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Techno-Economic Analysis and Optimisation of Campus Grid-Connected Hybrid Renewable Energy System Using HOMER Grid

T. M. I. Riayatsyah [1,*], T. A. Geumpana [2], I. M. Rizwanul Fattah [3], Samsul Rizal [4] and T. M. Indra Mahlia [3,5,*]

[1] Mechanical Engineering Program, Institut Teknologi Sumatera (ITERA), South Lampung 35365, Indonesia
[2] School of Information and Physical Science, University of Newcastle, Newcastle, NSW 2308, Australia; teuku.geumpana@newcastle.edu.au
[3] Centre for Green Technology, School of Civil and Environmental Engineering, Faculty of Engineering and Information Technology, University of Technology Sydney, Sydney, NSW 2007, Australia; islammdrizwanul.fattah@uts.edu.au
[4] Department of Mechanical Engineering, Universitas Syiah Kuala, Banda Aceh 23111, Indonesia; samsul.rizal@unsyiah.ac.id
[5] Department of Mechanical Engineering, College of Engineering, Universiti Tenaga Nasional, Kajang 43000, Malaysia
* Correspondence: t.indra@ms.itera.ac.id (T.M.I.R.); tmindra.mahlia@uts.edu.au (T.M.I.M.); Tel.: +62-8525-4483-660 (T.M.I.R.); +61-416-646-288 (T.M.I.M.)

Abstract: This study aimed to conduct a techno-economic performance and optimisation analysis of grid-connected PV, wind turbines, and battery packs for Syiah Kuala University, situated at the tip of Sumatra island in the tsunami-affected region. The simulation software Hybrid Optimisation Model for Electric Renewables (HOMER) was used to analyse and optimise the renewable energy required by the institution. The methodology began with the location specification, average electric load demand, daily radiation, clearness index, location daily temperature, and system architecture. The results revealed that the energy storage system was initially included in the simulation, but it was later removed in order to save money and optimise the share of renewable energy. Based on the optimisation results, two types of energy sources were chosen for the system, solar PV and wind turbine, which contributed 62% and 20%, respectively. Apart from the renewable energy faction, another reason for the system selection is cost of energy (*CoE*), which decreased to $0.0446/kWh from $0.060/kWh. In conclusion, the study found that by connecting solar PV and wind turbines to the local grid, this renewable energy system is able to contribute up to 82% of the electricity required. However, the obstacle to implementing renewable energy in Indonesia is the cheap electricity price that is mainly generated using cheap coal, which is abundantly available in the country.

Keywords: techno-economic analysis; grid-connected; wind turbine; HOMER grid; emission mitigation

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1. Introduction

Global warming was highlighted by scientists decades ago after the industrial revolution that burned a tremendous amount of fossil fuel. The impact of global warming can be felt today by climate changes around the globe due to the influence of human activity on the provision of energy [1]. One of the significant contributors to global warming is electricity generation, which mainly uses coal, gas and oil. These fossil fuels release a significant amount of greenhouse gas emissions. This has become worse with the current conflict between Russia and Ukraine. The price of fossil fuels has escalated remarkably; therefore, this is the perfect time to implement renewable energy policy more intensely in countries that import fossil fuels. The implementation of renewable energy as a replacement for fossil fuels and tackling global warming have been successfully implemented in developed countries, which developing countries can learn from [2].

Indonesia still uses coal as the primary energy source for electricity generation to provide cheap electricity to the population. Even though Indonesia is archipelagic in nature, there is still a lack of attention towards global warming at the societal level. There are symbolic gestures and jargon playing by the government about using the massive availability of renewable energy, but, still, little has been implemented at grass-root level. The country is not only blessed with plenty of solar energy, where an equatorial line splits the country, but it is also gifted with one of the most significant sources of geothermal energy. However, the potential development of geothermal energy for commercial electrical generation is still minimal. On some islands of the country there is a very high potential for wind energy, whether onshore or offshore, but very few wind turbines have been installed in the country. The proportions of total energy, electricity and renewable energy mix in Indonesia are presented in Figure 1 [3–5].

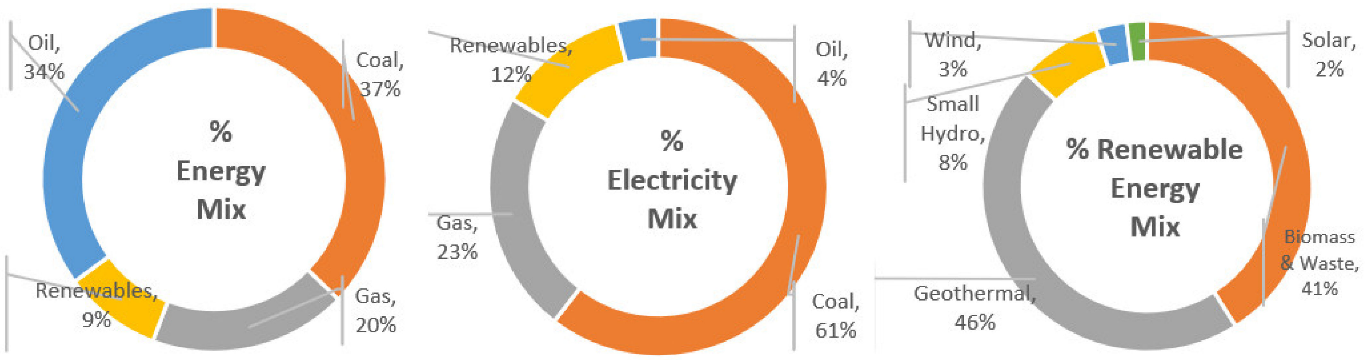

Figure 1. Proportions of total energy, electricity and renewable energy mix in Indonesia.

Renewable energy is not a new concept. It was implemented long ago, but it has become popular since the Middle East oil embargo in the 1970s. Since that crisis, renewable energy has progressed well and become comparable to fossil fuel after it was introduced many decades ago [6]. The most popular renewable energy source used to be hydropower, which requires massive investment to build a dam. Hydropower can also be used to reduce flooding, as seen in the Three Gorges Dam in China and the Itaipu Dam in Paraguay. Even though hydropower has a high initial investment cost, the levelised energy cost is lower in the long run. Hydropower can also be implemented on a microscale. The issue that microscale hydropower faces is unstable electricity generation. Meanwhile, the most popular renewable energy sources today are wind turbines and solar PV due to their remarkable price decrease and tremendous increase in efficiency, which makes levelised energy cost-competitive with cheap fossil fuels such as coal [7–9]. There is a lot of research to make solar energy competitive such as using nanofluid [10] and the improvement of performance by utilising a solar thermal dryer with a compound parabolic concentrator [11]. This grid-connected system has been used widely in many countries, especially for the smart city [12]. It has been shown through techno-economic analysis that standalone and grid-connected hybrid energy systems are feasible to implement [13]. Many papers have been published on renewable energy simulation using HOMER. However, this is the first attempt to use the HOMER grid to simulate the grid-connected system for a public institution. One of the main reasons Indonesia is still yet to implement renewable energy seriously is due to the society's and government's lack of critical mass concerning electricity generation commercially from renewable energy. Therefore, this study attempts to conduct a techno-economic analysis and optimisation of campus grid-connected solar PV–wind turbines using the HOMER grid, which the future generation and society can learn to create critical mass at the lower level of the society. The structure of the paper is divided into four sections: introduction, methodology, results and discussion, as well as conclusions.

