Journal of Advanced Research in Applied Sciences and Engineering Technology

Journal homepage:
https://semarakilmu.com.my/journals/index.php/applied_sciences_eng_tech/index
ISSN: 2462-1943

An Analysis of Hybrid Renewable Energy System Using HOMER Pro: A Case Study in Sungai Tiang Camp, Perak

Nur Farzana Athirah Mohd Fadzli[1], Azlin Mohd Azmi[2,3,*], Nofri Yenita Dahlan[1,3], Zubir Ahmad Mohd Ismail[4], Sreenath Sukumaran[5]

[1] School of Electrical Engineering, College of Engineering, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia
[2] School of Mechanical Engineering, College of Engineering, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia
[3] Solar Research Institute, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia
[4] Perbadanan Taman Negeri Perak, Kompleks Bangunan Kerajaan Negeri Perak, JKR 341 Jalan Sultan Abdul Aziz, 33000 Gerik, Perak Darul Ridzuan, Malaysia
[5] Department of Energy Technology, Tallinn University of Technology (TalTech), 19086 Tallinn, Estonia

ARTICLE INFO

Article history:
Received 23 April 2023
Received in revised form 15 July 2023
Accepted 22 July 2023
Available online 7 August 2023

ABSTRACT

An extraordinary worldwide shift is occurring in the twenty-first century, as people increasingly turn to renewable energy sources. However, hybrid renewable energy system (HRES) development in rural regions is technically difficult and financially expensive to provide energy access. Due to the various components necessary to produce a hybrid system, its construction is often costly. As the remote areas depend on unsustainable diesel-fuelled generators, they have greater operational expenses than non-remote areas due to the higher cost of diesel and the longer distances needed to transport the fuel. This work focuses on modelling a hybrid renewable energy system that is economically sustainable, environmentally friendly and technical consideration is taken into the design requirements. The energy cost ($/kWh) and lifecycle emission CO_2 (kg/year) are considered as economic and environmental indicators, respectively. In addition, a sensitivity analysis for varied diesel fuel price ($/L) and PV capital cost of the HRES is performed to achieve a more feasible configuration. To obtain a system that can fulfil demand while meeting specific technical requirements, three configurations are evaluated: 1) standalone diesel generators, 2) hybrid PV-Diesel without battery and 3) hybrid PV-Diesel with battery. This study proposed system 3 as the best system architecture due to the lowest value of COE of 0.258$/kWh and NPC of $22,130. A solar photovoltaic (PV) and lead acid (LA) battery-based hybrid renewable energy system is suggested to fulfil the camp facility load demand of 14.92kWh/day in a rural area of Sungai Tiang, Perak. Sensitivity analysis findings show that LCOE and NPC values are substantially responsive to fuel price and PV capital cost. Integrated solar and battery technologies can enhance the economic performance (e.g., NPC, COE), environmental performance (e.g., carbon dioxide emissions), and technical performance (e.g., fuel consumption) of a renewable energy system.

Keywords:
HRES; rural area; HOMER Pro

* *Corresponding author.*
E-mail address: azlinazmi@uitm.edu.my

https://doi.org/10.37934/araset.31.3.7992

1. Introduction

In recent years, escalating environmental degradation, energy consumption, fuel prices, and the decline in fossil fuel reserves have increased interest in renewable energy systems. The negative impacts of greenhouse gas (GHG) emissions may be felt beyond the boundaries of the nation, and the effects of climate change on countries might differ substantially from one another. A number of climate change initiatives have been initiated to combat global warming and decrease greenhouse gas emissions throughout the globe. Similarly, Malaysia plans to cut greenhouse gas emissions by 45% by 2030 [1,2]. In addition, Malaysia has begun the process of aligning the 12th Malaysia Plan (2021-2025) with the nation's sustainable development objectives. The electrification of industries and services using renewable energy may have an immediate and large effect on carbon emissions as more energy used to supply demand. Presently, around 19.7% of the world's ultimate energy consumption is accounted for by electricity; by 2050, this percentage might increase to 50% [3,4]. An extraordinary worldwide shift is occurring in the twenty-first century, as people increasingly turn to renewable energy sources. However, hybrid renewable energy system (HRES) development in rural regions is technically difficult because of the challenging terrain of the cable and financially expensive to provide energy access due to the dependency on diesel-fuelled generators that have greater operational expenses than non-remote areas due to the higher cost of diesel and the longer distances needed to transport the fuel [5-8]. In addition, due to the various components necessary to produce a hybrid system, its construction is often costly. The growth of renewable energy systems (RES) is severely constrained by the system's sustainability and the capability of local diesel generators to accommodate the instantaneous, intermittent production of renewable sources.

Developing an HRES includes a variety of factors, including component size and rating, mode of operation, material selection to enhance system dependability, cost minimization, and emission reduction. In 2022, Sharma *et al.,* [9] conducted the optimum size of HRES by minimizing the cost using multi-objective dynamic optimization. Of the several goals listed, the optimal sizing of the HRES has been widely researched in the literature. A detailed evaluation of integrated techno-economic-environmental-society architecture of India's hybrid renewable energy system by Kushwaha *et al.,* [10] showed that an appropriate dispatch method was needed to execute the programme for telecommunication. Along the same line, Hassan *et al.,* [11] did a similar optimum sizing analysis on the economic-environmental-social optimization for off-grid hybrid Photovoltaic (PV)/wind/hydro/biogas systems.

