for optimizing the system using HOMER software in terms of economical and efficiency. The location for this simulation is at Kampung Chuweh, Pulau Banding, Gerik, Perak, which is Orang Asli village. Solar, mini hydro and generator have been used to simulate the system design. All the data and results are provided in this paper.**

***Index Term*— Generator, hydro, solar, HOMER software, renewable energy.**

I. INTRODUCTION

Kampung Chuweh is situated exactly on the edge of Banding Lake in the State of Perak, with bearing at 5º32’34.01”N and 101 º20’45.6”E. This village is on the Banding Island of Belum Forest. The lake is located about 45 km from the Hulu Perak district capital,Gerik. Basically, Temenggor Lake is a man-made lake which is located south of 1,533m high Ulu Titi Basah peak in Hulu Perak. The population of this village is 120 peoples with average houses of 30. Most of the houses have a small living room, with only one bedroom. The village is suitable for this project due to the existing renewable energy resources; sun, and lake [1-4]. Moreover, the remote communities are living in stratification, which makes electrical wiring easier. Furthermore, the remote area is far from the last transmission line and cumbersome to bring diesel through the rough and unpredictable land road. It takes high-cost to connect the grid system across the lake [5-7]. This project is made based on Kampung Chuweh population and number of houses and estimation of the electrical load.

II. LOAD ESTIMATION

As a first step, the estimations of electrical appliances are itemized with their power ratings and time of operation during the day to obtain the average energy demand in Watt hour per day as shown below in Table I.

TABLE I
TOTAL AVERAGE ENERGY CONSUMPTION

Appliance	Quantity	Power (W)	Hours used per day ($hday^{-1}$)	Energy ($W\ hday^{-1}$)
Ceiling Fan	1	80	7	560
Wall Fan	1	50	5	250
Standard Fluorescent Lamp	3	30	6	540
19" CRT Television	1	90	4	360
DVD Player	1	40	4	160
Total Average Energy Consumption				1870 approximately 1900

The electrical load estimation is made for one house. It was calculated based on the appliance, quantity of appliance, and the power of appliance. The appliance is divided into 5 main needs, which are ceiling fan at the living room, wall fan in a room, standard fluorescent lamp in the room, living room and outside of the house, one for each place, television and DVD. DVD is provided due to bad radio frequency service at this village. The total average energy consumption for a house is about 1.9 kWh.

To simulate the system, the approximate energy consumption for each hour is required. Table II shows the energy in kW for each hour. All total is 24 hours. The energy consumption is for 30 houses.

TABLE II
ENERGY CONSUMPTION FOR EACH HOUR DAILY

Hours	Energy (kW)	Hours	Energy (kW)
6 – 7 am	0.800	**6 -7 pm**	0.800
7 – 8 am	3.000	**7 – 8 pm**	0.800
8 – 9 am	5.000	**8 – 9 pm**	0.800
9 – 10 am	5.000	**9 – 10 pm**	0.800
10 – 11 am	4.000	**10 – 11 pm**	0.800
11 – 12 pm	4.000	**11 – 12 am**	0.800
12 – 1 pm	4.000	**12 – 1 am**	3.000
1 – 2 pm	3.000	**1 – 2 am**	3.000
2 – 3 pm	3.000	**2 – 3 am**	0.800
3 – 4 pm	3.000	**3 – 4 am**	0.800
4 – 5 pm	3.000	**4 – 5 am**	0.800
5 – 6 pm	3.000	**5 – 6 am**	0.800

The pattern of the energy consumption each hour is shown is Fig. 1. From 6 to 11 am, the energy consumption is least from other time, the lamp might be off. So do the fan. It is due to the low temperature in the morning and morning activities such as fishing, so the villagers not in the house. From 11 am to 2pm, the electrical load starts to increase. The TV and both fans might be on. The electrical load is at the peak from 11 pm 2 10 pm. Both fans might be on to do the high temperature of ambient. The electrical load from 11 pm to 6 am starts to decrease. Only one lamp at the outside of the house might be on.

All the consumptions are estimated due to the villagers' lifestyle. The load profile might be changed from time to time. The total population of the villager may increase. Thus, any changes are not valid for this consumption and calculation.