2. Methodology

To properly investigate the operational behaviour of all feasible scenarios, the evaluation of renewable energy projects often needs the application of relevant criteria to on-site location data. The following analytical framework was employed in this study [14]:

(a) Location specification.
(b) The modelling data require:
   (i) average electric load demand;
   (ii) daily radiation and clearness index at the location;
   (iii) daily temperature at the location.
(c) System architecture.

The data collected from the plant's location were visualised and examined using these criteria. Each criterion was addressed and investigated to characterise the entire system design, emphasising the renewable energy component choices. The HOMER grid was used, which was developed in 2018 as a more efficient way for modelling hybrid energy systems and analysing solutions for lowering electricity costs for a grid-connected system. The elder sister of the software has been used widely for the techno-economic analysis of renewable energy simulation for standalone systems [14–17]. It is a powerful tool that integrates engineering and economics data into a single model, allowing complicated calculations to assess self-consumption value, demand charge reduction, and energy arbitrage quickly. Users may analyse several components and design outputs, find cost-competitive points for alternative technologies, examine strategies for reducing project risk, and identify the best cost-effective design. It also replicates real-world performance to help system designers and optimisers make better decisions. The flowchart of the methodology is presented in Figure 2.

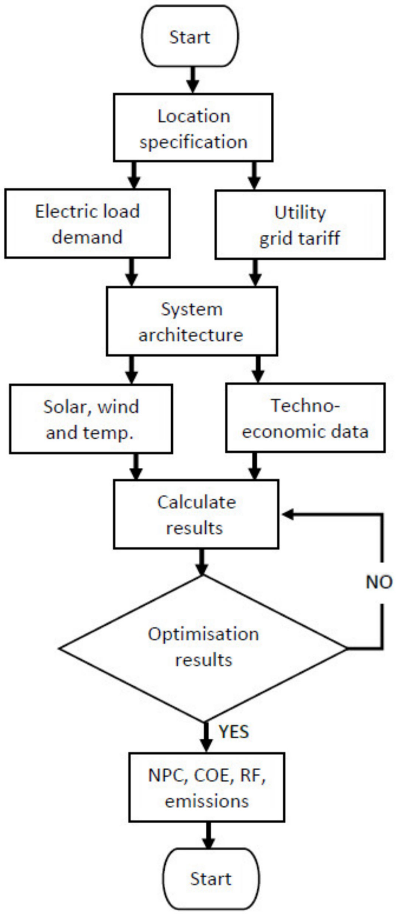

Figure 2. Methodology flowchart.

2.1. Location Specification

The location selected was a public university named Syiah Kuala University located exactly at the tip of Sumatra island, in the Aceh province, which was severely hit by the tsunami in 2004. The institution was established on 2 September 1961. It now has twelve faculties, all of which provide diplomas and undergraduate and postgraduate degrees. It consists of 131 student study spaces, laboratories for experimentation, and community service spaces. The departments and faculties include laboratories of economics, veterinary science, law, engineering, agriculture, medical, mathematics and natural sciences, with one integrated laboratory, and the university has a total campus size of 1,324,300 m^2. The university has 26,010 students and 1630 staff. The institution uses electricity from the grid provided by the national electricity company, which is well known for an unstable supply, especially for this part of the country.

The facility is at H997 + 7G Meunasah Papeun, Aceh Besar Regency (5°34.1′ N, 95°21.8′ E), Aceh, Indonesia, and is served by a utility company grid. The electricity tariff plan is currently the simple tariff. The location of the facility in the Republic of Indonesia map is presented in Figure 3, and the road view map of the facility is depicted in Figure 4. Some input data are required to calculate the optimisation system with optimal output and minimum cost for this renewable energy power generation, which will be presented in the figures and tabulated in the tables in this section.

Figure 3. Location of the facility on the Republic of Indonesia map [18].

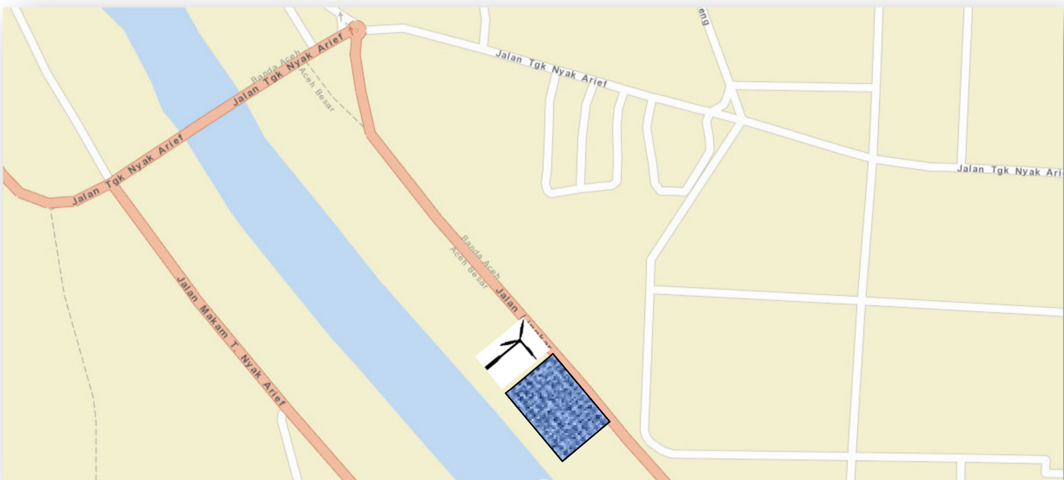

Figure 4. The road view map of the facility [18].

2.2. Modelling Data

2.2.1. Average Electric Load Demand

There is no electric load demand available for this institution. However, the electricity consumption and the institution's bill are available and are tabulated in Table 1 [19]. These data are used to predict the load demand of the system based on commercial HOMER grid electric load. Due to its tropical climate, it is believed that the average electric load is not much different for the whole year. The predicted average electric load of the institution based on the electric bill is depicted in Figure 5.

Table 1. The electricity consumption and the bill of the institution.

