Optimal Planning of Hybrid Renewable Energy System Using HOMER in Sebesi Island, Indonesia

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Abstract- This paper demonstrates the optimal design and techno-economic-environmental assessment of a hybrid renewable energy system (HRES) for electrification on Sebesi Island, South Lampung Regency, Indonesia. The renewable energy sources studied in this paper are solar photovoltaic (PV), wind turbines (WT), biogas generators (GBi), and energy storage or batteries (BAT). In planning, energy sources from PV contribute about 50% of the total daily load. This study aims to make the planned HRES feasible from a technological, economic, and environmental perspective. This study uses Homer Algorithm in generating the assessment parameters from the three perspectives. Researchers investigated and compared the results of six different scenarios with diesel generators (DG). The results show that the first scenario (PV-GBi-BAT) is the most excellent from an economic perspective. While the second scenario (PV-WT-GBi-BAT) is the most excellent when viewed from a technology perspective and an environmental perspective. These results indicate that the second scenario has a more dominant advantage when compared to the first scenario. Therefore, the second scenario is the most optimal.

Keywords Solar photovoltaic, wind turbine, biogas-generator, Sebesi Island, hybrid renewable energy system.

1. Introduction

The need for electrical energy has become a basic need today. The use of electrical power increases both for people living in urban areas and people in villages/islands [1]. Indonesia is a maritime country. The country consists of thousands of islands spread from Sabang to Merauke. The primary power grid far from the island is an obstacle for the country's electricity providers to draw a network that crosses the vast ocean. Connecting the electricity network to these islands requires a considerable investment cost. The current solution given by the Indonesian government is the construction of a diesel power plant (DG) [2].

The construction of the DG has very high operational costs and fuel costs. Moreover, the delivery of fuel oil requires both land and sea transportation facilities. Moreover, fulfilling the need for electrical energy from fuel oil is a problem in the future due to increasingly scarce availability and environmental damage. Therefore, the government must immediately consider the energy transition to economical and environmentally friendly energy, especially in isolated, frontier, and outermost areas [3].

Although renewable energy is the energy of the future, the availability of this energy is not always continuous. Several problems will arise when this resource uses a single technology to supply the load, such as high investment costs and low supply security. To solve the problem, Hybrid Renewable Energy Systems (HRES) can be a solution for remote areas or islands far from the big grid. HRES usually consists of one renewable energy source and one conventional or more renewable energy with or without traditional energy sources. In addition, HRES can work in stand-alone or grid-connected mode [4].

In HRES, optimal planning of the various components of energy resources is essential. Providing the optimal size for each element will help us to reduce system costs. In addition, the continuous supply of loads is an obstacle that must meet. Several studies have carried out optimal planning of renewable energy components connected to the grid or not connected to the grid. The researchers assessed based on economic, technological, and environmental perspectives. From a technical point of view, the researchers evaluated the optimal configuration, size of the renewable energy component, and a renewable fraction (RF). From an economic perspective, the researchers assessed based on the net present cost (NPC) and cost of energy (COE). Meanwhile, based on environmental aspects, the researchers evaluated the system's contribution in producing emission gases in CO_2, SO_2, NO, and others [4].

Previous researchers conducted a feasibility study in Ecuador with the combination of DG-PV-WT-BAT. The study resulted in the NPC and COE values of $115,766 and 0.28 $/kWh, respectively. Meanwhile, the emission gas produced is 18 tons/year [5]. Thlatlaganya is a village in South Africa. The village has conducted a renewable energy study involving DG-PV-WT-BAT and grid extension. The study obtained the NPC and COE values, namely NPC: $2,884,578, COE: 0.41 $/kWh [6]. Other researchers have also conducted studies in Bussan, South Korea, involving 100% renewable energy. The study results in the area obtained a COE value of 0.399 $/kWh [7]. Another study in a village in the Shafar region of Yemen conducted a PV-WT hybrid study. The study resulted in a COE value of 0.172 $/kWh and reduced CO2 emissions by 70% [8]. Other researchers have also conducted a PV-WT-DG hybrid study in the Gwagwalada-Abuja region of Nigeria. The study showed a COE value of 0.3145 $/kWh to 0.689 $/kWh [9]. Previous researchers conducted a study on micro-hydro (MH)-PV-WT-DG utilization in Punjabi village, Pakistan. The study resulted in an NPC value of $284,877 and a COE value of 0.0437 $/kWh [10]. Previous researchers have also conducted a study on the feasibility of micro-hydro using single technology at Disty Jalala Canal in Pakistan. The results showed that the energy price was auspicious, namely 0.049 $/kWh [11]. A different study conducted a study on the feasibility of a PV system to serve electrical loads on ships. The feasibility study was able to reduce energy costs by $0.53 $/kWh [12].