Several studies reported in literature have employed different types of algorithms such as particle swarm optimization (PSO) as conducted by Alshammari *et al.,* [12] in modelling HRES. Sharma *et al.,* [9] however, used multi-objective optimization formulation for in their study on HRES. In contrast to Sharma *et al.,* [9] genetic algorithm (GA) was used by Ismail *et al.,* [13] on modelling and designing of HRES and whale optimization algorithm (WOA) was conducted by Cai *et al.,* [14]. Numerous studies have assessed the sustainability of either the power producing system or electricity generation technology, and often both. To evaluate the HRES sustainability based on technical, economic and environmental performance, Chaurasia *et al.,* [15] compared the best-case scenario between PV-diesel generator (DG)-battery (BAT) to the base case (DG/BAT). Preliminary work of hybrid renewable energy system in conservation park was undertaken by Sreenath *et al.,* [16] that points out another standpoint that received less attention to other researchers which was social parameters.

Overall, the evidence reviewed here highlight a pertinent role for HRES to maintain the sustainability of a system according to social, environmental, economic and technical (SEET) parameters. Nonetheless, these studies continue to have a limited scope as they solely address the well-known diesel cost and neglect to emphasize the concealed transportation expenses associated with delivering diesel to remote regions. This oversight potentially jeopardizes both the final cost and the comprehensive simulation of the research study. Furthermore, although certain studies have examined remote areas, none have specifically focused on exploring the application of Hybrid Renewable Energy Systems (HRES) in conservation parks, where the load profile exhibits stochastic characteristics due to visitors arriving at unpredictable times. This highlights the necessity to comprehend the diverse perspectives on HRES within different types of location specifications. The purpose of this paper is to emphasize the significance of diesel transportation costs. The primary objective of this study is to assess the sustainability of Hybrid Renewable Energy Systems (HRES) within a conservation park.

The next part of this paper is organized as follows. Section 2 presents an assessment of locations with resources and loads, the optimization of HRES models and techno-economic-enviro factors, Section 3 discuss the results and discussions and in Section 4 conclusion is drawn.

2. Methodology

2.1 Site Specifications and Data Collections

This study is carried out at Royal Belum State Park in Perak, Malaysia. The coordinates are 5°40' N, 101°23' E. The map of Royal Belum State Park is illustrated in Figure 1. The Perak State Parks Corporation (PSPC), which is a statutory organisation under the jurisdiction of the State government of Perak, is in charge of managing this conservation park that is situated in the Hulu Perak District. Sungai Tiang is one of the four observation/recreational campgrounds available at the state park. The only way to reach the camps is via boat, and it is quite remote from any kind of connection to the national power system. Diesel and fuel generators are used to provide the necessary power.

Fig. 1. Map of the Royal Belum Park [17]

2.1.1 Solar radiation data

Solar radiation measurements taken at the Sungai Tiang camp and provided by National Aeronautics and Space Administration (NASA) are shown in Figure 2. The average daily solar radiation varies from 4.010 kWh/m2/day to 5.48 kWh/m2/day, with a yearly average of 4.82 kWh/m2/day.

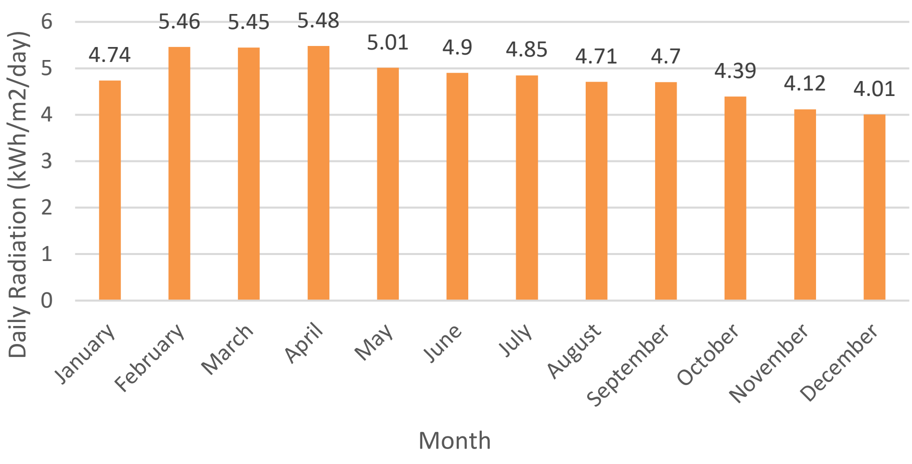

Fig. 2. Monthly average daily solar radiation profile at Sungai Tiang [18]

2.1.2 Temperature data

The temperature data for the Sungai Tiang may also be obtained from NASA and is shown in Figure 3. The average daily temperature is between 23.69℃ and 25.74 ℃, with a yearly average of 24.91℃.

