

Modelling And Assessment Of Renewable Energy Systems For Decarbonization In Perhentian And Tioman Islands

Zahari Dollah¹, Mohd. Kamal Mohd. Shah^{1*}, Nahiyah Al-Azad¹, Mohammad Syazwan Mokhtar¹

¹Faculty of Engineering, Universiti Malaysia Sabah, Kota Kinabalu, Malaysia

ZahariDo@tnb.com.my; mkamalms@ums.edu.my; nahiyahalazad@gmail.com;

mohammad_syazwan_bk20@iluv.ums.edu.my

*Corresponding Author: mkamalms@ums.edu.my

Abstract— This project focuses on developing a sustainable energy system utilizing renewable resources to address the power generation needs of Perhentian Besar Island and Tioman Island. Due to the remote location of many areas on these islands, electricity supply from the main grid is limited, leading to reliance on diesel generators. However, diesel-based power generation releases substantial pollutants, underscoring the need for a rapid transition to cleaner energy sources. This work proposes an integrated renewable energy solution incorporating solar, wind, and hydro resources to meet the islands' energy demands. An Energy Storage System (ESS) with an inverter will be included to provide backup power during low generation periods. Optimal configurations of renewable energy systems for each island will be analyzed using Homer Pro software, and a sensitivity analysis on diesel-based systems will be conducted to identify the most cost-effective renewable energy system for these remote island communities.

Keywords— *Energy storage system, Renewable energy system, Renewable resources, Optimal configuration.*

I. INTRODUCTION

Malaysia, a Southeast Asian nation of 32.7 million people spread across a tropical landscape, currently faces a growing energy demand due to rapid urbanization and rising population. This demand is also expected to increase by 2% annually until 2050, which can strain the energy sector. The energy sector in this country heavily relies on fossil fuels which contributes to Gross Domestic Product (GDP) and fiscal income of this country [1]. However, recognizing the potential of environmental issues that may occur, the Malaysian government has introduced the National Energy Transition Roadmap (NETR) in 2021. NETR aims to shift from fossil fuels to clean renewable energy sources, such as solar and wind power, by focusing on six key areas: energy efficiency, renewable energy, hydrogen, bioenergy, green transportation, and carbon capture. Additionally, the government also targets 100% renewable energy system utilization on resort islands by 2025 [2]. This energy system is expected to be able to provide clean and reliable electricity supply, especially in remote areas which currently rely on diesel generators. A modern energy solution based on renewable resources could guarantee the provision of reliable, secure, optimal cost energy and green energy supplies throughout the island regions with no access to electricity. Therefore, this study aims to develop a reliable energy system based on renewable resources, as well as increasing renewable energy penetration on Perhentian Besar Island and Tioman Island. There are also three main objectives that need to be achieved such as to conduct a feasibility study regarding the current energy management system on Perhentian Besar Island and Tioman Island, to identify potential renewable energy sources for developing renewable energy systems in Perhentian Besar Island and Tioman Island and to optimize the performance of the renewable energy systems based on experimental and simulation analysis.

II. BACKGROUND THEORY

A. Simulation Software

Homer Pro software will be employed to model and optimize the renewable energy system for this study. This software accounts for uncertainties in technology costs, energy resource availability and other variables [3]. By simulating various configurations and conducting economic analyses, this software allows us to select the most suitable and cost-effective solution of energy system for both islands.

B. Load Demand

Tourist seasonality significantly influences electricity demand on both islands. The higher consumption is during peak tourist periods from May to October. Residential loads, primarily from chalets, account for most of the electricity usage, with additional consumption from other utilities such as restaurants and government buildings. To accurately model load demand, two distinct load profiles should be created representing peak and off-peak seasons.

C. Solar Radiation

Solar radiation is a critical factor in designing efficient solar energy systems. Malaysia's equatorial climate provides abundant sunlight, averaging 1643 kWh/m² annually, but variations due to weather conditions must be considered [4]. Latitude, altitude angle and solar position also influence solar radiation levels. The clearness index, representing the ratio of actual to maximum solar radiation should be considered to estimate radiation on tilted surfaces of the solar panel.