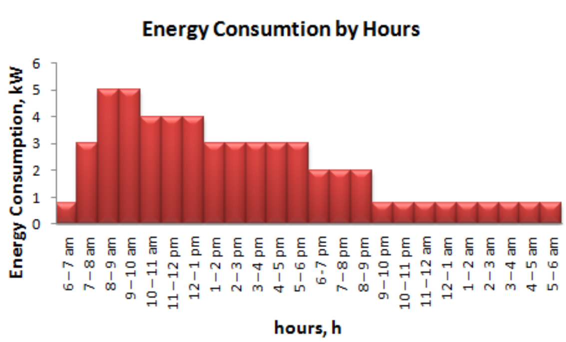

Fig. 1. Energy Consumption by Hours

III. SYSTEM DESCRIPTION

1) Diesel Generator

The diesel generator is used at the first place because the fuel cost per kilowatt produced is thirty to fifty percent lower than that of gas engines. The generator designed by HOMER should be able to supply an electrical load to about 24 houses. The diesel generator is connected to the AC bus and the AC bus is connected to the village load. Fig. 2 shows the schematic of those connections.

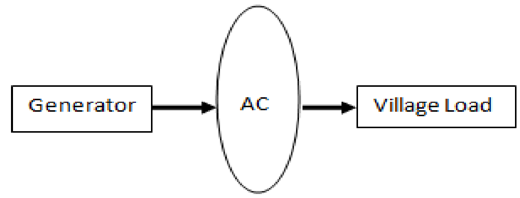

Fig. 2. The Connection of Generator, AC, and Village Load.

The simulation displays the average data of energy consumption per day of 54kWh/d for the settlement. HOMER also reports a peak load of 9kW. The random variability represents the differential between values which are day-to-day is 15% and time-step-to-time-step is 20%. The simulation also displays the load factor of 0.251. Table III represents the total energy consumption by month in kW. This assumed the total energy consumption from January to December is constant and the generator will be set up according to these values.

TABLE III
TOTAL ENERGY CONSUMPTION BY MONTH.

Month	Days	Total Energy , kW
January	31	1674
February	29	1566
March	31	1674
April	30	1620
May	31	1674
June	30	1620
July	31	1674
August	31	1674
September	30	1620
October	31	1674
November	30	1620
December	31	1674

Since the village's projected peak load is around 9kW, the generator is designed to a size of 10kW which is fulfilling the requirement for the village load and it is the maximum capacity range to simulate the system. Furthermore, it should be considered the facilities in the village, such as clinic and the main building.

The capital and the replacement cost are estimated to be 10,000 US dollar with 20000 hours of lifetime. Another property of generator that the system provides is minimum load ratio, which is 30%. The price of diesel is \$0.6/L. All the cost estimated is provided in Table IV.

TABLE IV
COST ESTIMATED

Size of Generator	10
Capital Cost, $	10000
Replacement Cost, $	10000
Operation and Maintenance Cost, $ /h	0.4
Diesel Price, $/L	0.6

The calculation shows the analysis of cost for generator alone and it is shown in table V. The COE means the cost of energy savings, whereas the total NPC means the net price cost.

TABLE V
ANALYSIS OF COST FOR GENERATOR

Size of generator, kW	9
Initial Capital, $	9000
Operating Cost, $/yr	14777
Total NPC, $	197900
COE, $/kWh	0.781
Diesel, L	13321
8759	3.848

2) Batteries and Converter

The next equipment needed is batteries as storage. Sometimes the generator must be shut down in some circumstances. So the battery will operate the system. The battery is operating for generator. For this system, the battery used is Trojan L16P. This is a common deep-cycle lead-acid battery. About 12 batteries bank storage are considered, with the capital cost and the replacement cost is $220, respectively. The nominal voltage for each battery is 6V and the nominal capacity 360 Ah.

The converter also is needed since the batteries supplies the DC current. The converter size is 12kW and it can be used until up to 15 years with 90% efficiency. The inverter can be operated simultaneously with AC generator. The capital and replacement cost for this converter is $800.

Fig. 3 shows the connection of the battery to DC bus points in two directions to indicate that energy flows into and out of the battery. The same concept goes to converter. Now the generator is connected to the AC bus, the AC bus is connected to the village load and converter, the converter is connected to DC bus and finally directly to the battery.