Consumption (kWh)	Bill (Rp)	Rp/kWh	Hour	Load (kW)	kWh/Day
814,040	663,756,828	815	744	1094	26,259
759,024	608,413,263	802	672	1130	27,108
766,541	619,772,327	809	696	1101	26,432
631,388	510,497,303	809	744	849	20,367
987,853	815,653,733	826	720	1372	32,928
906,319	737,186,032	813	744	1218	29,236
629,529	510,497,303	811	720	874	20,984
901,153	732,984,301	813	744	1211	29,069
1,000,082	833,579,199	834	744	1344	32,261
1,137,827	949,824,712	835	720	1580	37,928
1,049,616	884,629,528	843	744	1411	33,859
1,024,345	862,610,534	842	720	1423	34,145
Tot: 10,607,717	Tot: 8,729,405,063	Ave: 823	Tot: 8760	Ave: 1211	Ave: 29,062

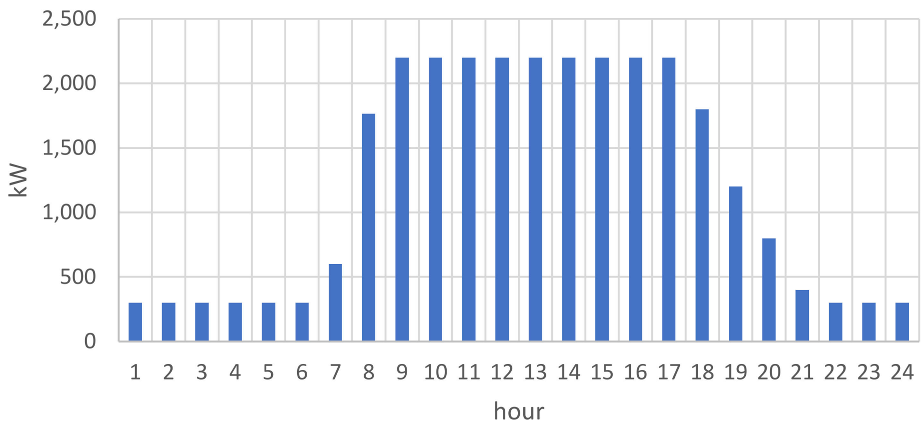

Figure 5. The predicted average electric load of the institution based on the electric bill.

2.2.2. Radiation, Clearness Index, Temperature and Wind Speed

The daily radiation and clearness index statistics are indicators of the atmosphere's clarity. The percentage of solar energy passes through the atmosphere and reaches the Earth's surface. It is a one-dimensional number between 0 and 1 calculated by dividing surface radiation by extra-terrestrial radiation. The clearness index has a high value when the weather is clear and sunny and a low value when the weather is overcast [20]. The solar daily radiation and clearness index at the location is depicted in Figure 6, the selected location's daily temperature is presented in Figure 7 and the monthly average wind speed at the location is given in Figure 8.

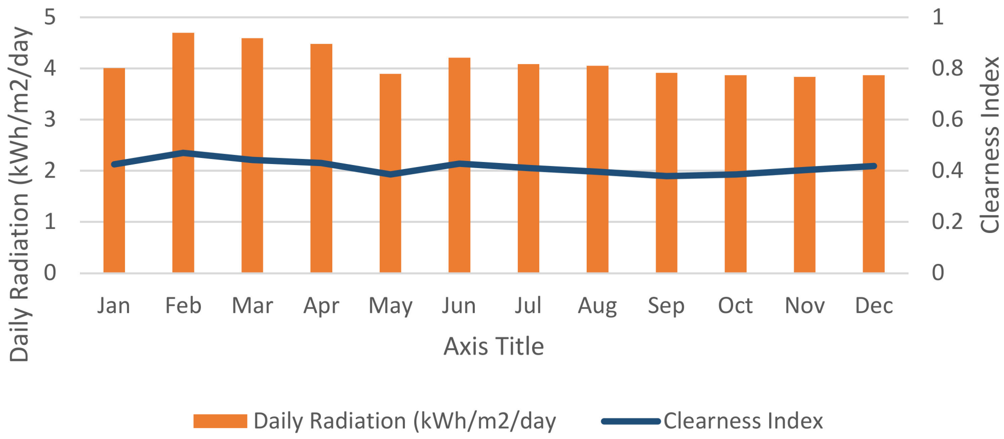

Figure 6. Solar daily radiation and clearness index at the location [21].

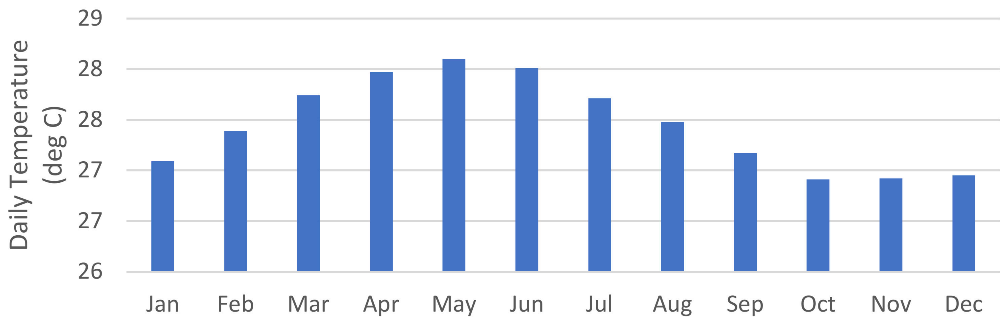

Figure 7. The daily temperature at the location [21].

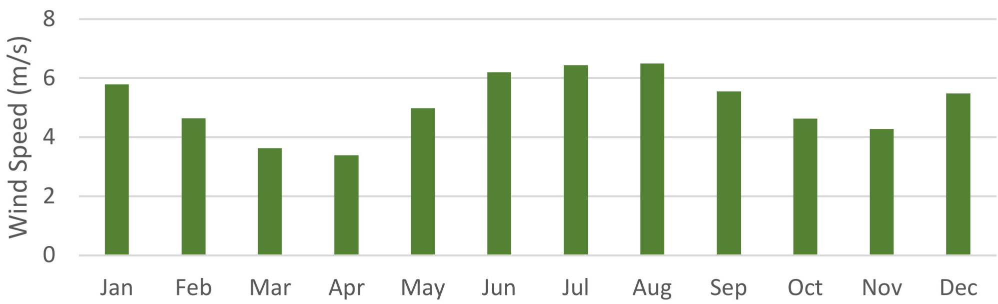

Figure 8. The monthly average wind speed at the location [22].

2.3. Proposed System Architecture

The system architecture must be designed first to simulate the renewable energy system. In this case, the system architecture consists of power sources from the utility, PV, wind turbine, lithium battery, converter and the load as presented above. The schematic representation of the proposed system design is presented in Figure 9. The detailed information of the proposed system is tabulated in Table 2. The location of the proposed system is H997 + 7G Meunasah Papeun, Aceh Besar Regency, Aceh, Indonesia (5°34.1′ N, 95°21.8′ E), which is only 200 m from Syiah Kuala University. The scenario of the suggested renewable energy system is for solar PV, wind turbines, and battery energy storage.

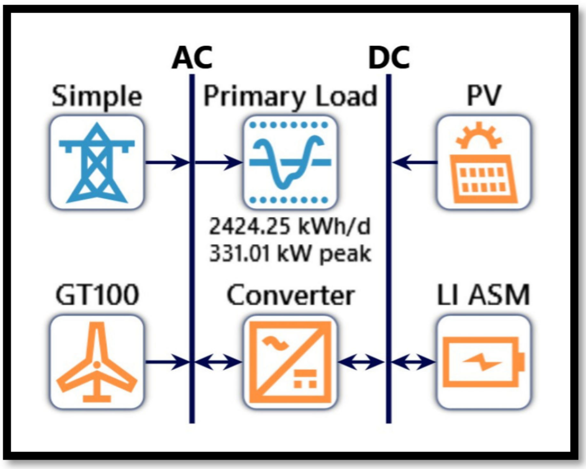

Figure 9. Proposed system architecture.