D. Wind Speed

Wind speed is the primary determinant of wind turbine power output. Higher wind speeds generate more power because stronger winds allow the blades to rotate faster [5]. Faster rotation translates to more mechanical power and more electrical power from the generator. Thus, it is essential to find areas with a lot of wind on a regular basis, which will be important to maximize wind turbine power generation.

E. Hydro-Current

A hydraulic turbine converts the energy of flowing water into mechanical energy. A hydroelectric generator then converts this mechanical energy into electricity [6]. Hydropower uses energy contained in flowing river water to generate electricity. This means that the power output of the hydropower depends on the river's flow rate. Therefore, it is essential to choose a river that has the highest flow rate so that electricity generation can be optimized.

III. METHODOLOGY

A. Load Profile

Electricity demand on Perhentian Besar Island and Tioman Island comprises residential, commercial, and municipal loads. Residential consumption is from homes and villages, while commercial loads originate from businesses and institutions. Meanwhile, municipal loads come from public infrastructure like streetlights. Table I shows the load profile on both islands. It should be noted that these data are obtained from Tenaga Nasional Berhad (TNB).

TABLE I LOAD PROFILE ON EACH ISLAND

Month	Average Load (kWh/day)	
	Perhentian Besar	Tioman
Jan	96,935.75	684,480.00
Feb	122,941.50	742,282.00
Mar	138,673.60	959,699.00
Apr	155,613.10	1,169,464.00
May	112,324.60	1,391,548.00
Jun	96,955.02	1,481,943.00
Jul	167,425.00	1,517,565.00
Aug	176,337.10	1,499,237.00
Sep	146,990.60	1,499,691.00
Oct	141,746.50	1,352,339.00
Nov	101,049.10	1,133,319.00
Dec	93,060.02	836,740.00

B. Wind Speed

The solar radiation data for both islands had been collected for over a 22-year period from 1983 until 2005. This data was obtained from the NASA POWER database which is from the NASA Langley Research Center Prediction of Worldwide Energy Resource Project funded through the NASA Earth Science Directorate Applied Science Program. Table II shows the solar radiation at the chosen location on each island [7].

TABLE III SOLAR RADIATION ON CHOSEN LOCATION AT EACH ISLAND.

Month	Perhentian Besar		Tioman	
	Clearness Index	Daily Radiation (kWh/m ² /day)	Clearness Index	Daily Radiation (kWh/m ² /day)
Jan	0.438	4.120	0.490	4.780
Feb	0.513	5.100	0.565	5.760
Mar	0.516	5.360	0.572	5.990
Apr	0.537	5.600	0.592	6.100
May	0.513	5.200	0.562	5.550
Jun	0.513	5.080	0.544	5.220
Jul	0.501	5.000	0.529	5.140
Aug	0.487	4.990	0.525	5.300
Sep	0.494	5.100	0.518	5.360
Oct	0.461	4.610	0.495	5.050
Nov	0.395	3.740	0.432	4.230
Dec	0.365	3.350	0.422	4.040

C. Wind Speed

The wind speed data for both islands in this research are collected from NASA POWER database which is from the NASA Langley Research Center Prediction of Worldwide Energy Resource Project funded through the NASA Earth Science Directorate Applied Science Program. This wind speed data had been collected for over a 30-year period from 1984 until 2013. Table III shows the wind speed at the chosen

TABLE IIIII WIND SPEED ON EACH ISLAND

Month	Average Wind Speed (m/s)	
	Perhentian Besar	Tioman
Jan	7.240	4.930
Feb	6.120	4.150
Mar	4.490	3.730
Apr	3.090	3.010
May	3.370	2.410
Jun	4.160	2.240
Jul	4.720	2.250
Aug	4.930	2.250
Sep	4.140	2.240
Oct	3.240	2.890
Nov	4.130	4.060
Dec	6.590	5.180

and tables must be centered in the column. Large figures and tables may span across both columns. Any table or figure that takes up more than 1 column width must be positioned either at the top or at the bottom of the page.