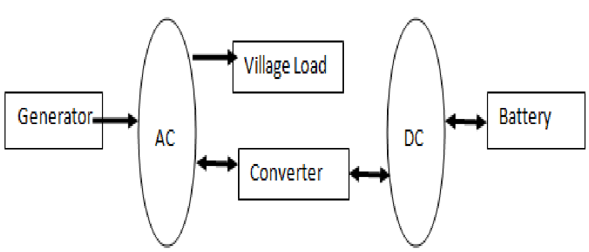

Fig. 3. The connection of battery, generator, converter and load.

The calculation by HOMER gives the system cost analysis. The analysis is including the size of generator, the unit of battery bank, converter size. The cost results will be in terms of initial capital, operating cost, total net price cost (NPC), operating cost, and cost of energy saving (COE). The result is shown in the Table VI.

The overall minimum initial cost for 4kW converter, 9kW generator and 12 battery banks unit is $14840. This is the only result by HOMER. The system can save the energy usage by $0.522. The operational cost is about $10830.

TABLE VI
SYSTEM COST ANALYSIS FOR GENERATOR, BATTERY, AND CONVERTER.

The most efficient system with the lowest cost energy saving	
Generator, kW	**9**
Battery, unit	**12**
Converter, kW	**4**
Initial Capital, $	**14840**
Operating Cost, $	**10830**
Total NPC, $	**153285**
COE, $	**0.522**
Diesel,L	**9497**

3) Photovoltaic System

Since Malaysia is situated at one of the most suitable climate location, the photovoltaic system can be applied in this project. To convert sunlight to electricity, PV panel should be applied in the system. They are to type of photovoltaic system, which is grid-connected system and standalone system. Fig. 4 shows the typical PV system. Sunlight strikes the solar collector panel. The process in the solar panel depends on its material. The higher the efficiency, the higher electricity can be produced. The DC current produced is then flow to charge controller and directly to battery storage, the battery connection means the system is standalone system, and flow to inverter to convert DC to AC current [8].

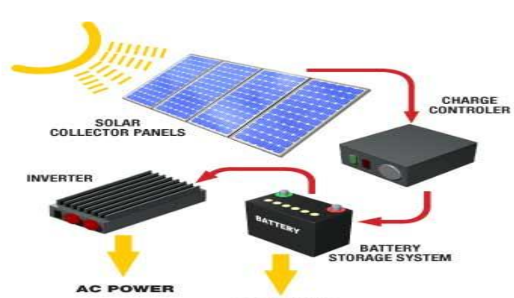

Fig. 4. Typical PV system

Before that, the solar radiation for the village is identified. For this simulation, the solar radiation data for bearing at 5º32'34.01"N and 101 º20'45.6"E, which is the village is located, is shown in Table VII and Fig. 5.

From Table VII, February and March show the highest solar radiation while the least solar radiation is on November with value of 4.927kWh/m^2/d [9].

TABLE VII
SOLAR RADIATION FOR EACH MONTH

Month	Solar Radiation, kWh/m^2/d
January	5.263
February	6.104
March	6.076
April	5.910
May	5.235
June	5.248
July	5.205
August	5.307
September	5.229
October	5.244
November	4.927
December	5.041
Average	**5.394**

Fig. 5 indicates the pattern of solar radiation from table VII. It is assumed that the solar radiation is constant every month. The solar radiation might change from time to time, depends on the climate and the weather of the location.

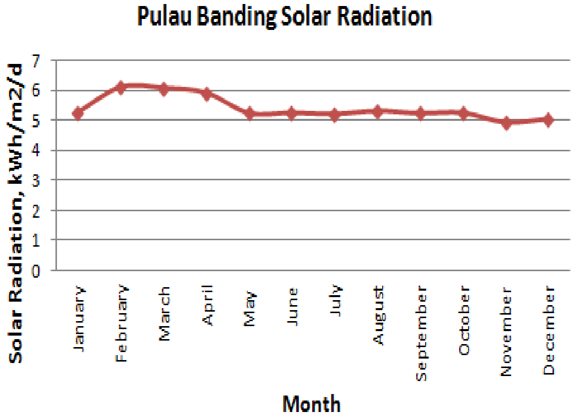

Fig. 5. Solar Radiation Received at Pulau Banding

After the solar radiation is identified, it is important to know what type of system is suitable for the settlement. Since the village is away from TNB grid-connected system, it is more suitable to use the stand-alone PV system. Standalone PV system is an independent system in which the system depends on the PV panel, and the battery.