Table 2. The components of the proposed system architecture.

Component	Name	Capital Cost ($)	Replacement Cost $	O&M Cost ($)	Lifetime	References
PV	Flat-plate PV	1073/kW	1073/kW	10/year	25 year	[23]
Storage	1 kWh Lead Acid	300/kW	2100/kW	25/year	10 year	[18]
Wind turbine	GT [100 kW]	210,000	210,000	3500/year	25 year	[24]
Converter	System Converter	700/kW	300/kW	0	15 year	[18]
Utility	Simple Tariff	0.06/kWh	-	-	-	[19]

2.3.1. Photovoltaic

In a photovoltaic system, a debating factor that is a scaling factor is applied to the PV array output and a debating factor of 90% for the component is added to account for the losses and those attributable to *PV* panel soiling [25]. The *PV* array's energy output is determined using the formula below [20]:

$$P_{PV} = f_{PV} \times Y_{PV} \times \left(\frac{I_T}{I_S}\right) \tag{1}$$

The price of solar *PV* will decrease when the installed capacity increases; for this project the price will decrease to 93%, 66% and 54% for 10 kW, 1000 kW and 2000 kW, respectively [18]. The solar *PV* price used in this system is tabulated in Table 3 [18].

Table 3. The capacity and the price of generic flat-panel solar PV.

Capacity (kW)	Capital ($)	Replacement ($)	O&M ($/Year)
5	5365	5365	100
10	9979	9979	180
1000	708,180	708,180	1500
2000	1,158,840	1,158,840	3000

2.3.2. Wind Turbine

HOMER models a wind turbine as a device that converts wind kinetic energy into AC or DC electricity via a power curve (a graph of power output against wind speed at hub height). HOMER estimates the wind turbine's electricity production every hour in a four-step procedure. First, it uses wind resource data to determine the average wind speed for the hour at the anemometer height. Second, it uses either the logarithmic or power laws to calculate the correlation of wind speed at the turbine's hub height. The third step is to do with the turbine's power curve, which is used to calculate the turbine's power output based on traditional air density assumptions for a particular wind speed. The fourth step is the air density ratio, which is the ratio of actual to standard air density multiplied by the total power output. To extrapolate wind speed data in HOMER, use the power-law formula below:

$$U_{hub} = U_{anem} \left(\frac{Z_{hub}}{Z_{anem}} \right)^{\propto} \tag{2}$$

Applying density correction, power curves generally describe wind turbine performance under conventional temperature and pressure conditions (*STP*). HOMER adjusts to real-world circumstances by multiplying the air density ratio by the power value estimated by the power curve with the air density at standard temperature and pressure (1.225 kg/m^3), as follows:

$$P_{WTG} = \left(\frac{\rho}{\rho_0} \right) \times P_{WTG,STP} \tag{3}$$

2.3.3. Battery

A group of one or more separate batteries is referred to as a "battery bank". A single battery is modelled by HOMER as a device capable of holding a specific quantity of DC power with fixed energy efficiency, subject to limits on how rapidly it can be charged or drained, as well as how much energy can cycle through it before it has to be substituted. HOMER implies that the battery's characteristics stay consistent over time and are unaffected by environmental influences such as temperature. HOMER predicted the life of the battery bank just by monitoring the amount of energy cycling through it as the lifetime throughput is independent of cycle depth in this situation; for this study, the life of the battery bank was assumed to be 4 years [18]. The battery bank's life in years is calculated by HOMER as follows:

$$R_{batt} = MIN \left(\frac{N_{batt} \times Q_{lifetime}}{Q_{thrpt}},\ R_{batt,f} \right) \tag{4}$$

The expense of cycling energy through the storage bank is known as the battery wear cost. Suppose the storage characteristics show that throughput is a constraint on storage life. In this case, HOMER estimates that the storage bank will need to be replaced when its total throughput equals its lifetime throughput. As a result, the storage bank approaches its necessary replacement with each kWh of throughput. HOMER uses the following calculation to compute the cost of storage wear:

$$C_{bw} = \frac{C_{rep,batt}}{N_{batt} \times Q_{lifetime} \times \sqrt{\eta_{rt}}} \tag{5}$$

The capacity and the price of generic 1 kWh Li-ion are tabulated in Table 4.

Table 4. The capacity and the price of generic 1 kWh Li-ion.

Capacity (kW)	Capital ($)	Replacement ($)	O&M ($/Year)
5	3500	3500	0
10	7000	7000	0
200	110,000	110,000	1800
2000	850,000	850,000	16,000
8000	3,200,000	3,200,000	64,000
16,000	6,000,000	6,000,000	112,000

2.3.4. Converter

A converter is a device that transforms electric power from DC to AC in the inversion process and from AC to DC in the rectification phase. HOMER is capable of modelling both solid-state and rotary converters. The inverter capacity, or maximum amount of AC power that the device can create by inverting DC electricity, is referred to by the converter size. The user defines the rectifier capacity as a percentage of the inverter capacity, which is the maximum amount of DC power that the device can create by rectifying AC power. As a result, the rectifier capacity is not a distinct choice variable. HOMER implies that the inverter and rectifier capabilities are continuous, not surged, and that the device can handle the load for as long as needed.

The inverter can run in parallel with another AC power source, such as a generator or the grid. The inversion and rectification efficiencies of the converter are the ultimate physical attributes of the converter, which HOMER expects to remain constant. The converter's economic features are the capital cost, O&M cost and replacement costs in the US dollars per year and the converter's projected lifespan is in years.

2.4. Economic Analysis

Some economic data are necessary to calculate the techno-economic analysis of an engineering system. Those data include the nominal discount rate, expected inflation rate and project lifetime, to mention a few. The economic data required for this analysis are tabulated in Table 5.

Table 5. Economic input data.

Description	Value	Unit	References
Currency	US$1	Rp 14,000	[26]
Nominal discount rate	6.6	%	[27]
Expected inflation rate	2.0	%	[28]
Project lifetime	25	year	[29]

2.4.1. Interest Rate

The annual real interest rate, sometimes known as the real interest rate or simple interest rate, is one of HOMER's inputs. It is the discount rate used to convert one-time costs to annualised expenses. The following equation relates the yearly real interest rate to the nominal interest rate [20]:

$$i = \frac{i' - f}{1 + f}. \tag{6}$$

2.4.2. Levelised Cost of Energy

The average cost/kWh of useable electrical energy generated by the system is defined by HOMER as the levelised cost of energy (*CoE*). HOMER divides the yearly cost of generating electricity (total annualised cost minus cost of feeding the load) by the total useable electric energy output. The *CoE* is calculated as follows [20]:

$$CoE = \frac{C_{ann,tot}}{E_{prim,AC} + E_{prim,DC} + E_{grid,sales}} \tag{7}$$

The total annualised cost is the sum of each system component's annualised costs plus the other annualised costs. It is a significant number as HOMER utilises it to compute both the levelised and total net present costs of energy.

