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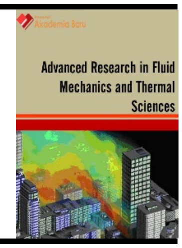

Renewable resource based decentralized power system to a remote village in Malaysia: Optimization and techno-economic evaluation

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ABSTRACT

A portion of rural and remote areas in Malaysia still do not have access to grid electricity and in near future they are unlikely to get grid access. Lack of electricity in rural areas jeopardises development and exacerbate the poverty. Decentralized off-grid rural electrification system that integrates various renewable energy sources became inevitable for areas where grid connection is neither available nor feasible. Moreover, designing and implementation of efficient and techno-economically viable off-grid electric supply is a challenging task. A hybrid combination of renewable energy technologies is appeared to be a suitable candidate over grid extension for remote areas. In this study, we model viable off-grid rural electrification system for a remote village Kampung Sungai Tiang located in Belum, Perak. We consider prospective electricity demand of the village and utilize available renewable resources to generate electricity to fulfil the demand. An optional diesel generator has been considered as backup power supplier whenever the renewable technologies cannot support the demand. This study implemented HOMER software to determine optimum electrification systems for the village and evaluate their techno economic performance. The simulation results reveal that Hybrid PV-Diesel-Biomass system is a better option to be implemented in this village in regard to viability, techno-economic performance, and environmental friendliness.

1. Introduction

Energy poverty and lack of electricity in the rural areas exacerbate the poverty in an emerging nation like Malaysia. In Malaysia, 3.8% of the total population are poverty stricken and most of them live in the rural areas. The electrification rate of Peninsular Malaysia is about 99.7% while Sabah and Sarawak are still low at 77% and 67%, respectively [1]. Electrification of the rural areas which do not have access to national electricity grid lines is important for the country's development. The access

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to electricity is dependent on various factors, which are social and geographical in nature, and the entire rural areas do not share similar geography and social indexes [2,3]. Some rural areas in Malaysia are located in mountainous areas and located far away from the national electricity grid. Providing them with electricity supply by connecting to the grid lines will not be economical as the installation, operation, and maintenance cost will be higher and installation of grid lines through thick jungles is not feasible [4,5]. As a solution, the rural community usually uses diesel generators for the electrification of the areas, but such solution has disadvantages such as high fuel and maintenance costs. Furthermore, the global price of these fuels always fluctuates as time passes, thus, the operational cost of a diesel generator is unpredictable. On the other hand, the usage of these fuel based electrification system also produces a lot of harmful gases like Carbon dioxide (CO2) and Carbon monoxide (CO) that pollute the environment [6]. Thus, renewable energy based electrification is considered as an alternative to the fossil-fuel based electrification as a way for clean, reliable and cost-effective electricity production.

Currently, Malaysia's electricity generation is led by two main resources, namely natural gas and coal, which are non-renewable resources and they cause a lot of GHG emissions [7]. Typically, 1 kWh of electricity production through coal releases 1 kg of carbon dioxide equivalent gases (CO2e) to the atmosphere. Malaysia is a tropical country, which endowed with enormous renewable energy potential such as solar, biomass and hydropower [8]. Despite the huge potential, the total renewable energy sources account for less than 10% of the total electricity production as of 2015 in Malaysia (Figure 1) [9–11]. These renewable energy sources should be properly utilized for the rapid development of the country and we should exaggerate this by utilizing in rural area electrification.

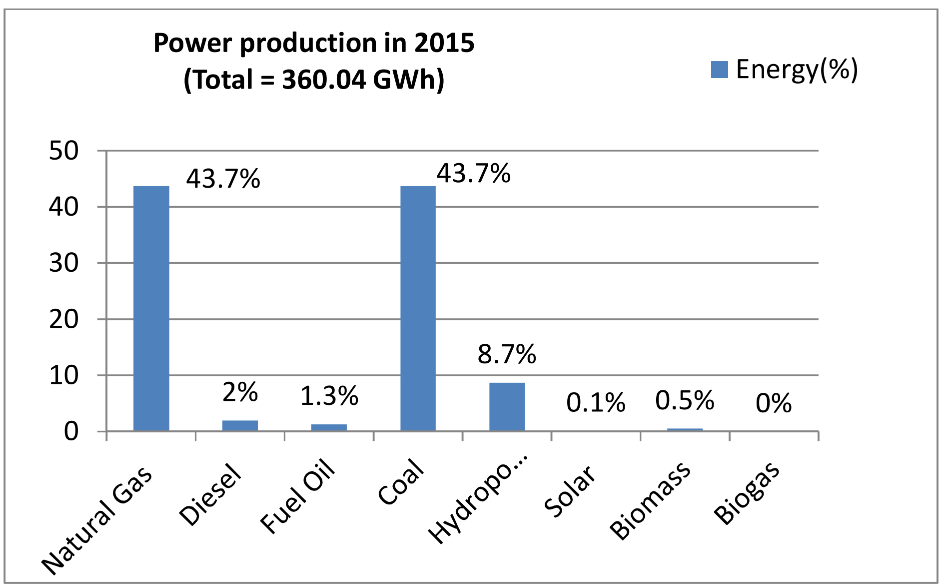

Fig. 1. Electricity production in Malaysia in 2013

Several studies [1,7,11–13] have reported renewable energy prospects and potential for rural electrification in Malaysia. Borhanazad *et al*. [10] assessed solar radiation intensity, wind speed and hydro potential of different States in Malaysia to be applied for rural electrification. Fadaeenejad *et al*. [12] found that combined photovoltaic-wind-battery system can be a cost-effective rural electrification alternative for villages in Malaysia. Neither of the studies has evaluated techno-economic performance of renewable resources to serve electricity to a specific island or village. In this study, we model an off-grid renewable resource based hybrid electrification system to serve electricity to the remote village, Kampung Sungai, with the use of HOMER software (Hybrid

Optimization Model for Electric Renewables). We also perform techno-economic evaluation of the proposed electrification system to examine its performance over existing diesel generator system. In this study, we also determine prospective electricity load profile of the village and assess the renewable energy sources to be available for electricity generation to input to HOMER software [14].