The system design is then connected to the PV panel, Fig. 6, and its property is depends on the solar radiation received.

From the figure, the PV is added and it flows to the DC bus. The PV panel size is estimated at 1kW, with the capital cost and replacement cost is $7500. The PV panel can be applied for about 20 years.

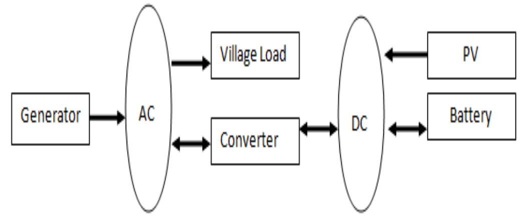

Fig. 6. The connection of Generator, Converter, PV and Battery

Table VIII shows the optimization results for 4, 8, 12 kW PV by HOMER. By using 4kW PV, 2kW generator, 12 battery banks and 4kW converter, the system can save the cost by $0.605 with initial capital is $37840. Although the operating cost for the system in column 2 displays HOMER is less than the operating cost for system in column 1, the COE is much higher.

TABLE VIII
0-4-8-12KW PV-GENERATOR OPTIMIZATION RESULTS

PV (kW)	4
Generator (kW)	9
Battery (unit)	12
Converter (kW)	4
Initial Capital ($)	14840
Operating Cost ($)	10830
Total NPC ($)	153285
COE ($)	0.605
Diesel (L)	9479

In order to check whether the cost of energy can be reduced or not, the PV array size is added since the system is very sensitive to the size of the PV array due to the expensive price of PV array. The PV array with size 2, 3 and 6 kW is added. The optimization is done step by step to get the exact value of system cost analysis. Table IX shows the optimization of 0, 2, 3, 4, 6, and 12 kW PV, generator, battery, and converter.

TABLE IX
0, 2, 3, 4, 6, 8, 12 KW PV-GENERATOR OPTIMIZATION RESULTS

PV (kW)	2
Generator (kW)	9
Battery (unit)	12
Converter (kW)	4
Initial Capital ($)	14840
Operating Cost ($)	10830
Total NPC ($)	153285
COE ($)	0.605
Diesel (L)	9497

The COE for both cases (Table VIII and Table IX) are the same, which is $0.605. The system is valid for 2kW PV, 9kW generator, 12 battery bank units and 4kW converter. For column 2 in table IX, there is a huge different of COE compared to column 1 in table IX. Yet, it is still can be considered to use the system.

4) Pico Hydro

The width of Banding Lake is about 5km with 124m deep. Its water velocity is approximately 0.645m/s. Fig. 7. The system is about to do a Pico hydro system since the number of houses is below than 50. Moreover, the village is at the edge of Temenggor Lake, which is suitable in order to support other systems. It is assumed that the flow rate of water is constant all the year with average displays by HOMER is 18L/s.

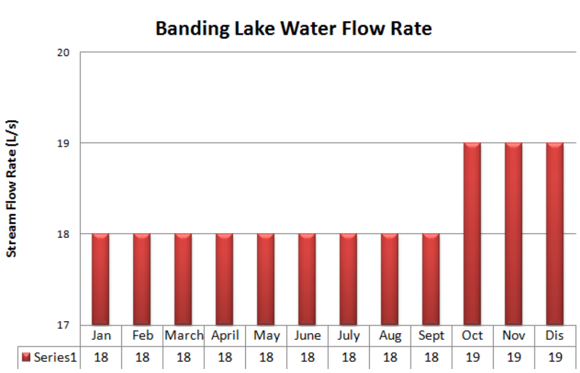

Fig. 7. Rate of Water Flow of Temenggor Lake

Fig. 8 shows the relation between all systems design, which is generator, battery, PV, converter and hydro. It is indicate that hydro system gives AC current.