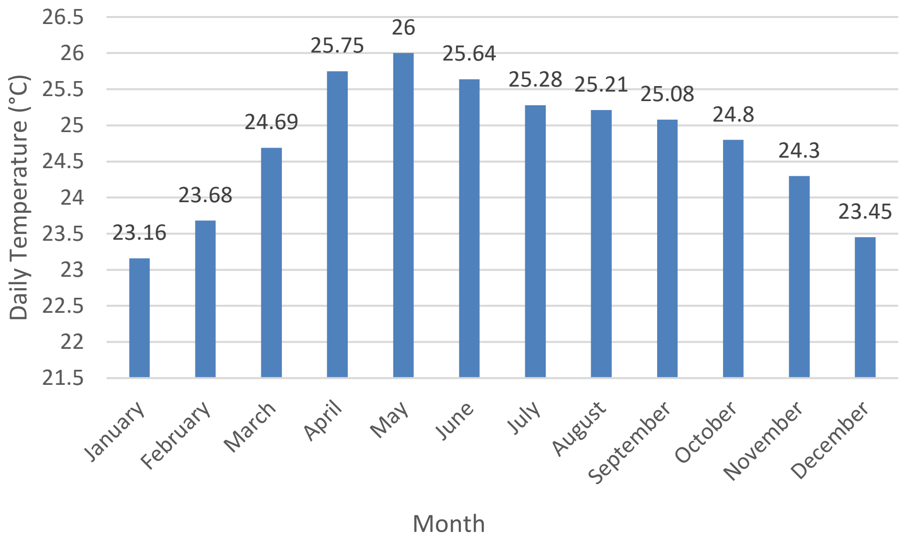

Fig. 3. Monthly average daily temperature profile at Sungai Tiang [18]

2.1.3 Load data

Hourly load profiles are estimated by collecting information on various electrical appliances, their power ratings, and their consumption profiles over the course of a given hour. The hourly average daily load profile of Sungai Tiang is shown in Figure 4, and it is clear from the chart that load readings range throughout the day.

According to the load pattern, the lowest demand comes in the morning, when guests are expected to have switched off unnecessary lights or be active in outdoor activities. The highest load demand is recorded at the whole family is in their rooms and all LED lights are on. The daily energy consumption in Sungai Tiang is estimated to be roughly 14.92 kWh, with a peak demand of 0.93 kW, based on measurements and speculations.

The load profile is based on several input and assumptions: the LED lights (outdoor and open spaces) are turned on for 14 hours to prevent the wildlife. Bathroom lights are used both in the morning and the evening. At Wakaf and the Arrival Hall, the LED are not used between the hours of 08:00 and 17:00. The information about campground appliances is provided in Table 1.

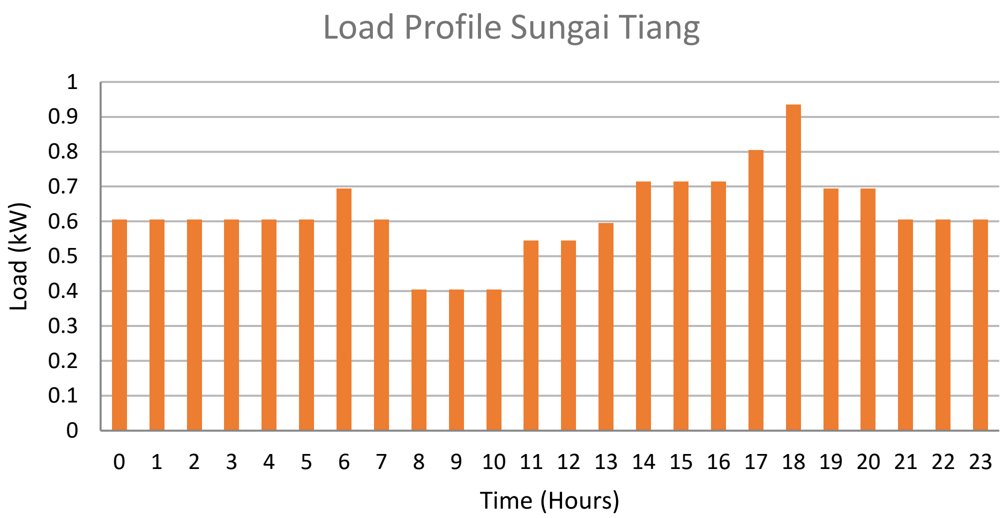

Fig. 4. Hourly average daily load profile at Sungai Tiang

Table 1
Details on appliances/items used in the camp

Appliances/ Items	Chalet		Camp	A' Shaped Chalet		Wakaf	Arrival Hall (AH)			Toilet	Dining Hall		Praying Room	
	LED	Fan	LED	LED	Wall Fan	LED	LED	Fan	Wall Fan	LED	LED	Fan	LED	Wall Fan
Quantity	5	5	10	2	2	5	6	2	2	2	2	2	2	2
Power (W)	10	45	15	10	45	10	10	60	45	10	10	60	10	45
Total (kW)	0.05	0.225	0.05	0.02	0.09	0.05	0.06	0.12	0.09	0.02	0.02	0.12	0.02	0.09

2.2 Hybrid Renewable Energy System (HRES) Design

In the design of HRES, several components must be taken into account. At the Sungai Tiang camp, the hybrid system is comprised of a Photovoltaic (PV) system that serves as the primary energy source, along with batteries and diesel generators as backup. In addition, one of the significant components that has to be taken into consideration is the converter. In this study, the currency conversion is taken as USD 1 = MYR 4.476 [19]. The following is a quick summary of each component of HRES.

2.2.1 Photovoltaic (PV) panels

PV panels are the primary source of energy for HRES. They are utilised during daylight hours when the sun is out. Throughout the night, batteries or diesel generators will be responsible for providing load. In the linear programming model, the derating factor and lifespan of PV panels are modelled as 77% and 25 years, respectively [20]. This is because PV panels need very little maintenance and may endure for a very long period. The replacement cost and capital cost of 1 kW of PV panels are fixed at $740 for economic inputs. A minimal operation and maintenance (O&M) expense is projected to cost $14.8 per year.

2.2.2 Battery

In this investigation, the 12V nominal voltage is accounted for using lead-acid batteries. HOMER's default lifespan prediction for the battery is 10 years. Capital and replacement costs are estimated to be 171.05 $/unit, with an annual O&M cost of 8.55$/year [18].