Previous researchers have also investigated the off-grid system combined with PLTS-DG in three villages in Peru. The three villages are Campo serio, El potrero, and Silicucho. The COE values generated by the villages of Campo serio, El potrero, and Silicucho are respectively 0.478 $/kWh, 0.460 $/kWh, and 0.504 $/kWh [17]. Other researchers have also conducted studies in the Korkadu district, India. The study involves three renewable energy sources, namely PV-WT-GBi. The study results resulted in an NPC of Rs.1.21M and a COE of 13.71 Rs/kWh. Another consequence of the study is that the system can reduce CO_2, CO, and NOx by 0.196 kg/year, 0.25 kg/year, and 0.291 kg/year, respectively [4]. Another researcher applied the combination of PV-WT-GBi-Syngas-Hydrokinetic-BAT in the Eastern District of Sikkim, India. The study resulted in a COE value of 0.095 $/kWh [18]. Previous researchers have also conducted a PV-WT-BAT hybrid study in the Colombian Community village of Unguía. Researchers use Branch and cut Algorithm to optimize cost and emission reduction. The results of the survey yielded quite promising costs and emissions [19].

In this study, researchers propose an HRES micro-grid on Sebesi Island, Rajabasa, South Lampung, Indonesia. The authors investigate the need for electrical energy to introduce the HRES concept to the island's energy area to achieve the goal. The authors present a feasibility study of six various configurations of HRES for island electrification. Candidate technologies considered include PV, Wind, biomass, and batteries. This study aims to ensure that the electrical load in the Sebesi Island settlement receives a continuous supply of electrical power by considering environmental and economic aspects. The researchers used the HOMER software in this study.

2. Methodology

This study uses the HOMER software to assess the base scenario and six different scenarios based on technological, economic, and environmental perspectives. Homer Pro uses license ID 150793. Component size, generation contribution, and renewable fraction measure from a technology perspective. The value of NPC and COE effort from the economic side. At the same time, the number of emissions shows an environmental assessment. Following is a brief explanation regarding the evaluations mentioned above [20].

The current net charge is the definition of an NPC. Homer simulates the total cost of installing and operating the system and then reducing the total revenue throughout the project. The average cost of electrical energy ($/kWh) is the definition of COE. Alternatively, in other words, this parameter implies the annual electricity production cost to the total electricity load. These parameters have a mathematical formulation in equation (1) [21].

$$COE = (C_{ann,tot} - c_{boiler}\, H_{served})/E_{served} \quad (1)$$

where:

$C_{ann,tot}$: the total annual cost of the system ($/year)
c_{boiler} : the marginal cost of the boiler ($/kWh)
H_{served} : total thermal load served (kWh/year)
E_{served} : total electricity load served (kWh /year)

Another parameter of the economic assessment is operating costs (OC). OC is the cost during operation and maintenance each year. The cost of capital does not include OC as part of the cost of capital. Therefore, OC is not part of the cost of capital. The mathematical formula of the parameter is shown in equation (2) [22]. The first cost of implementing the system is called the initial capital (IC). Capital costs are in the form of purchasing and installing components at the beginning of the project.

$$C_{operating} = C_{ann,tot} - C_{ann,cap} \quad (2)$$

where:

$C_{operating}$: total annual costs ($/year)
$C_{ann,cap}$: total annual capital costs ($/year)

The contribution of renewable energy to the total generation supplied to the electrical load is called The renewable fraction. The modeling is shown in equation (3)[23].

$$f_{ren} = 1 - [(E_{nonren} + H_{nonren})/(E_{served} + H_{served})] \quad (3)$$

where:

E_{nonren} : production of electrical energy that is not from renewable energy (kWh/year)
$E_{grid\ sales}$: energy sold to the grid (kWh/year)
H_{nonren} : production of thermal energy that is not from renewable energy (kWh/year)
E_{served} : total electricity load served (kWh/year)
H_{served} : total heat load served (kWh/year)

Emissions produced by diesel and biogas generators (GBi) are Carbon Dioxide (CO_2), Carbon Monoxide (CO), Unburned Hydrocarbons (UHC), Particulate Matter (PM), Sulfur Dioxide (SO_2), and Nitrogen Oxides (NO_X). However, this study only counts CO_2 as the pollutant that contributes the most to damaging the environment. The emission content of each pollutant in diesel fuel and biogas can be seen in Table 1 [20].

The researcher carried out HRES optimization planning through three stages, namely the assessment stage, the simulation stage, and the evaluation stage. First, the assessment stage is location studies, load profile studies, and energy source studies. At this stage, the researchers designed a PV system contributing about 50% of the total daily energy. Then, simulation stage, the HRES scenario is carried out based on data from the assessment stage. In the final step, the researcher compares the final results of several plans with the basic scenario based on a techno-economic-environmental study. Figure 1 shows the optimization procedure.

3. Input Parameter of System

3.1. Load Profile

Sebesi Island is an island located in the Sunda Strait, South Lampung. The data collection location has coordinates of 5°56.2'S and 105°30.6'E, as shown in Fig. 2. With an area of about 24.25 km2, the island has 2,742 people [24]. With an area of about 24.25 km2, the island has 2,742 people [24]. The majority of the electricity load on Sebesi Island is household. Other facilities such as health, village office, and port office are 1 unit each. In contrast, the mosque consists of 4 houses of worship. Therefore, the number of households on the island is about 751 households. Currently, the number of electricity customers is about 500 electricity connections. Table 2 summarizes the leading equipment used. The pattern of electricity consumption, both daily and monthly, can be seen in Fig. 3.

3.2. Solar Energy

For data on solar radiation on Sebesi Island, researchers obtained the data from the NASA Surface Meteorological and Solar Energy Tool available in the HOMER software. Figure 4 shows the average solar radiation on Sebesi Island that has the potential for solar energy with an annual average of 4.75 kWh/m^2/day. Table 3 shows a design with solar energy utilization of 50% of the total daily energy requirement [25].

3.3. Wind Energy

For wind energy data, researchers took data from Homer based on the research location points. The wind speed at the location ranges from 3.5 m/s – 4.2 m/s. The average wind speed is 3.79 m/s with a hub height of 10 m. Figure 5 shows the potential for wind energy on Sebesi Island.

3.4. Biomass

The main commodities from their plantations are coconut, coffee, cocoa, and bananas. Meanwhile, coconut production is 58.309 tons/year, coffee is 1.9370 tons/year, cocoa is 5.4696 tons/year, and bananas is 1,180.5 tons/year [26].

3.5. Diesel Generator

In this paper, the researcher considers the diesel generator scenario as the base case. The price of diesel fuel on Sebesi Island is around 0.665 $/liter. Table 4 shows the characteristics and costs of each component.