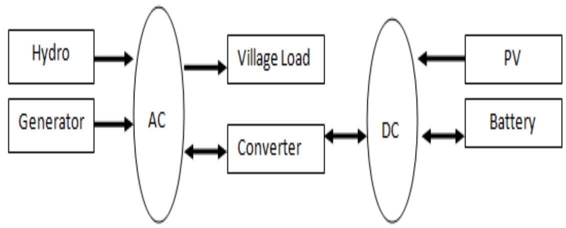

Fig. 8. Overall system

With 25 years of lifetime, the initial cost for Pico hydro is estimated to $3500 and the same number for replacement cost. The turbine efficiency displays by HOMER is 75% and its available head is 25m.

Table X shows the overall system cost analysis by HOMER. The cost of energy can be the value of $0.387 by using 2kW of PV, 2kW of generator, 12 units' battery banks, 4kW of converter, 3.31kW of hydro.

TABLE X
OVERALL SYSTEM COST ANALYSIS

PV (kW)	2
Generator (kW)	2
Battery (unit)	12
Converter (kW)	4
Hydro (kW)	4.78
Initial Capital ($)	11340
Operating Cost ($)	1122
Total NPC ($)	25688
COE ($)	0.101

The initial capital is $26340, the operating cost is $414 and its total NPC is $31632.However, the cost of energy saving can be more low if the system do not use a battery, but it is impossible since the generator needs the battery.

IV. RESULTS AND DISCUSSION

Overall, HOMER displays the simulation results. The system architecture suggested using 2kW of PV, 2kW of generator, 12 units' battery banks, 4kW of converter, 4.78kW of hydro, 4kW inverter and 4kW rectifier.

Fig. 9 indicates the cash flow by PV, hydro, generator, Trojan L16P and converter. PV has the highest capital cost, with the value of $1334/yr. whereas the lowest capital cost is by hydro and Trojan L1P6. The capital cost for PV is high because of the high construction and equipment, differently from hydro, which only using pumps and other small price equipment. The generator capital cost is quite high due to diesel usage.

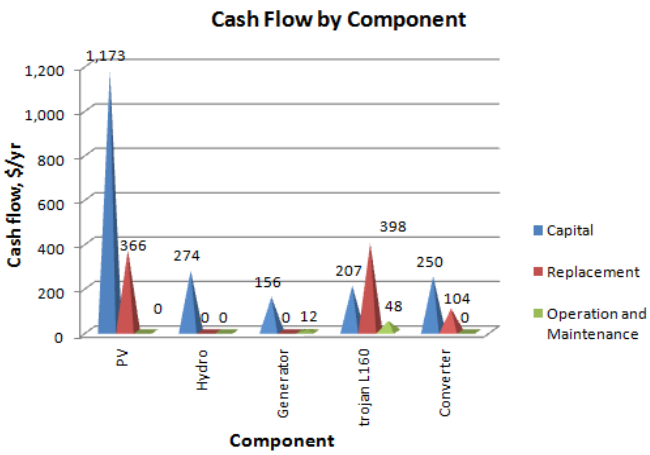

Fig. 9. Cash Flow by Component Summary

The replacement cost for PV is also high, while for hydro and generator is almost zero cost. Pico hydro component generally is a permanent component. It must have a good quality to avoid replacement. If the system needs to be replaced, the maintenance cost might be higher than that the components cost. Trojan L1P6 has the least NPC.

Fig. 10 shows the net present cost by PV, generator, hydro, Trojan L1P6, and converter. HOMER displays PV as a higher net present cost, and hydro has the lowest net present cost, because hydro needs not much maintenance per year, differently from PV, which is a very sensitive system that needs to be inspected from time to time.

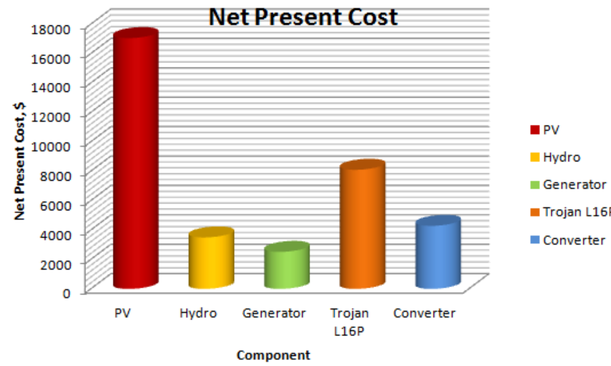

Fig. 10. Net Present Cost Summary

Fig. 11 represents the overall cash flow summary. PV has the highest annualized cost per year followed by generator, batter, converter and hydro. HOMER also displays that PV has the highest net cost. The total net price cost is $35463 with $714/yr. operating cost. The total annualized cost per year is $2774.