2.4.3. Net Present Cost (*NPC*)

The total net present cost (*NPC*) of a system is equal to the present value of all expenditures incurred over the system's lifespan minus the present value of all income earned over the system's lifetime. Capital expenses, replacement costs, operation and maintenance costs, fuel costs, pollution fines and the cost of obtaining electricity from the grid are all included in the costs. Salvage value and grid sales income are two sources of revenue. The total *NPC* is calculated by adding the total discounted cash flows in each year of the project's life cycle [20]:

$$C_{NPC} = \frac{C_{ann,tot}}{CRF(i, R_{proj})}. \tag{8}$$

In this study, the lifetime of the system is 25 years and the capital recovery factor is a ratio that is used to assess an annual present value (a series of equal annual cash flows). The capital recovery factor's equation is as follows [20]:

$$CRF(i, N) = \frac{i(1+i)^N}{(1+i)^N - 1}. \tag{9}$$

2.4.4. Salvage Value

The worth of a power system component that is still usable at the end of the project's lifespan is referred to as the salvage value. HOMER uses this equation to figure out how much each component is worth at the conclusion of the project's life cycle:

$$S = C_{rep}\frac{R_{rem}}{R_{comp}} \tag{10}$$

2.4.5. Internal Rate of Return

The internal rate of return (*IRR*) is the discount rate at which the reference case and the optimised system have the same net present cost. HOMER calculates the *IRR* by dividing the present value of the difference between the two cash flow sequences by the discount rate.

2.4.6. Return on Investment

The annual cost savings compared to the original expenditure is known as the return on investment (*ROI*). The *ROI* is calculated by dividing the difference in capital cost by the average annual difference in nominal cash flows during the project's lifespan. The return on investment is calculated by using the following equation:

$$ROI = \frac{\sum_{i=0}^{R_{proj}} C_{i,ref} - C_i}{R_{proj}\left(C_{cap} - C_{cap,ref}\right)} \tag{11}$$

2.4.7. Simple Payback

The number of years it takes for the cumulative cash flow of the difference between the optimised and reference case systems to transition from negative to positive is known as simple payback. The payback period is the time it takes to recover the investment cost difference between the optimised and reference case systems.

2.4.8. Total Annualised Cost

The total annualised cost of a component is the cost that would result in the same net present cost as the component's actual cash flow sequence if distributed evenly throughout the project's lifespan. The annualised cost is calculated by multiplying the net present cost by the capital recovery factor, as shown in the following equation:

$$C_{ann,\ tot} = CRF(i, R_{proj}) \times C_{NPC,tot} \tag{12}$$

2.4.9. Emissions Reduction

The potential energy generated by the purpose of the renewable energy system to replace energy from fossil fuels is used to calculate the emission reduction. This is measured in terms of emissions per unit of energy consumed. Table 6 shows the emission data used in this calculation.

Table 6. Emission data.

Emissions	Quantity (g/kWh)	References
Carbon dioxide	632	[18]
Sulphur dioxide	2.74	[18]
Nitrogen oxides	1.34	[18]

3. Results and Discussion

This section discusses the calculation results of the techno-economic analysis and optimisation of grid-connected solar PV and wind turbine using the HOMER grid for a whole campus. The optimisation results are discussed first, followed by the results of the techno-economic analysis, as well as the potential emissions reduction which is also presented briefly.

3.1. Optimisation Results

The optimisation results for the plant location H997 + 7G Meunasah Papeun, Aceh Besar regency, Aceh, Indonesia (5°34.1′ N, 95°21.8′ E) show that components were removed from the system architecture that is the energy storage lithium battery due to its high investment cost over the energy storage and due to its continuous supply of cheap electricity from the utility grid. The HOMER grid evaluates the cost for a list of system configurations and their capacities and selects the system based on the lowest *CoE* and renewable energy fraction. It determines the viability of hybridised energy systems over time in the simulation process. Following the hourly simulation, various configurations are generated, with the reference case system shown in light grey. In this study, eight distinct scenarios were evaluated among numerous configured energy systems to determine the optimal system design that best suits the institution's configuration system out of multiple combinations to meet the institution's load demand requirement. The optimised component detail is tabulated in Figure 10 (the reference case is in light grey). The most optimised system is presented in Figure 11. The optimised components' system detail is tabulated in Table 7.

Architecture				Cost				System
PV (kW)	GT100	LI ASM	Converter (kW)	NPC ($)	COE ($)	Operating cost ($/yr)	Initial capital ($)	Ren Frac (%)
682	1		431	$829,692	$0.0446	-$575.51	$838,217	81.9
				$786,452	$0.0600	$53,091	$0.00	0
		4	2.54	$789,209	$0.0602	$53,145	$1,961	0.00000843
0.00200			5.08	$789,640	$0.0602	$53,153	$2,276	0.000260
	1			$824,125	$0.0603	$40,445	$225,000	29.1
12.6		15	2.59	$801,495	$0.0611	$52,974	$16,779	0.911
	2	108	33.7	$935,991	$0.0630	$30,378	$485,996	53.1
50.5	1	62	10.4	$866,414	$0.0638	$39,465	$281,814	33.7

Figure 10. Optimisation results of the proposed system.

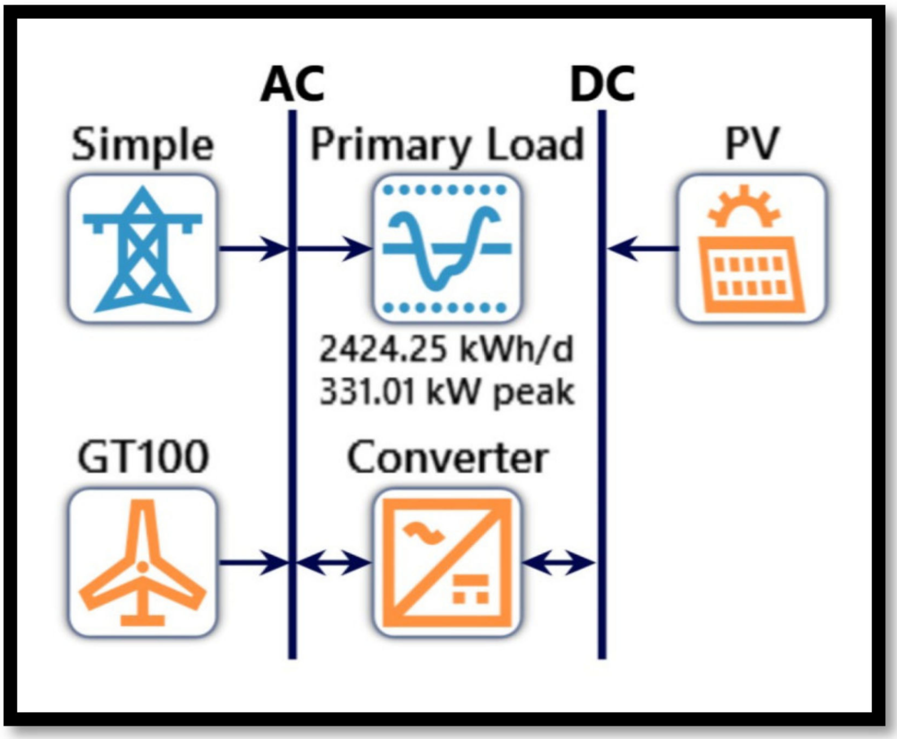

Figure 11. The optimised system architecture.