2. Methodology

2.1 Descriptions of the Remote Site

The off-grid rural area that has been under study is Kampung Sungai Tiang, a small aborigine's village located along Sungai Tiang in Belum Rainforest, Perak. The normal route to the village is via the lake way, from Gerik District to Lake Jetty Trojen Tasik Temenggor. The journey approximately takes around 3 hours on normal boats (located 8–10 km from mainland). Although, the place is famous for eco-tourism, the villagers are still much undeveloped. The details of the village are shown in the Table 1. Some of the houses are located in the small hilly areas while most houses are located in the flat areas. The village is located too far from national electricity grid making it unfeasible to connect it to supply electricity. So, the best possible way to provide electricity to the village is appeared as off-grid power system. Power supply is very essential for the residents of the village to serve their daily needs as well as to help boosting their economy such as handicrafts and herbs production, where they only have time to process their products at night. School also requires proper electricity connection in order to provide good study environment to the children. For years, these reasons made the villagers to choose standalone diesel generators as a power supply option since it is not connected to national electricity grid [15,16].

Table 1
Details about the selected village

Particulars	Details
Village	Kampung Sungai Tiang
District	Hulu
State	Perak
Country	Malaysia
Latitude	5°31'09.2"N
Longitude	101°26'18.2"E
Rivers available	Yes
Grid electricity	No
Number of Households	66
Population	409
Ethnic	Jahai
Average household's monthly income	RM 600 (100% live in poverty)

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2.2 HOMER Software

HOMER is a small and micro power system optimization model, which was developed by the National Renewable Energy Laboratory (NREL), USA to design small power system and perform the techno economic evaluation of various power generating technologies [14]. HOMER models the power systems characteristics and life cycle cost based on the data inserted by the users. Life cycle cost can be defined as the total costs of installing and operating the system for a particular lifespan [13]. Based on the simulation results, the user can make comparisons between many design alternatives based on their technical and economic merits depending on the need of the user.

A small or micro power system is a system that produces electricity to serve a load, which can be a building, a residential area or a town. It is a system that can be designed and built using any of the various combinations of electrical power generation and storage. HOMER can be used to model grid connected and also off-grid micro power systems serving electrical loads. The purpose of using HOMER is because the analysis and design phase of a micro power system can be really difficult, due to the combination of variety of design options and variability in the load demand. Apart from that, from renewable energy point of view, it is more difficult to perform analysis due to the transient nature of renewable energy such as sunlight [17]. HOMER performs its tasks in three major steps:

a) Simulation: In this stage, it determines all the technical configurations that are feasible
b) Optimization: It selects the configurations with lowest life cycle cost
c) Sensitivity analysis: In this stage, it examines the effects of uncertainty of sensitivity variables such annual real interest rate, component prising, solar irradiation etc. on decision variables.

Figure 2 illustrates the architecture of HOMER, which is composed of three main segments such as inputs, simulation and outputs.

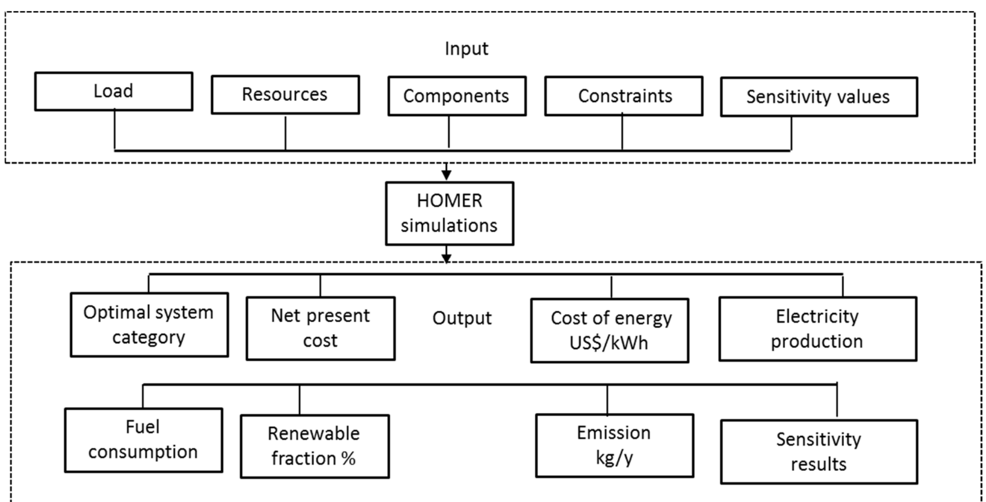


Fig. 2. The architecture of HOMER software

2.3 Applied Data for Power Generation Options

Malaysia has an abundant potential for using renewable energy resources, such as solar, wind, hydro, biomass and tidal [6,12,13]. Descriptions of major renewable energy sources are presented in the following sections.