2.2.3 Diesel generator

Diesel generators are utilised to meet the load requirement when there is no output from the PV system and the batteries have reached their minimal capacity. This research utilizes autosize generators with an initial capital and replacement cost of $191.40. The default O&M cost provided by the HOMER software is $0.03 per operating hour. This generator automatically adjusts its output to accommodate the load. The generator's capacity will be the least that will prevent a capacity shortage in all sensitivity cases.

The cost of diesel at fuel station is 0.479 USD/L [21]. To accommodate the cost of fuel transportation in remote location, 50% higher than the normal fuel price is considered at the campsite.

2.2.4 Converter

The converter in the HRES system is rated according to PV size since it is critical to provide full power delivery from PV panels. The initial cost is estimated to be $330/kW, the replacement cost is estimated to be $330/kW, and the annual O&M cost is $6.60. In the meanwhile, the operating lifespan of the converter is estimated to be 15 years [18].

2.3 System Configuration

The configurations of systems analysed in this work are provided in three instances: 1) standalone diesel generators, 2) hybrid PV-diesel without battery and 3) hybrid PV-diesel with battery storage. The standalone diesel generator system relies on diesel generators to supply load requirements.

In addition, a hybrid PV-diesel system without a battery is a configuration of the system in which photovoltaic panels are given more priority to meet the load demand and a diesel engine is used during times of low solar radiation. The hybrid PV-diesel with battery design will enable the PV panels to meet the load requirement, as shown in Figure 5. The PV panels' excess energy is utilised to charge the battery until it is completely charged. So, if there are insufficiencies of energy from PV panels, the battery will fulfil the requirement. If the battery is unable to satisfy the higher demand, the diesel generators are used later to handle the load.

Journal of Advanced Research in Applied Sciences and Engineering Technology
Volume 31, Issue 3 (2023) 79-92

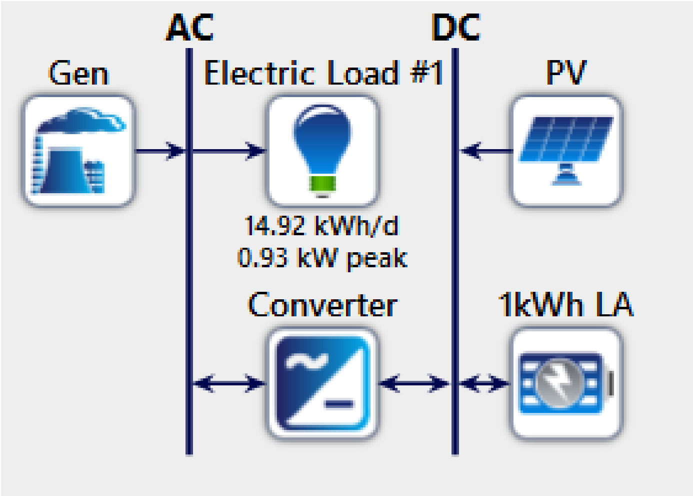

Fig. 5. Schematic of components of hybrid renewable energy system in Sungai Tiang

2.4 Operating Strategies

In the renewable energy system, a dispatch strategy is a method of control for energy storage devices or generators to deliver electricity when renewable supply is insufficient [22]. Load following (LF) and cycle charging (CC) control algorithms are frequently used as operation dispatch techniques in the HRES. The CC method permits diesel generators to supply the load requirement while simultaneously charging the batteries. In this investigation, the LF technique was chosen because it generates less surplus energy than the CC strategy [22]. In contrast, LF approach enables generators to meet demand when PV panels are incapable of doing so. In the meanwhile, the excess energy produced by the PV panels is utilised to charge the battery [22].

2.5 Optimization of Hybrid Model and Economic Evaluation

An objective function is required to develop an optimum hybrid system. The whole net present cost is taken into consideration as the objective function in this research. Take into consideration the fact that a hybrid system has diesel generators, photovoltaic panels, and a battery. Hence, the goal function is provided by the Eq. (1) [23].

$$c_{TNPC} = \frac{c_{ann,tot}}{CRF(i,R_{proj})} \tag{1}$$

$$CRF_{(i,N)} = \frac{i(1+i)^N}{(1+i)^N-1} \tag{2}$$

where

i. $c_{ann,tot}$ = total annual cost of the system (\$/yr),
ii. $CRF_{(i,N)}$= recovery ratio, which depends on the interest rate (%) and project lifespan R_{proj} and *I* is the real discount rate,
iii. N = number of years.

The average cost per kWh of useful electrical energy provided by the HOMER simulated system, defined as the levelized cost of energy (LCOE), and the cost of energy, will equal the total annual cost of the system divided by the total electrical load served. To calculate the LCOE, the following formula is used

$$COE = \frac{c_{ann,tot} - c_{th}}{E_{served}} \tag{3}$$

where

i. c_{th} = total cost of thermal load served ($/yr),
ii. E_{served}= total electrical load served (kWh/yr).

2.6 Environmental Evaluation

Every system configuration's environmental impact is calculated based on its emissions of nitrogen oxides, carbon monoxide, sulphur dioxide, unburned hydrocarbons, carbon dioxide, and particulate matter. The measuring of emissions is deemed essential due to its close relationship with major environmental concerns such as acid rain and the greenhouse effect.

In this research, all emissions of pollutants come from diesel generators used to produce energy. It is measured in kilogrammes per year (kg/yr).