Table 1. Emission content for every pollutant [20]

Types of pollutants	Symbol	Unit	Amount of pollutants
Carbon dioxide	CO_2	%	88
Carbon monoxide	CO	gr/L	17.794
Unburned hydrocarbon	UHC	gr/L	0.72
Particulate matter	PM	gr/L	0.0712
Sulfur dioxide	SO_2	%	2.2
Nitrogen Oxides	NO_x	gr/L	1.4235

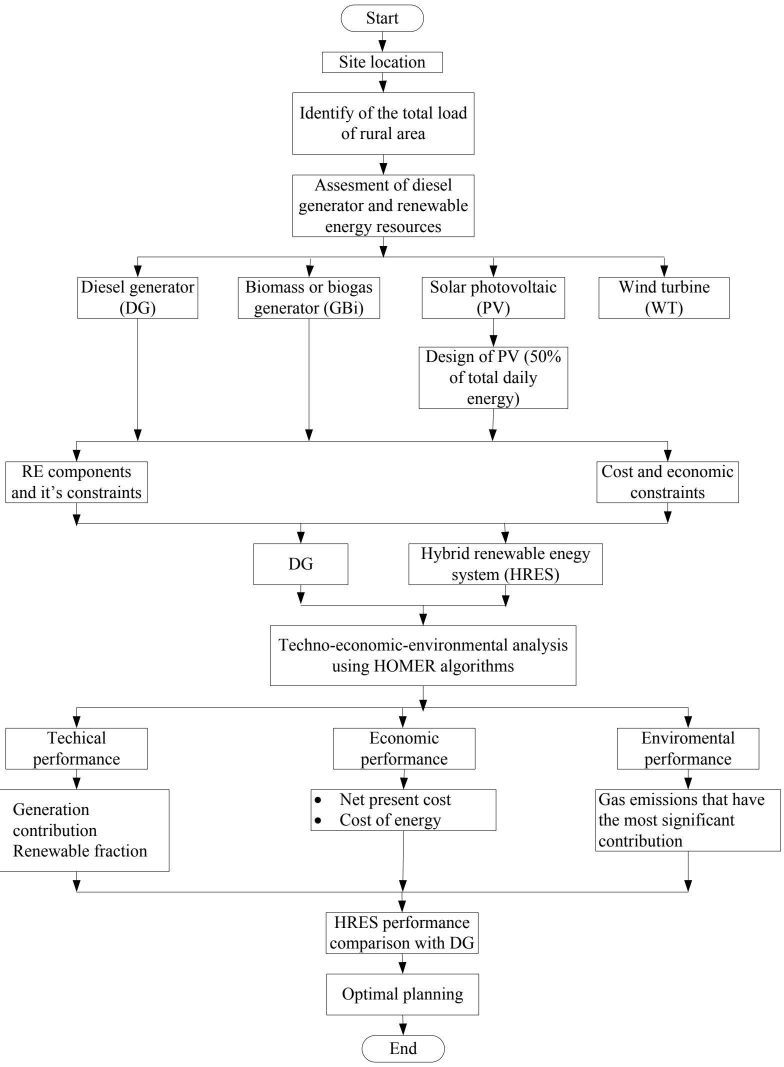

Fig. 1. Methodology of the analysis of the proposed hybrid renewable energy system.

Fig. 2. Site coordinates in Sebesi Island.

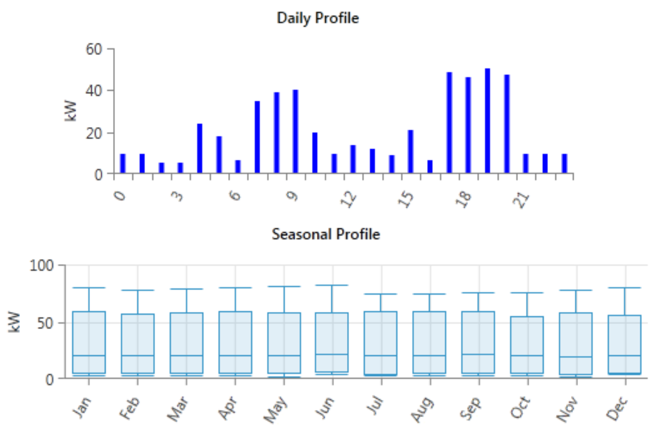

Fig. 3. Daily and monthly load profiles in Sebesi Island.