Graphics may be full color. All colors will be retained on the CDROM. Graphics must not use stipple fill patterns because they may not be reproduced properly. Please use only SOLID FILL colors which contrast well both on screen and on a black-and-white hardcopy, as shown in Fig. 1.

D. Hydro Current

Air Seler River has been chosen as the location for developing mini hydro at Tioman Island. The data on average flow rate of this river was obtained from a previous reconnaissance study that was done in 2013 by researchers from Universiti Tenaga Nasional (UNITEN). Table IV shows the average stream flow by month of the Air Seler River.

TABLE IVV AVERAGE STREAM FLOW OF AIR SELER RIVER AT TIOMAN ISLAND

Month	Average Flow Rate (L/s)
Jan	4.930
Feb	4.150
Mar	3.730
Apr	3.010
May	2.410
Jun	2.240
Jul	2.250
Aug	2.250
Sep	2.240
Oct	2.890
Nov	4.060
Dec	5.180

E. Design Specification

The design specification of the renewable energy system and diesel-based energy system can be seen in Table V shown below.

TABLE VV AVERAGE STREAM FLOW OF AIR SELER RIVER AT TIOMAN ISLAND

Component	Brand / Type	Capacity
Solar panel	Canadian Solar Max Power CS6U-325P	100kW
Wind turbine	Bergey BWC XL.1	1kW
Mini hydro	Natel Freejet FJ-20C	533kW
Energy Storage System	Generic 4hr 1MW Li-Ion	4220kWh
Inverter	CPS SC100KT-O/US-480 grid-tied PV	100kW

F. Proposed Energy System Configuration

The proposed systems aims to enhance energy security, reduce dependence on fossil fuels, and support sustainable development through the integration of solar, wind, and hydro energy sources with energy storage and power electronic interfaces.

Fig. 1 illustrates a hybrid renewable energy configuration specifically designed for Perhentian Besar Island, which relies primarily on solar photovoltaic (PV) and wind energy sources. The configuration includes both alternating current (AC) and direct current (DC) components and is structured to optimize the utilization of locally available renewable resources.

On the AC side, a wind turbine serves as a primary source of electricity generation, supplying power directly to the AC load, which includes residential and tourism-related infrastructure. A bidirectional inverter is employed to manage the conversion between AC and DC, facilitating the integration of DC sources and storage components.

The DC subsystem consists of solar PV arrays and an energy storage system (ESS). The PV panels generate DC electricity, which is converted to AC by the inverter to serve the load or charge the ESS. The ESS stores surplus energy generated during periods of high renewable availability and discharges during periods of low generation or peak demand, thereby enhancing system reliability and grid stability.

This configuration is particularly well-suited to Perhentian Besar Island due to its strong solar irradiance profile and coastal wind potential. The system offers a sustainable and decentralized energy solution, reducing the island's dependence on diesel generators while ensuring reliable power supply for critical infrastructure.