Table 7. Optimised components detail.

Component	Name	Size	Electricity Prod (kWh/Year)
Solar PV	Generic flat-plate PV	682 kW	833,813
Wind Turbine	GT100 (1 Unit)	100 kW	371.859
Utility	Simple Tariff	$0.06/kWh	226,981
System converter	System Converter	431 kW	-

This whole institution's electricity consumption is 2424 kWh per day with peak loads of 331 kW. The proposed system serves the electrical load by the following generating sources. The findings revealed that a grid-connected solar PV and wind turbine system had the lowest *CoE* (0.0446/kWh) throughout the project lifetime and the highest renewable energy faction (81.9~82%), as opposed to the reference scenario, which relies entirely on grid power, as can be seen in Table 7.

3.2. Electricity Generation and Consumption

The optimised system produces 82% renewable energy fraction share generated by solar PV at 822,813 kWh/year (62%) and wind turbine at 269,099 kWh/year (20%), as shown in Table 7. The electricity consumption is 884,852 kWh (70%) and grid sales are 371,859 Wh/year (30%). A summary of the optimised system's annual and monthly performance is presented in Figure 12, and the monthly electric production from PV, GT100 and grid is shown in Figure 13. The solar PV output and generic wind turbine output is presented in Figure 14, and the generic flat-plate PV output, energy purchased from the grid and energy sold to the grid are depicted in Figure 15.

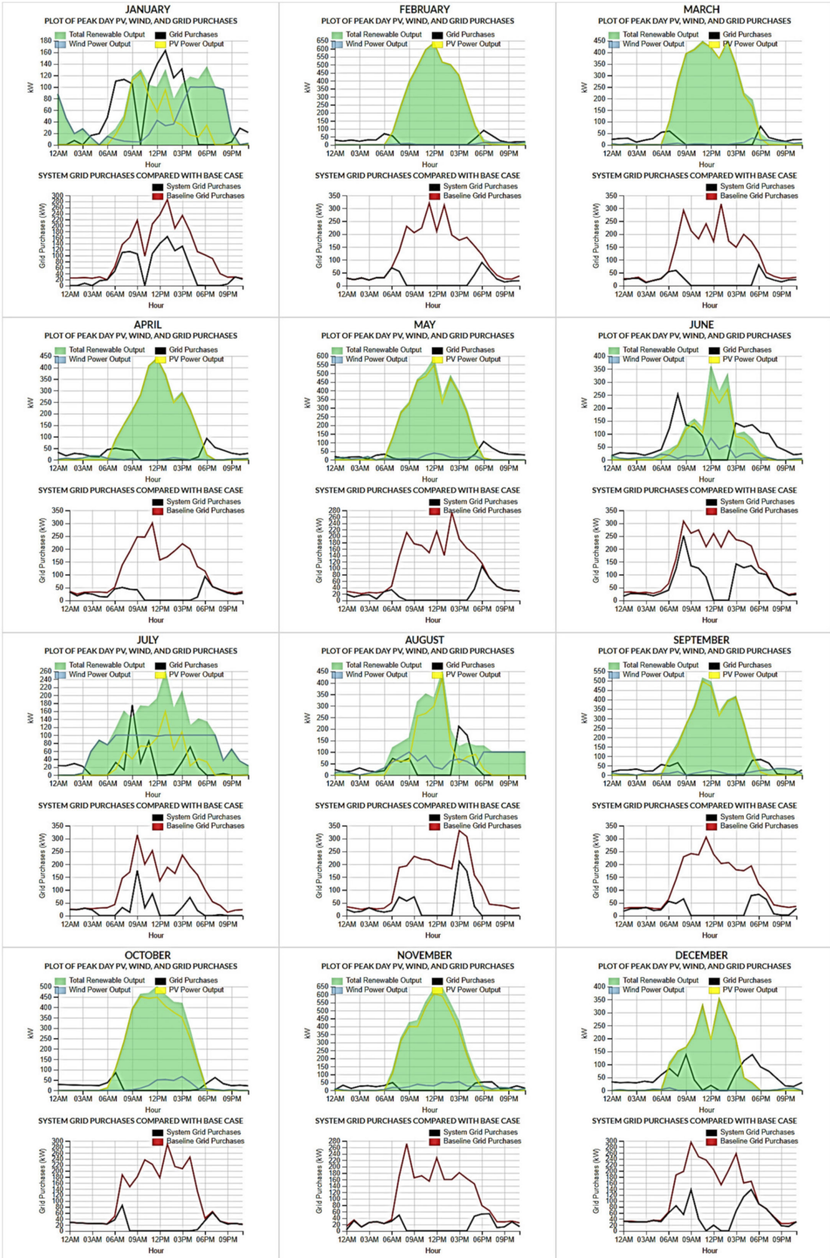

Figure 12. Summary of the annual monthly performance of the optimised system.

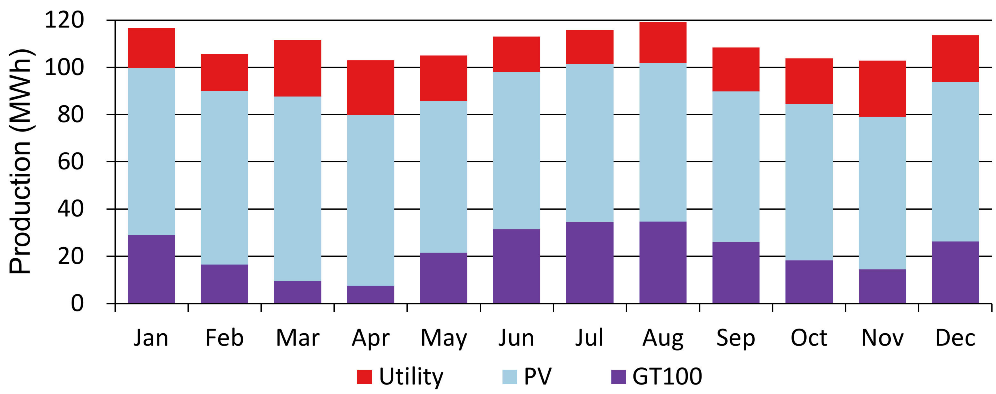

Figure 13. Monthly electric production of solar PV, GT100 and grid.