Table 2. Typical Electrical Loads for Household and Office Scale are The Main Loads on Sebesi Island

No	Main Load	Power (kW)	Duration of Use (h)	Energy Consumption (kWh)
1.	Television	0.08000	4	0.3200
2.	Rice cooker	0.35000	1	0.0720
3.	Water pump	0.27000	1	0.2700
4.	Lighting	0.04800	6	0.2880
5.	Fans	0.03000	1	0.0300
6.	Other	0.01006	3	0.0302
Total consumption of 500 electricity customers				505.10

Table 3. The Summary of Calculated Result from Component Design to Supply Fifty Percent of Total Daily Energy [25].

Steps	The components	Index	Parameters	Unit	Formula	Capacity	
						Calculation	Rounding
A	Load	A1	50% of the supplied load	kWh	505.1 × 50 %	252.55	252.55
		A2	GHI	kWh/ m²/ day	-	4.76	-
B	Module Capacity	B1	Peak Power	kWp	A1/A2	53.06	54
		B2	Additional capacity	%	-	125	-
		B3	Total module capacity	kWp	B1×B2	67.5	68
C	Land	C1	The efficiency of the solar module	%	-	16.94	-
		C2	Effective area	m²	B3/C1	401.42	402
		C3	Addition of area capacity	m²	-	200	-
		C4	Total area	m²	C2×C3	804	804
D	Module PV	D1	The capacity of each module	Wp	-	320	-
		D2	Number of modules	Unit	(B3 ×1000)/D1	212.5	214
E	Battery	E1	Autonomous day	day	-	2	-
		E2	Battery capacity	Wh	(A1 ×1000)×E1	505,100	505,100
F	Maximum power	F	Maximum load	kW	-	50.592	-
G	Converters	G1	Capacity per unit	kW	-	25	-
		G2	Additional percentage	%	-	125	-
		G3	Total capacity	kW	F × G2	63.240	64
		G4	Number of inverters	Unit	G3/G1	2.56	3
		G5	Nominal voltage system	Vdc	-	580	-
H	Battery	H1	Nominal voltage	Vdc	-	12	-
		H2	Nominal current	Ah	-	2,060	-
		H3	Number of series batteries	Unit	G5/H1	48.33	50
		H4	Number of parallel batteries	Unit	E2/(G5 ×0.8 ×H2)	0.53	1
		H5	Number of batteries	Unit	H3 × H4	50	50

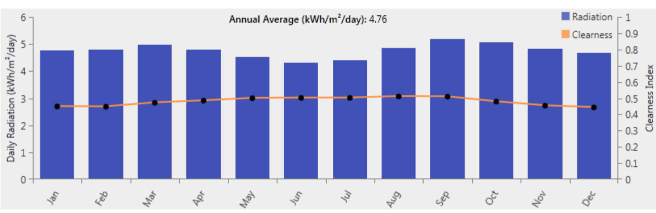

Fig. 4. Global horizontal irradiance (GHI) resource [20].

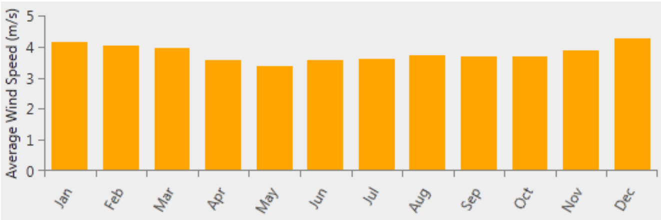

Fig. 5. Profile of average wind speed [20]

Table 4. Components Characteristic and Their Corresponding Costs

Descriptions	Size	Homer suffix	Capital cost ($)	Replacement cost ($)	Operation & Maintenance ($)	Fabricant
PV [27]	325 W	PV	120.25	120.25	13.85	Canadian Solar
CONV [27]	25 kW	Converter	10,000	10,000	0.00	Fronius Symo
BAT [27]	24.8 kWh	PowerSafe 1800	5,580	5,580	4.20	EnerSy PowerSafe
DG [28]	100 kW	Generator	12,327	12,327	0.300 + 0.665/L	Generic
WT [29]	1 kW	AH1	1,250	1,250	50.00	Aeolos
GBi [28]	100 kW	BioCo	40,000	40,000	2.00	Generic

4. Results and Discussion

This paper will determine the optimal values of technology, economy, and environment using Homer software. Seven various scenarios are identified in this paper, as shown in Table 5. The three diesel generators are only compared with other scenarios to assess technologically, economically, and environmentally.