2.7 Sensitivity Evaluation

When designing a hybrid renewable energy system, the HOMER programme is used to execute iterations until the best possible outcome is found for every choice, including the sensitivity variable. To learn how different factors, including the global solar and diesel fuel price, affect energy costs, we conduct sensitivity analyses. With cost analysis in mind, from least to most expensive, the table of the many possible hybrid renewable energy system configurations will be compiled. In this research, the sensitivity analysis for diesel fuel prices ($/L) is analysed to achieve a more feasible configuration.

3. Results

This section summarises the economic, environmental, and technological (sensitivity analysis) outcomes of each configuration.

3.1 Economic Analysis

As was noted before, the NPC and LCOE values are going to be the primary economic measures that are analysed in this study. The economic outcomes may be shown as follows

3.1.1 Standalone diesel generator

In order to accurately assess the effect of integrating PV into the system, it is essential to introduce the first case, which is a standalone diesel generators setup. This case exhibits an NPC value of $27,579.90 and an LCOE value of 0.3215 $/kWh making it the configuration with the most expensive cost of energy. In addition, the system reveals O&M cost, replacement cost, fuel cost, and capital cost for the project’s 25-year duration are $4,553.70, $1,862.61, $20,985.24, and $210.54, respectively.

3.1.2 Hybrid PV-diesel without battery

As indicated in Table 2, the O&M cost, replacement cost, fuel cost, and capital cost of the hybrid PV-diesel system without batteries are $4,828.68, $1,943.69 $18,686.64 and $1,083.35 respectively. The total NPC and LCOE for this configuration are $26,491.77 and $0.3088 $/kWh respectively. As the implementation of RE resource is implement into the system in this case, the recorded NPC and LCOE is lower compared to standalone diesel generator which considered as the base case in this study. However, the total cost for the system in case 2 is more expensive than case 1. This is because there's a lot to install upfront, making the initial investment bigger. Hybrid systems may minimise long-term energy costs by compensating for diesel fuel use with renewable generation. The solar array generates electricity throughout the day, while the diesel generator provides backup power at night or when there is no sunshine.

Table 2
Economic evaluation for hybrid PV-diesel without battery

Component	Capital Cost ($)	O&M Cost ($)	Replacement Cost ($)	Fuel Cost ($)
DG	210.54	4,553.70	1,862.61	18,686.64
PV	728.44	229.49	0.00	0.00
Converter	144.38	45.49	81.08	0.00
System	1,083.35	4,828.68	1,943.69	18,686.64

3.1.3 Hybrid PV-diesel with battery

The third configuration is a battery-powered hybrid PV-diesel system. The results reveal an NPC value of $22,129.92 and an LCOE value of 0.2580 $/kWh which has the lowest value compared to all configurations. This is due to the constant power supply offered by hybrid solar systems, which is a significant advantage over previous ways. As the batteries of hybrid solar systems store energy, they give power without interruption. As indicated in Table 3, the figures for O&M cost, replacement cost, fuel cost, and capital cost are $4,048.17, $2,872.40, $11,912.89, and $3,488.76, respectively.

Table 3
Economic evaluation for hybrid PV-diesel with battery

Component	O&M Cost ($)	Replacement Cost ($)	Fuel Cost ($)	Capital Cost ($)
DG	$2,692.19	$1,053.78	$11,912.89	$210.54
PV	$538.73	$1,653.87	$0.00	$684.20
Battery	$724.82	$0.00	$0.00	$2,300.67
Converter	$92.42	$164.74	$0.00	$293.36
System	$4,048.17	$2,872.40	$11,912.89	$3,488.76

This architecture requires the use of diesel generators to provide the demand, particularly at night when PV is unavailable, and the battery is depleted. Furthermore, this system will not create any stability issues since it has a battery that can be utilised to store excess PV energy for later use.

3.2 Environmental Analysis

The simulation result of the HOMER Pro programme is used to figure out the amount of each kind of pollutant produced annually by the power system in kilogrammes. With renewable energy, greenhouse gas (GHG) emissions from sources other than power plants are dominant. Table 4 shows the emissions generated by each system architecture according to the simulation results. From the table, it is clear that the addition of a battery to stand-alone diesel generators and hybrid PV-diesel generators without a battery would substantially reduce dangerous gas emissions. Sustainable resources reduce carbon dioxide emissions, making this system environmentally friendly because it doesn't pollute our planet by adding more CO_2 gas into our atmosphere, which would cause global warming and climate change issues if we don't stop using fossil fuels as soon as possible.

Based on the information shown in Table 4, the configuration of the standalone diesel generators has led to the highest rate of hazardous pollutants being released into the environment. In addition, the present standalone diesel generators system benefited from the addition of PV as well as batteries, which allowed for a greater decrease in harmful emissions. The value of emission reduction is calculated with respect to base case which is standalone diesel generator in system 1.

Table 4
Environmental evaluation for hybrid PV-diesel with battery

Emission/System Architecture	Standalone Diesel Generator	Hybrid PV-Diesel Without Battery		Hybrid PV-Diesel with Battery	
		Emission	Emission Reduction	Emission	Emission Reduction
Carbon dioxide (kg/yr)	4,774	4,251	523	2,710	2,064
Carbon monoxide (kg/yr)	30.1	26.8	3.30	17.1	13.00
Unburned hydrocarbons (kg/yr)	1.31	1.17	0.14	0.745	0.57
Sulfur dioxide (kg/yr)	0.182	0.162	0.02	0.104	0.08
Particulate matter (kg/yr)	11.7	10.4	1.30	6.64	5.06
Nitrogen oxide (kg/yr)	28.3	25.2	3.10	16	12.30

3.3 Sensitivity Analysis

The sensitivity analysis may be used to assess the technical analysis for each possible configuration of the system. This analysis involves changing numerous parameters of the system. Throughout the course of this research, two criteria, namely fuel price and PV capital cost, have been subjected to a range of different treatments. The price of fuel is adjusted by plus or minus 3% of the standard price. Meanwhile, the PV capital cost has been lowered by 40%. Table 5 provides an illustration of the findings obtained from the sensitivity analysis.