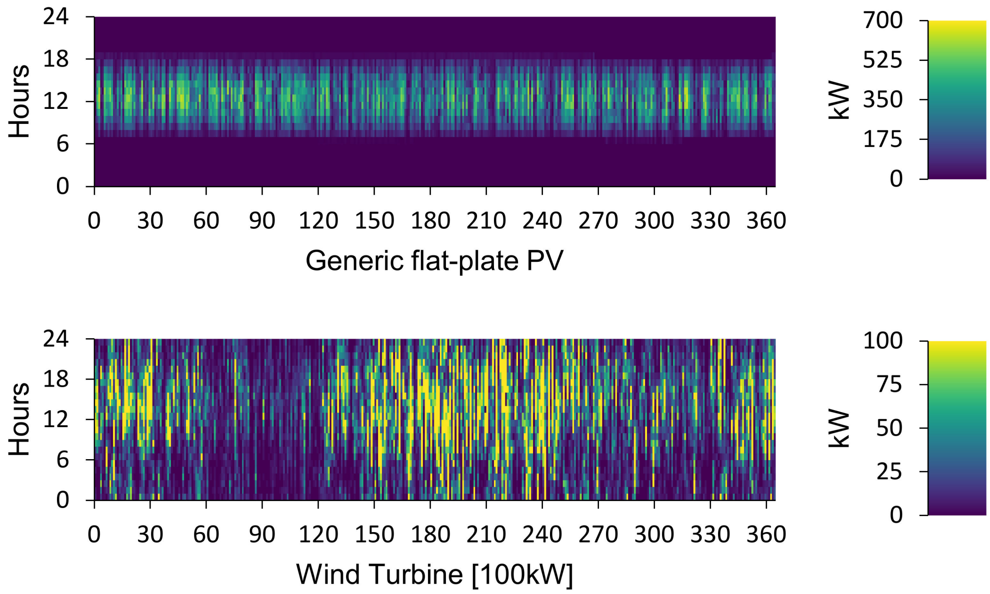

Figure 14. Solar PV output and generic wind turbine output.

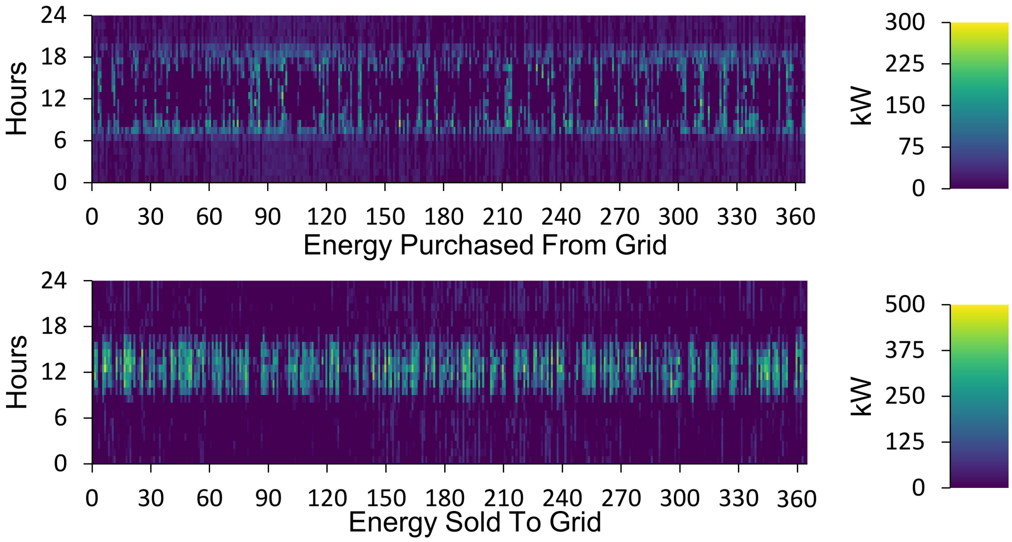

Figure 15. Energy purchased from the grid and sold to the grid.

3.3. Economic Evaluation Results

The renewable energy system's economic performance was analysed using techno-economic analysis. The system's operational expenses and the original investment and replacement costs should be included in calculating the economic advantages of the proposed system. All costs that arise over the system's lifetime are included in this analysis. To identify the most beneficial system in the HOMER grid model, the total net present cost (*TNPC*) was used. The *TNPC* was utilised in the optimisation process to rank all scenarios with various setups and discover the smallest one. In some cases where renewable energy needed to be promoted, the levelised *CoE* and the faction of renewable energy were also used in selecting an optimised system. The monthly utility bill savings by month annually are depicted in Figure 16.

The *TNPC* of the system is $829,692, with the levelised *CoE* being $0.0446/kWh. The cost summary of the project components is presented in Figure 17, and the economic and component chronological cash flow for the 25 years of the project lifespan is given in Figure 18. It can be seen that most of the cost is the operating cost followed by capital cost and replacement cost.

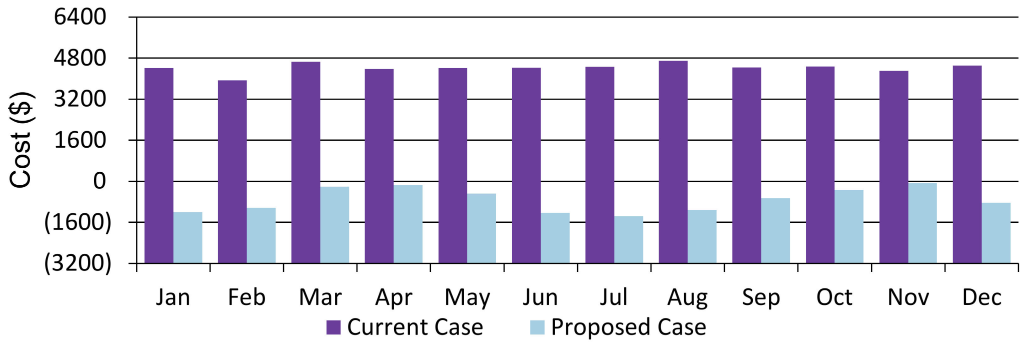

Figure 16. Monthly utility bill savings by month.

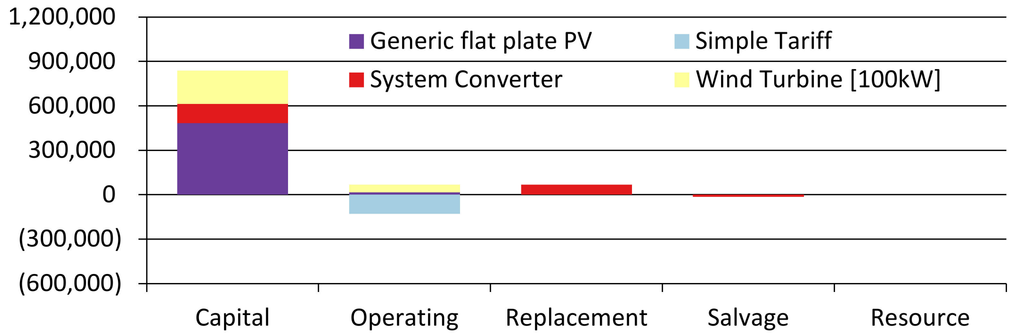

Figure 17. The cost summary of the project components.