2.3.1 Solar energy

Solar radiation data is a famous subject of study in Malaysia. Malaysia's favourable conditions are suitable for utilisation of Photovoltaic (PV) systems due to high amount of solar radiation received throughout the year. Considering global average, Malaysia's solar radiation is high, which ranges from 1470 kWh/m² per year to 1900 kWh/m² [17]. Moreover, since renewable energy is clean, it is estimated that one square metre of solar panel in Malaysia can result in an annual reduction of 40 kg of CO_2e emission. Table1 shows annual average solar radiations received among big cities in Malaysia. Kota Kinabalu has the highest annual average value of solar radiation among the cities. The solar resource data were used for Kampung Sungai Tiang is at a location of 5° 41' 32.2"N latitude and 101° 26' 32.9994"E longitude. The annual average solar irradiation was scaled to be 5.33 kWh/m²/day and the average clearness index was found to be 0.536. The highest solar irradiation estimated at (6.036 kWh/m² per day) in February and the lowest is at (4.873 kWh/m² per day) in December.

2.3.2 Wind power

Another free available energy source that can be utilized for rural electrification is wind energy, however, some uniform periodic changes in the wind flow patterns were observed. Based on these changes, four seasons can be distinguished, namely, the southwest monsoon, northeast monsoon and two shorter periods of inter-monsoon seasons. According to a study, due to Malaysia's location, the mean wind speed is low and lower than 2 m/s [18]. However, wind does not blow uniformly throughout year and varies according to place and time. Strongest winds blow in East Cost of Peninsular Malaysia. Although wind speed in Malaysia is quite slow, it is still can be utilised to generate electricity especially for rural areas in East Coast Malaysia with an average wind speed at 15.4 m/s. The greatest wind power location is Mersing and Kuala Terengganu. As Malaysia is mainly a maritime country, the effect of land and sea breezes on the general wind flow pattern is very marked especially during days with clear skies. On bright sunny afternoons, sea breezes of 10 to 15 knots very often develop and reach up to several tens of kilo meters. On clear nights, the reverse process takes place and land breezes of weaker strength can also develop over the coastal areas. These situations should be well utilized by generating energy through the wind power. Although having inconsistent average wind speeds throughout the year, the site has quite sufficient wind source which indicates the possible installation of wind turbine for electrical generation in the area to supply the demand of load. The annual average wind speed at the village is 2.29 m/s.

2.3.3 Biomass

Since the village is surrounded by vast area of forests, most of the villagers visit the forests (collecting woods to make handicrafts, and herbs) in daily basis, it is a good idea of having a biomass system as a power generation option. Forest wood is considered as a main source of biomass in the biomass system as it is easily available in the forest. The average amount of wood is taken at a weight of 100 kilograms per day for every month. Although 100 kilograms per day is still low, but it is acceptable as the wood source may not be constant all the time [19].

2.3.4 Hydropower

Hydropower is one of the most cost-effective, reliable, predictable and least environmentally intrusive among all renewable energy technologies that can be considered for rural electrification in less developed countries. As Malaysia receives sufficient amount of rainfall, hydropower is well-suited to apply in rural areas in Malaysia [2]. Malaysia is blessed with around 150 river systems and 50 river systems in Sabah and Sarawak regions with annual rainfall at 2000 mm compared to the world's average rainfall at 750 mm. Thus, potential for hydropower electric generation is high in Malaysia.

2.4 Electricity Loads

Power consumption for this rural area is based on simple appliances. The people in this village require electricity mainly for lighting purposes, TV, fan, refrigerator and few others. A load profile was build based on the informal survey on the villagers regarding their intended and prospective use of electrical appliances. Figure 3 shows the proposed residential hourly load profile for the village for an average household.

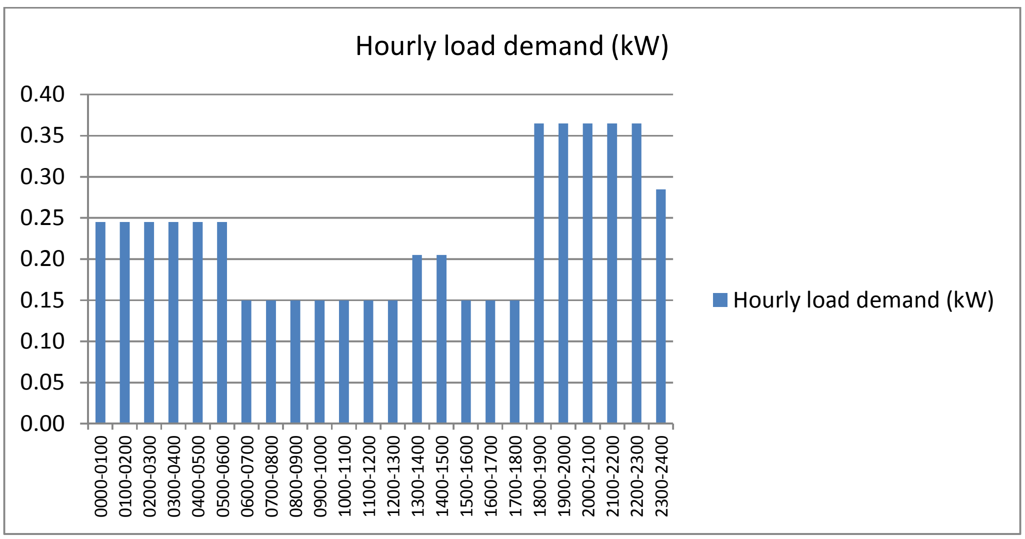


Fig. 3. Hourly-load demand (kW) for an average household in the village

As seen from the Figure 3, the usage is lowest during daytime from 6am to 1pm and 3pm to 6pm. There is slight increase in usage during 1-3pm which is lunch hour of the villagers. The peak hours of power consumption lasts for approximately 5 hours starting from 6pm to 11pm when simultaneous loads from refrigerator, television, fan and lighting enact. The total daily average power consumption of the village accounts to 5.49 kWh/day (Table 2).