3.3.1 Sensitivity analysis result with variation on fuel price

This project adjusted the diesel price to vary between \$0.694/L, \$0.731/L, and \$0.767/L considering 5% of increment and decrement. According to Table 5, a rise in the price of fuel will result in an increase in the price of electricity. Therefore, the NPC value for the load demand of 5446 kWh/day is reduced to \$21,572 for a fuel price of \$0.694/L, \$22,130 at current price of diesel of \$0.7341/L, and increased to \$22,732 with a fuel price of \$0.767/L. Similarly, LCOE values are seen to rise proportionally by \$0.251, \$0.258, and \$0.265 for gasoline prices of \$0.694/L, \$0.731/L, and \$0.767/L, respectively.

3.3.2 Sensitivity analysis result with variation on PV capital cost

This study modified the capital cost of PV by a factor between 1 and 0.6. The factor of 1 represents the real capital cost of the PV panel and battery, whereas the factor of 0.6 represents a 40% decrease in the PV panel's capital cost. This represents the variance in PV panel capital costs between $1,711 per kW and $2,301 per kW. Table 5 shows the result of the sensitivity analysis.

Table 5
The result of sensitivity analysis

Sensitivity Variables	PV (kW)	DG (kW)	Battery (Units)	Converter (kW)	Initial Capital ($)	Operating Cost ($/yr)	TNPC ($)	LCOE ($kWh)
Variations of Fuel Price								
$0.694/L	2.98	1.10	4	0.909	3,402	1,153	21,572	0.251
$0.731/L	3.11	1.10	4	0.889	3,489	1,183	22,130	0.258
$0.767/L	3.11	1.10	4	0.898	3,490	1,222	22,732	0.265
Variations of Solar PV Capital Cost at Fuel Price $0.694/L								
1	2.98	1.10	4	0.909	3,402	1,153	21,572	0.251
0.6	4.32	1.10	3	0.890	2,936	1,117	20,536	0.239
Variations of Solar PV Capital Cost at Fuel Price $0.731/L								
1	3.11	1.10	4	0.889	3,489	1,183	22,130	0.258
0.6	3.85	1.10	3	0.891	2,739	1,166	21,097	0.246
Variations of Solar PV Capital Cost at Fuel Price $0.767/L								
1	3.11	1.10	4	0.898	3,490	1,222	22,732	0.265
0.6	3.99	1.10	3	0.893	2,790	1,199	21,675	0.253

3.4 Discussions

This subsection will discuss the findings in terms of cost and environmental analyses for each system design. NPC and LCOE are used to represent the expected cost of each configuration. Each configuration also displays the pollutant emission rate and the impact of changing the fuel price and PV price factors.

3.4.1 Techno-economic analysis

Table 6 illustrates the different architectures categorized based on their highest NPC (Net Present Cost) and COE (Cost of Energy). Introducing PV (Photovoltaic) and BAT (Battery) into the system reduces both the total net cost and the cost of energy. Figure 6 demonstrates that the hybrid PV-Diesel system with a battery exhibits the most favorable economic characteristics, followed by the hybrid PV-Diesel system without a battery and the standalone diesel generator. The estimated capital costs of hybrid systems are higher compared to standalone diesel generators, primarily due to the additional investment required for PV or batteries, which can be costly to acquire.

Table 6
Categorised system architecture based on techno-economic

System Architecture	Solar PV (kW)	DG (kW)	Battery (kWh)	Converter (kW)	NPC (USD)	COE (USD)
DG only	-	1.10	-	-	27,580	0.322
PV/DG	0.984	1.10	-	0.438	26,492	0.309
PV/DG/BAT	3.11	1.10	4	0.889	22,130	0.258