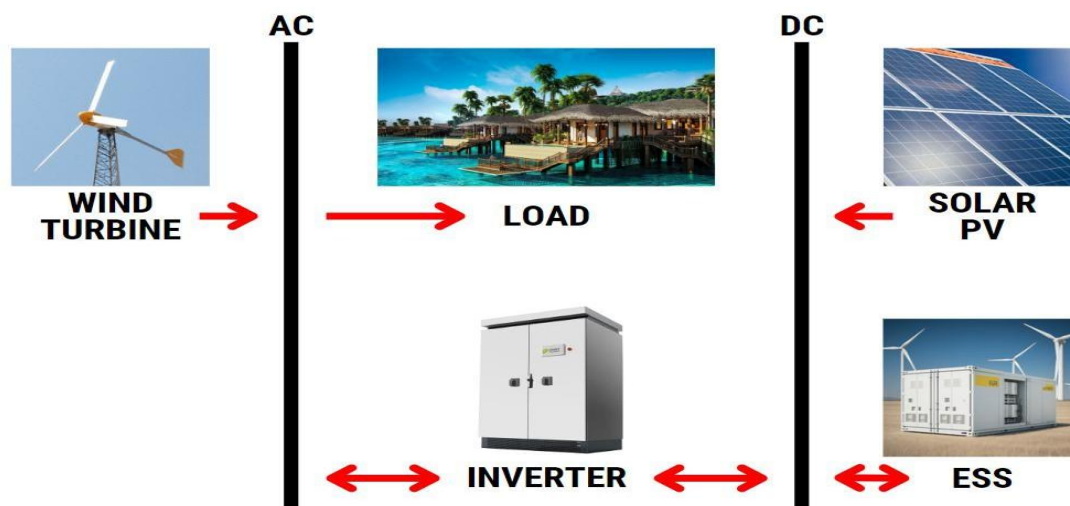


Fig I. Proposed renewable energy system design for Perhentian Besar Island.

Fig. 2 presents an expanded hybrid energy configuration proposed for Tioman Island. This system builds upon the architecture used in Fig. 1 by incorporating a third renewable energy source which is a mini-hydropower in addition to wind and solar PV. The inclusion of a mini-hydro system is justified by the island's favorable topography and the availability of freshwater resources suitable for small-scale hydroelectric generation.

The AC subsystem consists of both the wind turbine and the mini-hydro generator, which collectively supply electricity directly to the load or through the bidirectional inverter for further regulation. The presence of the mini-hydro component provides a more stable and continuous form of generation, particularly beneficial during periods when solar and wind outputs are insufficient.

On the DC side, solar PV panels generate power which is directed to the inverter for conversion. An ESS is incorporated similarly to the Perhentian system to store excess energy and provide backup power during renewable supply shortfalls or peak consumption periods. The inverter manages bidirectional energy flow between AC and DC networks, ensuring real-time power balancing and optimized energy dispatch.

The integration of mini-hydro into the Tioman Island system enhances the overall robustness of the microgrid, allowing it to support higher base loads with increased reliability. This configuration is well-aligned with the island's energy needs and resource availability, offering a comprehensive and sustainable approach to rural electrification.

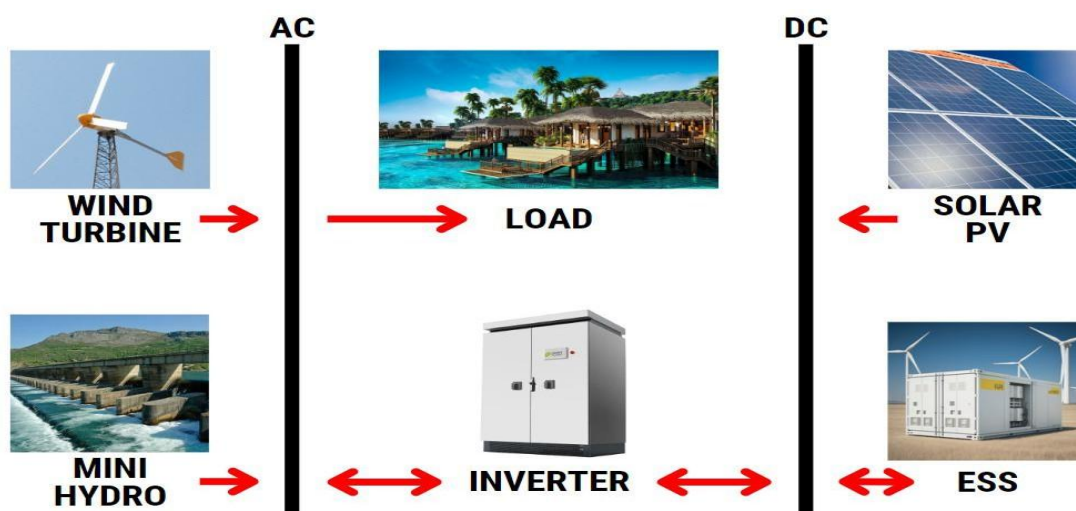


Fig II. Proposed renewable energy system design for Tioman Island.