A random variability factor is input to HOMER for estimating the differences that may be encountered each day when using the load profile. They are known as day-to-day variability and time-step-to-time-step variability, with each approximated to be around 10% and 15%, respectively. The variability inputs results in an average power requirement of 360 kW/day and daily 38kW peak load demand in HOMER. This variability is important as the actual load pattern is might change from time to time [20].

Table 2
Important details of the village load

Particulars	Values
Average load per household (kWh/d)	5.49
Average load for 66 households (kWh/d)	362.34
Peak load per household (kW)	0.365
Peak load for 66 households (kW)	24.09

2.5 System Components

A range of typical power system components are selected including Solar Panel, Wind turbine, Diesel generator, Biomass generator, a Battery bank, and Converter.

2.5.1 Photovoltaic

HOMER requires information regarding the PV array such as the capital cost, replacement cost, operation and maintenance cost, the range of size of PV array and the lifetime of the PV array as the input of the simulation. The cost of standalone photovoltaic in the market ranges from a minimum of RM 2000 to a maximum RM 12000/kW. A cost of RM 9000 per kW was selected for this study, which includes the installation costs, connecting wire costs and others (Table 3). The size of PV array that was considered in this study was limited from 30 kW to 120 kW, which is taken after doing preliminary runs.

Table 3
Photovoltaic panel specifications

Particulars	Descriptions
Model	Jinko Eagle 72
Type	PID Free Polycrystalline, 72-cell Module
Maximum power	335 W peak
Cell type	Polycrystalline
Price	RM 9000 per kW peak
Lifetime	25 year life
O&M costs	RM50/year

2.5.2 Battery

The types of battery used in this study were Surrette 6CS25P batteries. The capacity of this battery is 6.94 kWh and the lifetime of the batteries would be 12 years. The batteries have a full depth of discharge and the cost of each unit is RM5000. The batteries arranged in a string and each string has 10 batteries. The size of batteries that was considered in the optimization process was big and ranges from 10 units to 200 units, since there is no limitation on number of batteries that can stacked together [21].

2.5.3 Diesel and biogas generator

There are a lot of choices of diesel generators, a high quality and affordable generator, Cummins generator was chosen in this study. A 40 kW diesel generator is selected and is chosen as it should always support village peak load 37 kW and the biomass generator of size 10 kW, 20 kW, 30 kW, 40 kW and 50 kW was chosen. Table 4 shows the details of the selected generators.

Table 4
Diesel and biomass generator specifications

Generator fuel	Particulars	Descriptions
Diesel generator	Model	Cummins Generator
	Rated power	40 kW
	Price per unit	RM 20,000.00
	Lifetime	15 years
	O&M costs	RM 0.129/hour
Biogas generator	Model	Cummins Generator
	Rated power	40 kW
	Price per unit	RM 20,000.00
	Lifetime	15 years
	O&M costs	RM 0.129/hour

2.5.4 Wind turbine

The suitable wind turbine that has been selected for the village were Enercon E33 because it has ability to function in low wind speeds compared to other standard wind turbines, since the average wind speed in the village is considered as low at 2.29m/s. Table 5 shows the details of the selected wind turbine.

Table 5
Wind turbine specifications

Model	Enercon E33
Rated Power	330kW
Hub height	44 m
Number of Blades	3
Price	RM 380,000 /unit
O&M costs	RM 500/year

2.5.5 Inverter

A power electronic converter is used to maintain the flow of energy between the AC and DC busses. These units turn DC power into conventional AC power, as well as provide backup power during a power outage. When an electrical appliance is used is only accesses the DC power where an inverter with same nominal voltage as the battery is appropriate. For standalone system, the inverter must be large enough to handle the total amount of watts to be used at one time. The price of RM815 is chosen according to the current market price of inverter.

2.6 Operational Strategies
2.6.1 Existing system

The existing system in the village that is standalone diesel generator system is using the 40 kW rated generator for the electrical power supply. In this simulation, the diesel generator is set to produce electrical energy only from 7 am to 8 pm all days and forced off in the rest of the period as shown in Figure 4. This setup is done as to avoid noisiness during night time when most villagers are at home during night and also to ensure good comfort of sleep. This system uses cycle charging dispatch strategy which means, when the generator runs, it runs at maximum power and charges the batteries connected. While the generator is forced off, maintenance program can be done during night since the village obtains electrical energy from battery after charging from the generator.