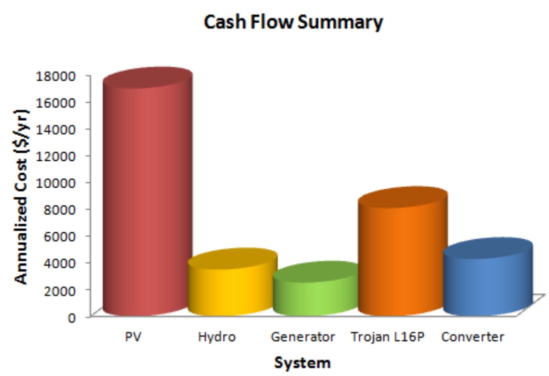

Fig. 11. Cash Flow Summary

Fig. 12 shows the electricity production by PV array, hydro turbine and generator. Even though hydro turbine has the least capital cost, its electricity production is the highest since the they are water flow source, in fact, Temenggor Dam is one of the biggest hydroelectric power stations.

PV contributes the electricity production of 11% or 3158kW/yr. PV arrays are depends on the climate and weather of the location. Another factor is the material of the PV panel. The high cost of the panel may constraint to the least usage of PV system. The generator contributes only 1% of electricity productions. The higher electricity production is hydro which 25064kW/yr.

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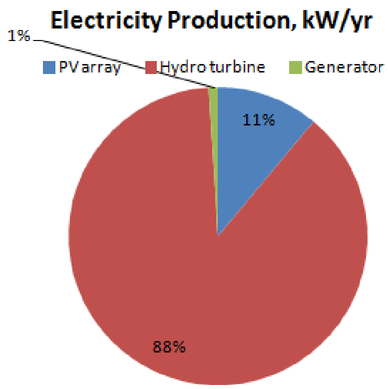

Fig. 12. Electricity Production by System

Fig. 13 indicates the emissions from diesel generator. The generator produces about 1554kg/yr. of carbon dioxide, 384kg/yr. of carbon monoxides and unburned hydrocarbon. Although it is a common problem for every diesel generator, research to lower the emission is still going on. It is important to the ecological and biological system.

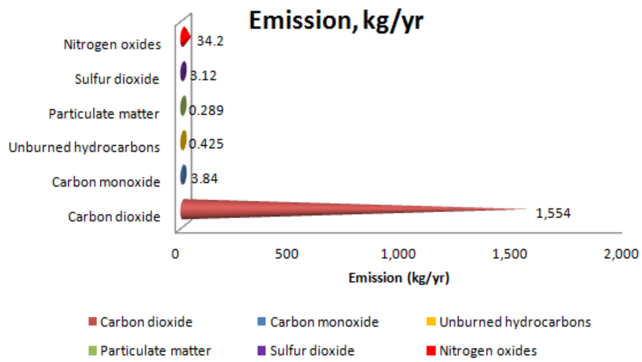

Fig. 13. Emission from Diesel Generator

V. CONCLUSION AND RECOMMENDATION

Solar, hydro, battery, converter and generator have been used to simulate the system design by using HOMER, in order to find the most optimize renewable energy at Kampung Chuweh, Pulau Banding, Gerik, Perak, which is Orang Asli village.

The overall electricity production is 28222kW/yr; with the total of net price cost is $31632 and $414/yr of operating cost. The total annualized cost per year is $2474. The system architecture suggested using 2kW PV, 3.31kW hydro, 2kW generator, 12 Trojan LI6P, 4kW inverter, and 4kW rectifier in as it is the most efficient system with the lowest cost.

There are several recommendations to the system. The location of Kampung Chewah is at the island. It is going to be a problem to bring the PV panel installation equipment. In fact, the capital cost for PV is high. So it is recommended that only hydro is installed for the settlement. According to electricity production, it is enough to cover the electricity for the whole village. In fact, the overall capital cost might be lower than this cost.

The emission from the diesel generator is high. It is recommended to use equipment that can reduce the emission, for example, by using carbon capture or any other equipment, in order to avoid Belum Forest ecological system from pollution.

All in all, the simulation is done successfully and it can be used for further research to enhance the system.

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