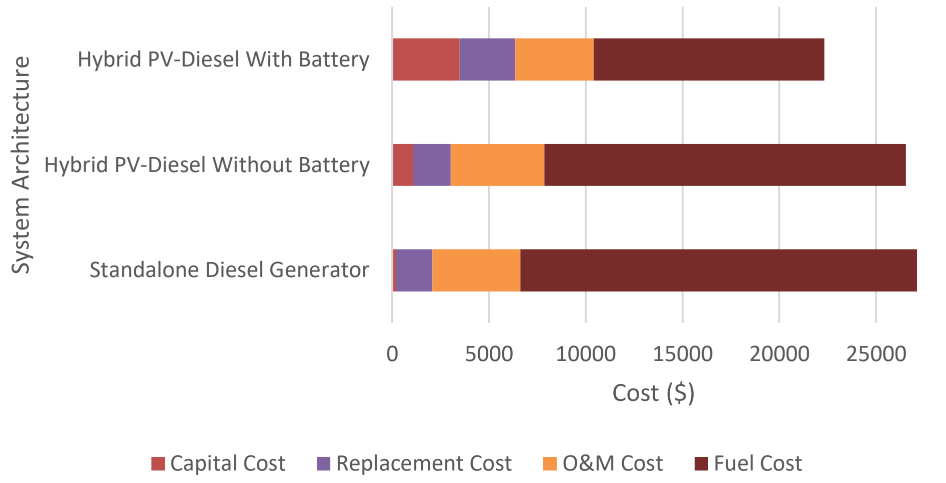

Fig. 6. Estimation cost of every system configuration

By altering the parameters of fuel price and PV price on the performance of each design, the sensitivity analysis of each configuration is determined. Surprisingly, the findings indicate the reliance on hybrid PV, diesel generators, and batteries in the case of high load demand and high fuel prices. Additionally, in the case of NPC and LCOE values, the increase in load demand and fuel price, as well as the decrease in the capital cost of PV, has led the system to utilize a hybrid system consisting of PV, diesel generators, and batteries. Battery and PV prices are likely to decrease in the future, lending credence to the feasibility of a system that relies only on these sources of clean energy.

Measurements of fuel consumption may also be used to quantify the performance of standalone diesel generators and hybrid systems. As can be shown in Figure 7, the fuel consumption of hybrid systems is lower than that of conventional diesel-only power plants. As a consequence, diesel generators will operate fewer, hence decreasing replacement, fuel, maintenance, and operating expenses. Hence, NPC and LCOE values will also decline.

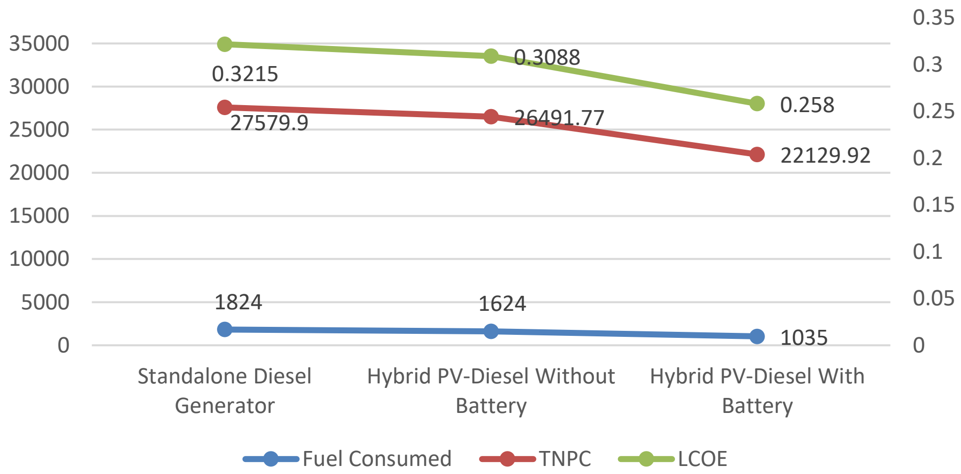

Fig. 7. Fuel consumption, TNPC and LCOE in system configuration

3.4.2 Environmental analysis

The results of sub section 3.2 indicates that standalone diesel generators emit the most dangerous pollutants into the atmosphere, while hybrid systems release fewer harmful pollutants.

This indicates that the insertion of PV or batteries into the existing standalone diesel generators reduced hazardous gas emissions. The outcomes of a comparison between hybrid PV-diesel without battery and hybrid PV-diesel with battery indicate that hybrid PV-diesel with battery offers greater performance. This is owing to the fact that the hybrid PV-diesel without a battery system does not use excess energy produced from PV to charge the battery. As a consequence, the surplus energy becomes excess energy, and diesel generators will be responsible for delivering the load. Hence, diesel generators provide an enormous quantity of energy and emit a greater number of dangerous pollutants into the atmosphere. In conclusion, the quantity of dangerous pollutants emitted is significantly correlated with the system structure and amount of energy produced.

4. Conclusions

In this study, the HOMER Pro programme is used to provide estimates for the HRES's techno-economic-environmental analysis. The findings of this research indicate that a combination of a diesel generator, PV, and battery to create energy is an efficient and economical means of satisfying the required power supply.

The simulation reveals that a hybrid system with 1.1 kW diesel generators, 3.11 kW PV, a 0.889 kW system converter, and 4 units of batteries with a nominal voltage of 12 V is the ideal hybrid design based on the minimal NPC and LCOE values. Using HOMER Pro, the optimal renewable energy use strategies for campsites in Sungai Tiang were established. Independent analyses were conducted to determine the profitability of solar and hybrid energy investments. This project includes five scenarios with distinct system architectures.

Sensitivity analysis findings show that LCOE and NPC values are substantially responsive to fuel price and PV capital cost. The inclusion of renewable energy sources into generating electricity has reduced reliance on the standalone diesel generator, enhanced system performance, and produced less hazardous emissions. This study confirmed the significance of installing a battery to decrease energy losses and store extra energy. It also increased the system's sustainability. In addition, cutting the cost PV may reduce NPC and LCOE, which will increase the adoption of both technologies in the existing system. Studies indicate that the PV/DG/BAT combination is better to a single RE technology in rural areas such as the Sungai Tiang campsite. Hybrid RE systems provide quicker returns, greater cost reductions, and less emissions. In conclusion, the hybrid renewable energy system with the battery has the potential to be adopted in the current system, particularly to upgrade and to replace the existing standalone diesel generators system in Malaysia. This is because the hybrid system combines the benefits of both conventional and renewable energy sources. Further research might explore the implementation of hydro and biomass energy as RE sources in the conservation park.

Acknowledgement
Authors are grateful for the support and assistance provided by Perak State Parks Corporation in carrying out the study.