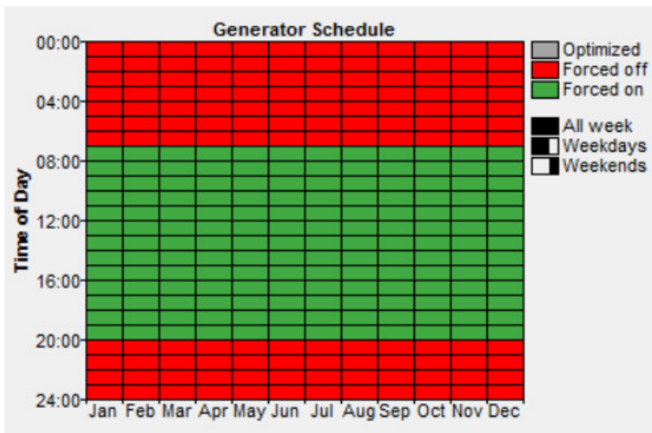


Fig. 4. Generator schedule for standalone diesel generator system

2.6.2 Proposed options

The optimized systems are hybrid PV-Wind-Biomass and hybrid PV-Diesel-Biomass systems and only hybrid PV-Diesel-Biomass system is using Diesel generator. This system differs from the standalone diesel generator system in terms of generator schedules and dispatch strategies. Hybrid PV-Diesel-Biomass system is using generator that is using optimized run time as shown in the Figure 5.

This means, it does not have fixed on/off timings as it functions to support additional power required by the village load whenever the renewable energy technologies cannot serve it. This hybrid system also uses load following dispatch strategy whereby whenever a generator operates, it produces only enough power to meet the primary load. Lower-priority objectives such as charging the battery bank or serving the deferrable load are left to the renewable power sources.

2.7 Economic Analysis

Economic analysis is an integral part of HOMER's simulation process, whereby it operates the system such as to minimize the total net present cost. In the optimization process, the software was used to analyse the system configuration with the least total net present cost. This section discusses the equations that were used in determining the costs. The project lifetime is taken to be 25years.

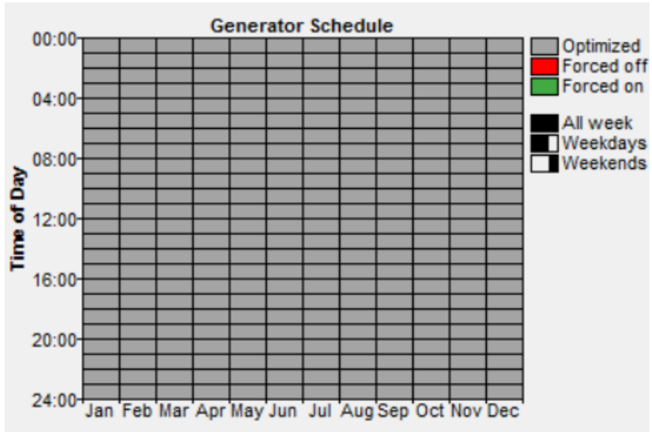


Fig. 5. Generator schedule for hybrid PV-Diesel-Biomass system

2.7.1 Annual interest rate

The annual interest rate is the discount rate which was used to change onetime costs into annualized cost and vice versa. The calculation is done based on Eq. (1). In Eq. (1), f is annual inflation rate, i` is the nominal interest rate and i is real interest rate. Current Malaysian annual interest rate is at 3%.

Annual real interest rate,

$$i = \frac{i' - f}{1 + f} \tag{1}$$

2.7.2 Net present cost (NPC)

Net present cost is the cost of installing and operating the system in its lifetime in the project that is referred to lifecycle cost. The result of optimization was based on net present cost and was calculated using Eq (2) and (3).

$$C_{NPC} = \frac{C_{annual.total}}{CRF(i, N)} \tag{2}$$

$$CRF(i, N) = \frac{i(1+i)^N}{(1+i)^N - 1} \tag{3}$$

As shown in the equation $C_{annual,total}$ is the total annual cost, which includes all the costs. Meanwhile, CRF is the capital recovery factor, which was used to calculate present value of series of annual cash flow, i is the interest rate and N is the lifetime of the project in years. The lower the NPC, the better the system is.

2.7.3 Cost of energy (COE)

Cost of energy is the average cost per kilowatt hour of electrical energy produced by the system which is useful. It was calculated using Eq. (4).

$$COE = \frac{C_{annual,total}}{E_{primary,AC} + E_{primary,DC}} \tag{4}$$

In Eq. (4), COE is the cost of energy, meanwhile Eprimary,AC is AC primary load served and $E_{primary}$, DC is the DC primary load served. The system is considered economically good if it is able to produce low COE values.

2.8 Constraints Input

2.8.1 Maximum annual capacity shortage

A capacity shortage is a shortfall that occurs between the required operating capacity and the actual amount of operating capacity the system can provide. The maximum annual capacity shortage is set at 5% implies that there are chances maximum 5 per cent in the year there could be electricity shortages (blackouts). This value is practical because if the maximum annual capacity shortage is set to zero, HOMER will size the system to meet every load including very high peak loads. This could mean that the system has to include large, expensive equipment that is not fully used most of the time. If you allow a small amount of capacity shortage, HOMER could choose to install smaller, less expensive equipment that would be able to supply all but that peak load.

2.8.2 Operating reserves

Operating reserve is surplus operating capacity that can instantly respond to a sudden increase in the electric load or a sudden decrease in the renewable power output. Operating reserve provides a safety margin that helps ensure reliable electricity supply despite variability in the electric load and the renewable power supply. In this study, for load, hourly load is set at 10% and solar and wind power outputs are set at 25% and 50% respectively.