Both proposed configurations present technically and environmentally sound solutions for powering remote islands through hybrid renewable energy systems. The configuration for Perhentian Besar Island is optimized for locations with strong solar and wind potential but limited hydro resources. In contrast, the Tioman Island configuration integrates an additional hydropower source, enhancing base-load supply

and system reliability. The use of bidirectional inverters and energy storage systems in both models ensures operational flexibility and supports real-time energy balancing.

IV. RESULTS AND DISCUSSION

Simulation of two different energy system designs: renewable energy system and diesel-based energy system, has been performed using Homer Pro software. For the renewable energy system, its performance was evaluated with the lowest Net Present Cost (NPC) indicating the most cost-effective configuration. Table V and Table VI show the optimization result of the renewable energy system for Perhentian Besar Island and Tioman Island.

TABLE VIV PERHENTIAN BESAR ISLAND RENEWABLE ENERGY SYSTEM OPTIMIZATION RESULTS.

SP = Solar Power, WT = Wind Turbine, ESS = Energy Storage System, I = Inverter, OC = Operating Cost, IC = Initial Cost, COE = Cost of Energy, NPC = Net Present Cost								
	SP	WT	ESS	I	Total NPC (RM)	COE (RM/kWh)	OC (RM/yr)	IC (RM)
Config. 1	177,240		23	9,030	51.1M	0.839	986,744	38.4M
Config. 2	167,504	18	25	13,236	52.4M	0.860	1.04M	39.0M

TABLE VI PERHENTIAN BESAR ISLAND RENEWABLE ENERGY SYSTEM OPTIMIZATION RESULTS.

SP = Solar Power, MH = Mini-Hydro, WT = Wind Turbine, ESS = Energy Storage System, I = Inverter, OC = Operating Cost, IC = Initial Cost, COE = Cost of Energy, NPC = Net Present Cost									
	SP	WT	ESS	MH	I	Total NPC (RM)	COE (RM/kWh)	OC (RM/yr)	IC (RM)
Config. 1	1,187,800		293	533	65,618	451M	0.803	9.26M	331M
Config. 2	1,062,360	24	337	533	71,638	463M	0.824	9.75M	337M

According to Table VI, Homer Pro suggests a solar PV, ESS, and inverter combination as the most cost-effective option for Perhentian Besar Island, with a total NPC of RM51.1 M. A 177,240-kW solar PV system able to generate 243,222,080 kWh/yr, along with 23 ESS units which were used as a backup supply during night and cloudy day operation. Meanwhile on Table VII, a combination of solar PV, mini-hydro, ESS, and inverter system is the optimal configuration suggested by Homer Pro for Tioman Island. This configuration yields a total NPC of RM451 M, lowered compared to the configuration with wind power. A 533 71,638 463M 0.824 9.75M 337M 1,187,800-kW solar PV can produce 1,766,607,872 kWh/yr, with 533 kW mini-hydro as an additional electricity supply and 293 ESS units which serves as a backup supply. Both energy system configurations are estimated to be able to supply the load demand on each island.

V. CONCLUSIONS

Overall, the aim and objectives of this study was successfully achieved. The renewable energy system for Perhentian Besar Island and Tioman Island can be developed by utilizing solar, wind and hydro as sources to generate electricity. By using Homer Pro simulation, the optimal configurations of renewable energy systems are also able to be determined. Homer suggests a combination of solar and ESS as the most cost-effective solution for Perhentian Besar Island. Meanwhile, a combination of solar, mini-hydro and ESS for Tioman Island. Sensitivity analysis has also been done on diesel-based energy systems using Homer Pro software. The analysis results show that the increase in diesel price gives an effect of increasing diesel-based energy system overall costs. This makes this energy system to be more costly in the future. To further enhance future research, integrating additional renewable sources, conducting comprehensive resource assessments, and establishing robust data monitoring systems are recommended.

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