Assessment from the technology side using optimal capacity (component size), generation contribution, and renewable fractions. Table 6 shows a summary of these assessments. The table shows that GBi has an optimal capacity of 100 kW for scenarios 1 to 6. The generation contribution is in the range of 47.1% - 100%. PV has an optimal size of around 69.2 kW – 69.5 kW. The components have a contribution to the generation in the range between 20.3% - 51.9%. As for WT, of the three scenarios involving the energy, scenarios 2, 4, and 6 recommend component sizes ranging from only 1 kW – 4 kW. The contribution of generation from the power is relatively minimal, namely 0.118% - 0.868%. The recommended number of batteries is 49 battery units.

For an assessment from a technology perspective, scenario 2 has the minor generation contribution (GC). However, the scenario can produce the most significant renewable fraction (RF). The means that can use the energy produced by scenario two can be used optimally with a daily energy requirement of 505.1 kWh. Table 7 shows the assessment based on an economic perspective. Researchers investigated the six scenarios from HRES to determine the scenario with the lowest NPC and COE values. From Table 7, it can see that the minimum NPC and COE values are $928.279 and $0.286/year. These values are generated by scenario 1. The scenario can reduce the NPC and COE values by 28.04% and 27.96%, respectively. So it can say that scenario 1 is the most optimal scenario from an economic perspective.

Table 8 shows the assessment based on an environmental perspective. The HRES scenarios that can reduce gas emissions are the highest from the table compared to the baseline scenario. The results of the investigation show that the second scenario produces the lowest emission gases. From the emission gases produced, the scenario can reduce gas emissions such as CO_2 by 81.87%, CO by 68.88%, Hydrocarbons by 68.92%, Particulate Matter by 68.84%, Sulfur Dioxide by 93.78 %, and NO_x of 69.02%. The second scenario is also able to reduce fuel consumption by 93.74%. Based on these analyzes, it can conclude that the second scenario is the most optimal scenario based on the environmental perspective. Several previous analyzes show that the first scenario is only superior based on an assessment from an economic perspective. In contrast, the second scenario has the evaluation advantage from the standpoint of technology and the environment. Because the second scenario has the most dominant advantage, from the results of this study, the researchers recommend the second scenario as the most feasible scenario to be implemented based on the three assessment perspectives.

Table 5. Scenarios Used in This Paper

Scenarios	Scenarios
Base	3DG
1	PV-GBi-BAT
2	PV-WT-GBi-BAT
3	GBi
4	WT-GBi
5	PV-GBi
6	PV-WT-GBi

Table 6. Summary of Optimal Capacity and Generating Contribution in Each Scenario Investigated

The components			Scenarios						
			Base	1	2	3	4	5	6
3DG	OC[a]	(kW)	100	-	-	-	-	-	-
	GC[b]	(kW/yr)	268,469	-	-	-	-	-	-
		%	100	-	-	-	-	-	-
GBi	OC	(kW)	-	100	100	100	100	100	100
	GC	(kW/yr)	-	91,386	89,285	268,469	268,330	251,775	251,650
		%	-	48.1	47.1	100	99.8	71.9	71.8
PV	OC	(kW)	-	69.5	69.5	-	-	69.3	69.2
	GC	(kW/yr)	-	98,701	98,704	-	-	98,349	98,279
		%	-	51.9	52	-	-	28.1	28.1
WT	OC	(kW)	-	-	4	-	1	-	1
	GC	(kW/yr)	-	-	1,647	-	412	-	412
		%	-	-	0.868	-	0.153	-	0.118
Total	GC	(kW/yr)	268,469	190,087	**189,636**	268,469	268,742	350,124	350,341
BAT		(Unit)	-	49	49	-	-	-	-
CONV		(kW)	-	35.2	.5	-	-	25	25
Renewable Fraction		(%)	0.0	90.0	**91.1**	81.2	81.2	86.5	86.5