3. Results and Discussion

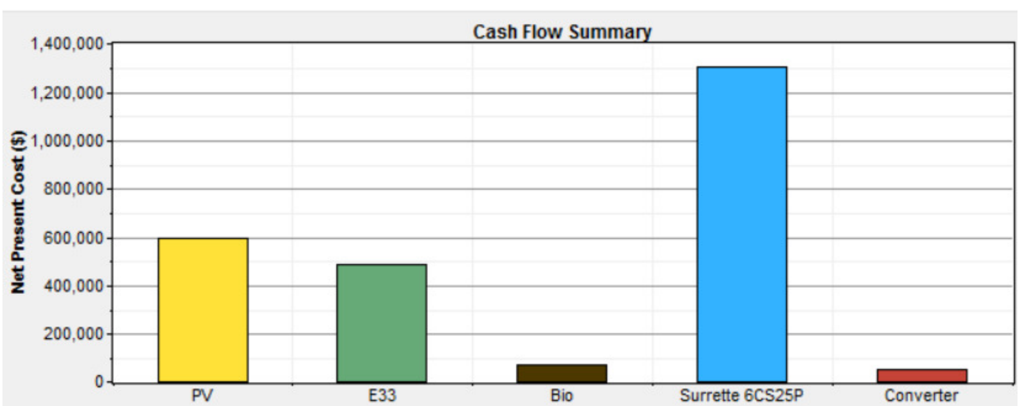
The simulation results give that Hybrid PV-Wind-Biomass and Hybrid PV-Diesel-Biomass systems are the two best possible options to supply electricity to the Kampung Sungai Tiang village. Hybrid PV-Wind-Biomass system has the lowest Net Present Cost (NPC), and lowest Cost of Energy (COE) with entirely renewable energy based system. The second system is hybrid PV-Diesel-Biomass system with slightly higher NPC and COE and with 0% capacity shortage, which means there is no chances of electricity shortages (blackout) occurs throughout the year, the electrical reliability of the system is good. The hybrid PV-Diesel-Biomass system also modifies the existing system in a way that the generator supports the system whenever it requires additional power, for example in peak hours where the load demand might exceed the power generation. This system can make use of the readily available generator rather than disposing it.

3.1 Optimized System Descriptions
3.1.2 Hybrid PV-wind-biomass

The system configuration of Hybrid PV-Wind-Biomass system is presented in Table 6. This is entirely renewable based system, have a total NPC of RM 2,497,495 and COE of RM 1.126 per kWh. Compared to the standalone diesel generator system, this system has lower NPC, and COE/kWh. Figure 6 shows the breakdown of NPC for the hybrid PV-Wind-Biomass system. Big portion of the NPC is incurred by batteries, as this system requires 140 batteries to operate compared to the 80 batteries in standalone diesel generator system. In terms of operational costs, this system only requires RM 45,543 per year, about 4 times lower amount compared to the standalone system. Monthly average electricity production from different sources for hybrid PV-Wind-Biomass system is presented in Figure 7.

Table 6
System configuration of Hybrid PV-Wind-Biomass system

Particulars	Descriptions
PV Array	60 kW
Wind turbine	1 Enercon E33
Biomass	40 kW
Battery	140 Surrette 6CS25P
Inverter	30 kW
Rectifier	30 kW
Dispatch strategy	Cycle Charging



Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
PV	540,000	0	52,239	0	0	592,239
Enercon E33	400,000	210,397	8,707	0	-136,118	482,986
Biomass	40,000	0	35,042	0	-6,686	68,356
Surrette 6CS25P	700,000	835,320	73,135	0	-306,464	1,301,992
Converter	24,450	15,694	15,672	0	-3,892	51,923
System	1,704,450	1,061,410	184,795	0	-453,160	2,497,495