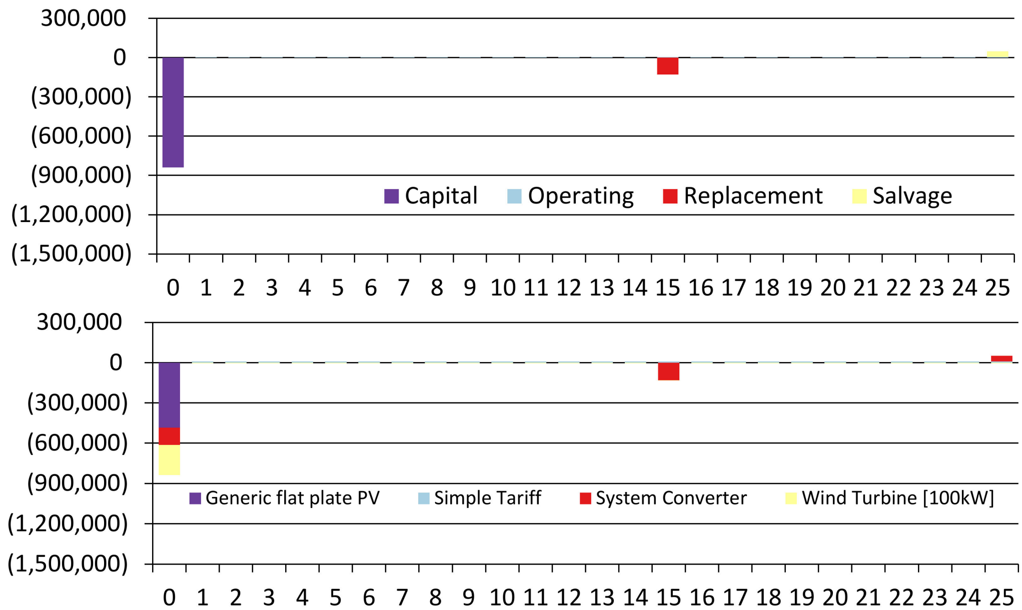

Figure 18. The economic and component chronological cash flow.

The optimised system proposes adding 682 kW of generic flat solar PV and 100 kW of wind turbine, which would reduce the levelised *CoE* from $0.060/kWh to $0.0446/kWh. The sale of electric production to the traditional grid, solar PV and wind energy systems, contributed to reducing emissions. The emissions for this case are carbon dioxide, sulphur dioxide and nitrogen oxides, which are the most common emissions of the utility grid. The complete economic metrics and potential emissions reduction result are presented in Table 8, and the economic comparison between the reference and optimised systems is tabulated in Table 9.

Table 8. Economic metrics and potential emissions reduction.

Description	Value
Internal Rate of Return	4.00%
Return on Investment	2.41%
Simple Payback	16.9 year
Annualised Utility Bill Savings	−$8693/year
Net Present Value	−$43,239
Annualised Savings	$53,667
Carbon Dioxide	143,452 kg/year
Sulphur Dioxide	622 kg/year
Nitrogen Oxides	304 kg/year

Table 9. The economic comparison between the reference system and the optimised system.

Description	Reference System	Proposed System
Net Present Cost	$786,452	$829,692
CAPEX	$0.00	$838,217
OPEX	$53,091	−$575.51
Annual Energy Charge	$53,091	−$8693
LCoE (per kWh)	$0.0600	$0.0446
CO_2 Emitted (kg/year)	559,226	143,452

The study demonstrates that grid-connected solar PV and wind turbine systems are preferable in terms of levelised cost of energy, the fraction of renewable energy and the environmental impact.

4. Conclusions

After the 2004 Indian Ocean earthquake and tsunami that struck Aceh, Indonesia, little has changed at the province's largest higher education institution. Despite the abundance of potential renewable energy sources, including wind and solar, the university continues to use electricity produced from fossil fuels for energy sources owing to low power rates. The study found that it is possible to implement a renewable energy system generated by solar PV and wind turbine systems in public higher education in a low electricity rate country such as Indonesia. The originality of this article is that it is one of the first efforts in a developing country such as Indonesia to use HOMER software for a public institution connected to the utility grid with the percentage of renewable energy production up to 82%. The optimisation results show that 682 kW solar PV, 100 kW wind turbine and 431 kW converter are connected to a local utility grid to power the institution. However, the most important aspect of this project is to show society that by attending this institution it is possible to start a business while also saving the planet. The other conclusion is that proposing many renewable energy devices sometimes will only increase the costs when electricity prices are low, as for the energy storage devices in the proposed system. Proposing a simple and dependable system is crucial for a difficult-to-access location. The main impediment to implementing renewable energy in Indonesia is the low electricity cost, primarily generated using cheap coal that is abundant in the country. Finally, because of limitations in the software used, the exchange rate, nominal discount rate and expected inflation rate were assumed to be constant in this study. As a result, it is suggested that in future research other types of software that can be programmed for this type of calculation should be used.

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Nomenclature

$C_{ann,tot}$	total annualised cost [$/year]
C_{cap}	capital cost of the current system [$]
$C_{cap,ref}$	capital cost of the reference system [$]
$C_{i,ref}$	nominal annual cash flow for reference system [$]
C_i	nominal annual cash flow for current system [$]
$C_{NPC,tot}$	total net present cost [$]
CoE	levelised cost of energy [$/kWh]
CRF	capital recovery factor
C_{rep}	component replacement cost [$]
$C_{rep,batt}$	storage bank replacement cost [$]
$E_{prim,AC}$	AC primary load served [kWh/year]
$E_{prim,DC}$	DC primary load served [kWh/year]
$E_{grid,sales}$	total grid sales [kWh/year]
f	yearly inflation rate [%]
f_{PV}	derating factor [%]
i	nominal interest rate [%]
i_0	rate at which you may acquire a loan [%]
I_T	solar irradiation [kW/m^2]
Is	standard amount of radiation [kW/m^2]
IRR	internal rate of return [%]
N	lifetime of the system [year]
N_{batt}	storage bank number of batteries
P_{WTG}	wind turbine power output [kW]
$P_{WTG,STP}$	wind turbine power output at standard temperature and pressure [kW]
RF	renewable energy fraction [%]
$Q_{lifetime}$	single storage lifetime throughput [kWh]
Q_{thrpt}	storage throughput annually [kWh/year]
R_{batt}	life of storage bank [year]
$R_{batt,f}$	storage float life [year]
R_{comp}	component lifetime [year]
ROI	return on investment [%]
R_{proj}	project lifetime [year]
R_{rem}	component remaining life [year]
S	salvage value [$]
U_{anem}	wind speed at anemometer height [m/s]
U_{hub}	wind speed at the wind turbine hub height [m]
Y_{PV}	total installed capacity of the PV panel [kW]
Z_{hub}	wind turbine hub height [m]
Z_{anem}	anemometer height [m]
α	power-law exponent
ρ	actual air density [kg/m^3]
ρ_o	air density at standard temperature and pressure (1.225 kg/m^3)
η_{rt}	storage roundtrip efficiency [%]

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