OC[a] : Optimal Capacity,
GC[b] : Generation Contribution

Table 7. Economic Assessment Using The Homer in Each Scenario Investigated

Scenarios	The Parameters					
	NPC	ΔNPC	COE	ΔCOE	OC	IC
	$	%	$	%	$/yr	$
Base	1.29M	0.00	0.397	0.00	72,364	15,000
1	**928,279**	**28.04**	**0.286**	**27.96**	32,704	363,219
2	934,837	27.53	0.288	27.46	32,763	358,739
3	1.40M	-8.53	0.433	-9.07	77.621	40,000
4	1.41M	-9.30	0.435	-9.57	77,791	41,250
5	1.46M	-13.18	0.450	-13.35	78.714	75,633
6	1.46M	-13.18	0.452	-13.85	78.878	76,865

Table 8. Environmental Assessment Using The Homer in Each Scenario Investigated

Parameters	Unit	Scenarios						
		Base	1	2	3	4	5	6
Carbon Oxide (CO_2)	(kg/ yr)	241,812	44,584	43,843	140,772	140,718	133,806	133,753
Reduction	(%)	0.00	81.56	**81.87**	41.78	41.81	44.67	99.94
Carbon monoxide (CO)	(kg/yr)	1,645	524	512	1,645	1,644	1,564	1,563
Reduction	(%)	0.00	68.15	**68.88**	0.00	0.06	4.92	4.98
Unburned Hydrocarbon	(kg/yr)	66.6	21.2	20.7	66.6	66.5	63.3	63.2
Reduction	(%)	0.00	68.17	**68.92**	0.00	0.15	4.95	5.11
Particulate Matter	(kg/yr)	6.58	2.1	2.05	6.58	6.58	6.26	6.25
Reduction	(%)	0.00	68.09	**68.84**	0.00	0.00	4.86	5.02
Sulfur Dioxide	(kg/yr)	593	37.7	36.9	119	118	113	113
Reduction	(%)	0.00	93.64	**93.78**	79.93	80.10	80.94	80.94
Nitrogen Oxides (NO_x)	(kg/yr)	132	41.9	40.9	132	132	125	125
Reduction	(%)	0.00	68.26	**69.02**	0.00	0.00	5.30	5.30
Fuel Consumptions	(L/yr)	92,451	5,919	5,786	18,528	18,520	17,607	17,600
Reduction	(%)	0.00	93.60	**93.74**	79.96	99.98	80.96	80.96

5. Conclusion

This paper investigates the techno-economic-environmental performance of a power generation system for the off-grid community in Indonesia. Researchers conducted a study on Sebesi Island, South Lampung, Indonesia, by modeling six different wind turbines, solar panels, biomass, and battery/non-battery. To minimize NPC and COE, Homer will simulate six scenarios based on the optimal size of each component, the contribution of energy produced, the given renewable fraction, and the amount of emission generated. The results achieved are then evaluated by considering the economic index and environmental performance.

From a technology perspective, the second scenario is the best compared to other HRES scenarios. The scenarios can contribute to the most efficient generation with the most significant renewable fraction. From an economic perspective, the first scenario is the best. The scenario can reduce the parameters of the NPC and COE to the base scenario, which are 28.04% and 27.96%, respectively. As for the environmental perspective, the second scenario shows the best scenario. The scenario can produce the lowest emission gases when compared to other scenarios. However, if the government implements an emission incentive policy, then COE can create lower value. From the results above, it can say that the second scenario (PV-WT-GBi-BAT) is the ideal scenario, so it is feasible to be recommended to the government and investors when they want to implement HRES in the future. However, this study has not mitigated the existence of resource uncertainty, changing component prices, and other uncertainties. So that in future research, researchers will use sensitivity analysis as a mitigation measure against the uncertainty factor.

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