Fig. 6. Breakdown for the hybrid PV-Wind-Biomass system

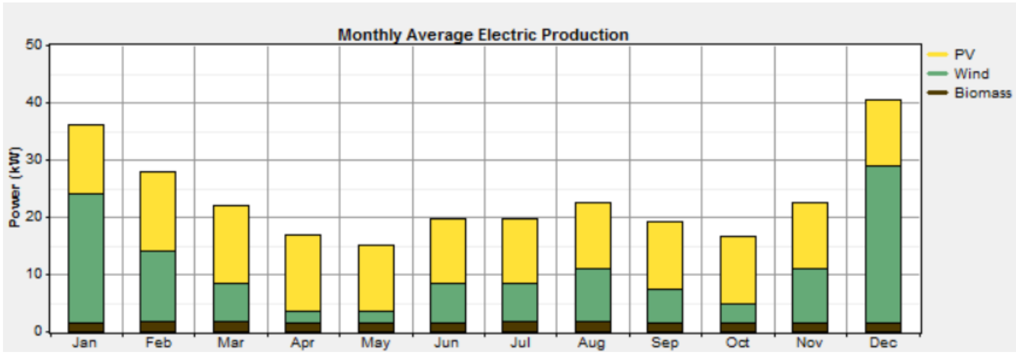


Fig. 7. Monthly average electric production for hybrid PV-Wind-Biomass system

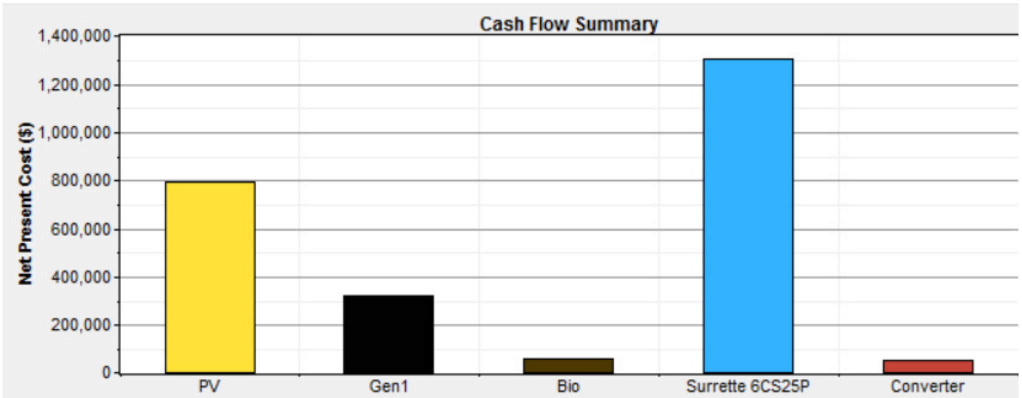
Most of the electricity is generated by PV panels and wind turbines whereas the biomass is low because its resource is set limited at 100 kg per day. Up to this point, it should be highlighted that most of the load demand occur at night time, which is when the PV is not available. But the system can still support the load by having the biomass and wind turbine system and also through charged batteries. Note that the system is running on Cycle charging dispatch strategy which means the batteries are charged simultaneously as the load is being served, so that the charged batteries can be used to support the extra demand of load along with the PV panels, wind turbines or biomass generators. For example, in a rainy day, when the PV panels and wind turbines cannot be utilised, the batteries will support and serve the load along with biomass generator.

3.1.2 Hybrid PV-diesel-biomass

The system configuration of Hybrid PV-Wind-Biomass system is presented in Table 7. This system supplies power through both renewable and non-renewable energy sources. The NPC of the system for 25 years is RM 2,516,926 and COE of RM 1.1 per kWh (Figure 8). Almost half of the NPC comes from batteries, as the large number of 140 batteries costs big amount of money to be spend at the start of the project and also while replacing them every 12 years in the 25 years lifetime.

Table 7
The system architecture of Hybrid PV-Diesel-Biomass system

Particulars	Descriptions
PV Array	80 kW
Diesel Generator	40 kW
Biomass	10 kW
Battery	140 Surrette 6CS25P
Inverter	30 kW
Rectifier	30 kW
Dispatch strategy	Load Following



Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
PV	720,000	0	69,653	0	0	789,653
Diesel Generator	32,000	17,690	67,209	212,806	-11,513	318,191
Biomass	10,000	13,071	34,278	0	-2,181	55,169
Surrette 6CS25P	700,000	835,320	73,135	0	-306,464	1,301,992
Converter	24,450	15,694	15,672	0	-3,892	51,923
System	1,486,450	881,774	259,947	212,806	-324,051	2,516,927

Fig. 8. Total NPC for the hybrid PV-Diesel-Biomass system

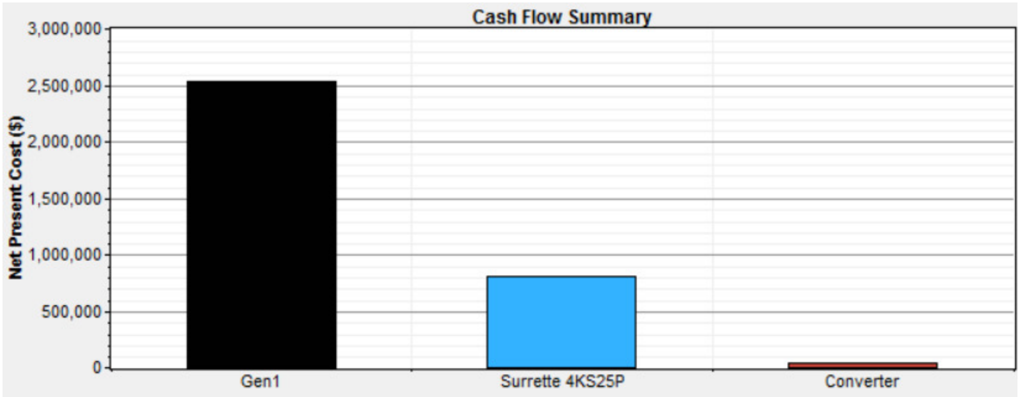
In terms of effective use of electrical power, diesel generator is the most effective system because it produces no excess electricity while unmet load and capacity is near to zero. The hybrid PV-Wind-Biomass system produces very high excess electricity at 29.5% of total electricity and this cannot be avoided as it occurs when there is a surplus of power being produced by the system and the batteries are unable to absorb it all. Its unmet electric load is also considered quite big compared to other systems but is still under critical value/acceptable.

3.1.1 Standalone diesel generator system (existing system)

The system configuration of existing diesel generator system is presented in Table 8. Currently, the villagers are using this standalone diesel generator system. From the simulation result shown in Figure 9, the use of standalone diesel generator system, is costlier compared to standalone PV system, with total NPC at RM 3,383,949 and COE at RM 1.483/kWh. The initial capital cost of this system is RM 444,450, where big portion of it comes from battery purchase cost. Operating cost per year accounts at staggering RM 168,809, as most of the cost comes from generator's fuel. Note that the diesel price is set at RM2.02/litre. Figure 9 shows the breakdown of NPC for the system.