References
[1] "Malaysia. " UNDP Climate Promise. Accessed Feb 28, 2023.
[2] "Malaysia's Renewable Energy Outlook 2022." MIDA, January 31, 2022.
[3] IEA. "Share of World Total Final Consumption by Source, 2019 – Charts – Data & Statistics." IEA. Accessed Feb 28, 2023.
[4] "Renewable Energy." Center for Climate and Energy Solutions, November 10, 2021.

[5] Ali, Fahad, Muhammad Ahmar, Yuexiang Jiang, and Mohammad AlAhmad. "A techno-economic assessment of hybrid energy systems in rural Pakistan." *Energy* 215 (2021): 119103. https://doi.org/10.1016/j.energy.2020.119103
[6] Arief, Yanuar Z., Nur Anisah Aziera Abdul Halim, and Mohd Hafiez Izzwan Saad. "Optimization of hybrid renewable energy in Sarawak remote rural area using HOMER software." In *2019 International UNIMAS STEM 12th Engineering Conference (EnCon)*, pp. 1-5. IEEE, 2019. https://doi.org/10.1109/EnCon.2019.8861255
[7] Yap, Christine Monique F., Kent Marc Kobe C. Bismark, Lorenzo Gabriel C. Caballa, Robert Alfie S. Peña, Raymark C. Parocha, and Erees Queen B. Macabebe. "Feasibility Study of a Hybrid Renewable Energy System for a Remote Rural Community Using HOMER Pro." In *2022 IEEE International Conference on Power and Energy (PECon)*, pp. 30-35. IEEE, 2022. https://doi.org/10.1109/PECon54459.2022.9988815
[8] Ha, Chin Yee, Terh Jing Khoo, and Jia Xuan Loh. "Barriers to green building implementation in Malaysia: A systematic review." *Progress in Energy and Environment* (2023): 11-21. https://doi.org/10.37934/progee.24.1.1121
[9] Sharma, Reena, Hariprasad Kodamana, and Manojkumar Ramteke. "Multi-objective dynamic optimization of hybrid renewable energy systems." *Chemical Engineering and Processing-Process Intensification* 170 (2022): 108663. https://doi.org/10.1016/j.cep.2021.108663
[10] Kushwaha, Pawan Kumar, and Chayan Bhattacharjee. "Integrated techno-economic-enviro-socio design of the hybrid renewable energy system with suitable dispatch strategy for domestic and telecommunication load across India." *Journal of Energy Storage* 55 (2022): 105340. https://doi.org/10.1016/j.est.2022.105340
[11] Hassan, Rakibul, Barun K. Das, and Mahmudul Hasan. "Integrated off-grid hybrid renewable energy system optimization based on economic, environmental, and social indicators for sustainable development." *Energy* 250 (2022): 123823. https://doi.org/10.1016/j.energy.2022.123823
[12] Alshammari, Nahar, and Johnson Asumadu. "Optimum unit sizing of hybrid renewable energy system utilizing harmony search, Jaya and particle swarm optimization algorithms." *Sustainable Cities and Society* 60 (2020): 102255. https://doi.org/10.1016/j.scs.2020.102255
[13] Ismail, Mahmoud S., M. Moghavvemi, and T. M. I. Mahlia. "Genetic algorithm based optimization on modeling and design of hybrid renewable energy systems." *Energy Conversion and Management* 85 (2014): 120-130. https://doi.org/10.1016/j.enconman.2014.05.064
[14] Cai, Wei, Xing Li, Akbar Maleki, Fathollah Pourfayaz, Marc A. Rosen, Mohammad Alhuyi Nazari, and Dieu Tien Bui. "Optimal sizing and location based on economic parameters for an off-grid application of a hybrid system with photovoltaic, battery and diesel technology." *Energy* 201 (2020): 117480. https://doi.org/10.1016/j.energy.2020.117480
[15] Chaurasia, Ravi, Sanjay Gairola, and Yash Pal. "Technical, economic, and environmental performance comparison analysis of a hybrid renewable energy system based on power dispatch strategies." *Sustainable Energy Technologies and Assessments* 53 (2022): 102787. https://doi.org/10.1016/j.seta.2022.102787
[16] Sreenath, S., Azlin Mohd Azmi, and Zubir Ahmad Mohd Ismail. "Feasibility of solar hybrid energy system at a conservation park: Technical, economic, environmental analysis." *Energy Reports* 9 (2023): 711-719. https://doi.org/10.1016/j.egyr.2022.11.065
[17] Perbadanan Taman Negeri Perak - Perak State Parks Corporation. Accessed March 3, 2023.
[18] Homer Energy Support Center. Accessed March 3, 2023.
[19] Exchange rates - Bank Negara Malaysia. Accessed Dec 21, 2023.
[20] IEA. Rep. *National Survey Report of PV Power Applications in Malaysia 2019*. International Energy Agency | Photovoltaic Power Systems Programme, 2019.
[21] "Malaysia Diesel Prices 27-Feb-2023." GlobalPetrolPrices.com. Accessed March 3, 2023.
[22] "Homer pro 3.10." Welcome to HOMER. Accessed May 17, 2023.
[23] Al-Najjar, Heyam, Hala J. El-Khozondar, Christoph Pfeifer, and Rafat Al Afif. "Hybrid grid-tie electrification analysis of bio-shared renewable energy systems for domestic application." *Sustainable Cities and Society* 77 (2022): 103538. https://doi.org/10.1016/j.scs.2021.103538