Table 8
System configuration of existing diesel generator system

Particulars	Descriptions
Generator 1	40 kW
Battery	80 Surrette 4KS25P
Inverter	30 kW
Rectifier	30 kW
Dispatch strategy	Cycle Charging



Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
Generator 1	20,000	84,110	426,347	1,999,170	-751	2,528,876
Surrette 4KS25P	400,000	511,454	13,931	0	-111,786	813,599
Converter	24,450	15,694	5,224	0	-3,892	41,475
System	444,450	611,258	445,502	1,999,170	-116,430	3,383,950

Fig. 9. Total NPC for the standalone diesel generator system

It should be noted that the high portion of NPC comes from Generator, where the fuel cost is the highest among the generator sub-costs at RM 114,808 per year. Note that the capacity shortage is at 1% which implies that there are 1% chance of power cut equivalent to 821 kWh/year, shortage occurs throughout the year ,which is still at acceptable limit. Figure 10 shows the monthly electric production for standalone diesel generator system and we can see the generation of power matches the monthly load requirement

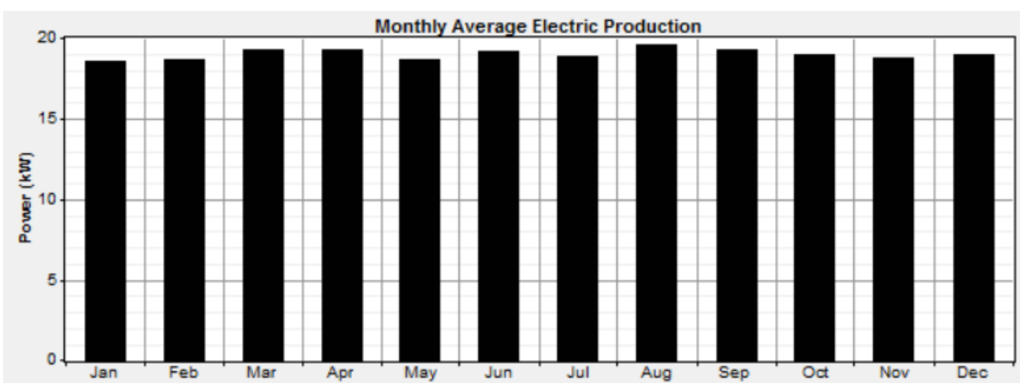


Fig. 10. Monthly average electric production for stand-alone diesel generator system

3.2 GHG (Greenhouse gas) Emissions

The renewable based hybrid systems save huge amount of greenhouse gases and other emissions (Table 9). This means that if the emission savings are credited through carbon pricing or emission saving certificate it results a huge monetary saving for the new systems. The emission saving effects on the price of per unit of electricity generation provided that emission pricing are accounted in country's energy policy.

Table 9
Comparison of the emissions of the three systems

Pollutants	Emissions (kg/y) Standalone Diesel Generator (existing)	Pollutants	Emissions (kg/y) Standalone Diesel Generator (existing)
Carbon dioxide	149 667	Carbon dioxide	149 667
Carbon monoxide	369	Carbon monoxide	369
Unburned hydrocarbons	40.9	Unburned hydrocarbons	40.9
Particulate matter	27.8	Particulate matter	27.8
Sulphur dioxide	301	Sulphur dioxide	301
Nitrogen oxides	3296	Nitrogen oxides	3296

4. Conclusions

The simulation results give that Hybrid PV-Wind-Biomass and Hybrid PV-Diesel-Biomass systems are the two best possible options to supply electricity to the Kampung Sungai Tiang village. Among these two options, Hybrid PV-Wind-Biomass option is a fully renewable energy based system that has lowest Net Present Cost (NPC) and lowest Cost of Energy (COE) with one constraint such that it has 5% annual capacity shortage. On the other hand, Hybrid PV-Diesel-Biomass system has fossil fuel share, slightly higher NPC and can serve the village with 0% capacity shortage. Considering the fact that Hybrid PV-Diesel-Biomass having NPC and COE only slightly higher than the hybrid PV-Wind-Biomass system and having the advantage of 0% annual capacity shortage, it can be selected as the best system to be implemented in the village.

When comparing the hybrid PV-Diesel-Biomass system to the existing standalone diesel generator system, the hybrid system offers a lot of advantages. The diesel generator system is expensive as its NPC is more than RM 3millions. This is contributed by the annual operating cost of the diesel generator system which is almost 4 times higher than the Hybrid PV-Diesel-Biomass system due to its high fuel costs. The hybrid system also offers COE value RM 0.38 cheaper than the existing diesel generator system. The Hybrid PV-Wind-Biomass system is the environmental friendly system with 100% renewable power sources and zero harmful gas emissions, however, it has capacity shortage constraints. Despite, the Hybrid PV-Diesel-Biomass system is not completely emission free, however, it saves huge emissions comparing to the existing diesel generator system. With a projection period of 25 years and 3% annual interest rate, it is found that the use of hybrid PV-Diesel-Biomass system could serve electricity with significantly lower COE as compared to the standalone diesel system. In sum up, the Hybrid PV-Diesel-Biomass system is the best alternative in replacing or upgrading existing stand-alone diesel system in the studied village.

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