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Off-Grid Photovoltaic-Biogas Hybrid System for an Indonesia Boarding School

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Abstract: Future energy with bright prospects is renewable energy. One strategy to enhance the proportion of renewable energy in the energy mix is to switch from conventional to renewable energy-based energy sources. Previously using conventional energy sources, one of the male dormitories of Baiturrahman Boarding School will be converted to 100% renewable energy. When Homer software is used to simulate it, the best system will be chosen, with the input coming from locally available energy sources like sunlight from a photovoltaic module and biogas. From optimal output which consists of a 7.54 kW PV, a 5 kW biogas-fueled generator, an 18.78 kWh battery, and a 4 kW converter. 9.989 kW (98.13%) and a 190 kW (1.87%) biogas-fueled generator combined to produce electricity. The cost of energy is worth $0.216, and the present net cost is worth $17.769, according to the system's economic study. The results of the sensitivity analysis show that changes in the discount rate and variations in the value of inflation have an effect on the present net cost.

Keywords: Photovoltaic/ Biogas hybrid, Homer, off grid, techno-economic analysis

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1. INTRODUCTION

The topic of climate change continues to be high on the agendas of many nations. Reducing reliance on fossil fuel use and switching to renewable energy sources are two ways to address this issue. The use of bioenergy and solar energy in Indonesia, a tropical nation, offers immense potential. Every year, the amount of energy produced from renewable sources rises, and almost all nations have set a goal for their new and renewable energy output to reach 15% to 25% of total energy production by 2020 [1]. Azzuni et al. also examined energy security for 100 % renewable energies (RE) in Jordan- by 2050 [2], and Hansen et al. conducted numerous analyses of 100% RE in Germany by 2050 to [3], among other research.

Undoubtedly, renewable energy has great promise for the future. However, at the moment, RE's uneven production rates are its biggest shortcoming [4]. Hybrid technology can be used to solve these shortcomings. In this situation, it is impossible to avoid the instability of electricity production [5][6]. By combining generators, energy storage systems, and renewable energy sources, hybrid technologies can improve the dependability and efficiency of power generation.

Numerous studies based on hybrids of renewable energy are concentrated on supplying the electrical demands of rural homes and communities using homer, among others off-grid study that creates a 100% renewable energy system that can be duplicated in remote places and rural institutions using PV and biogas-producing technologies. When raw materials are readily available throughout the year, making similar institutions energy autonomous, a hybrid energy system like this one is demonstrated to be a workable and sustainable solution [7]. Additionally, Homer can be used with the maximum simulation per optimization technique to test as many combinations as possible, the system design precision technique to choose the best system, the net present cost (NPC) precision technique to determine the best NPC, and the category optimization winning technique to perform additional optimizations with or without individual components [8][9], with Homer, it's also possible to calculate each renewable energy generator's percentage contribution [10] and reduction of emission [11][12]

Research in the village of Nangal, Punjab, India, near Barnala has revealed the energy resources that are easily accessible: biomass, agricultural waste, and solar photovoltaic (PV) technology are used to provide the electrical energy needs of roughly 450 dwellings. The calculated energy cost was found to be $0.032/KWh and the total net current cost to be $76.837 [13].

Another crucial step in promoting the use of renewable energy and addressing environmental issues is the use of organic waste as a source of energy [14]. One of the boarding schools in West Java Province, Indonesia, serving kids in senior and senior high school is called Baiturrahman. One of the male dormitories at school, which previously used conventional energy sources, will be simulated to 100% RE Numerous cows are kept at this school, and it is well known that cow excrement may be processed to create biogas [15][16]. The school district, like other areas of Indonesia, has adequate solar radiation all year long, which can also be transformed into electricity using a photovoltaic (PV) system. The presence of a biogas power plant and a photovoltaic system at this location may enable the implementation of a hybrid system [17][18] to lessen reliance on the State Electricity Company's (PLN) supply of electricity. Hybrid systems with renewable energy can lower the cost of generating electricity [19], saving on electricity bills and simultaneously decreasing emissions.

The study focuses on renewable energy hybrids, specifically a photovoltaic-biogas hybrid system, to address the challenges of uneven renewable energy production and enhance energy sustainability in educational institutions. Using HOMER software, the research simulates and optimizes the hybrid system's design and analyzes its techno-economic viability. The study showcases a degree of novelty by creatively combining photovoltaic and biogas technologies, particularly in the context of a specific Indonesian boarding school.

The paper demonstrates technical depth through its detailed analysis of the hybrid system's performance, taking into account factors like net present cost, cost of energy, and renewable energy contribution. To further enhance its depth, the paper could include a more comprehensive methodology, in-depth sensitivity analysis results, and a comparative evaluation with other renewable energy solutions. Overall, the research presents valuable insights into the potential of renewable energy hybrids in educational settings, while suggesting avenues for future improvements and practical implementation.

2. METHOD AND MATERIALS

Through a case study of the school's male dormitories, this study intends to show the techno-economic viability of remote solar and biomass on-grid hybrid power systems electrification for boarding schools. In order to build hybrid power systems, HOMER was utilized to execute techno-economic analysis and estimate the ideal size of each component. Methods for off-grid hybrid system design optimization and techno-economic analysis are explained below, and the corresponding drawing is shown in Fig. 1.

In order to meet electrical and thermal demands, HOMER develops energy systems that can use both renewable and nonrenewable energy sources. The cost of energy and the overall net present cost (NPC) are taken into consideration throughout the cost of energy (COE) and Operating and Maintenance (O&M). Based on the total NPC, HOMER optimization solutions for recommended system setup are rated. The entire discounted cash flows for each year over the project's lifetime are added up to determine the total NPC of the project, which is the sum of the NPCs for all system components. Additionally, energy cost and total annualized cost are also computed using NPC. The annualized version of NPC known as the total annualized cost is required to calculate the cost of energy.

These values are calculated based on the Equation (1) and (2):

$$NPC\ (\$) = \frac{TAC}{CRF} \tag{1}$$

Where TAC is the total annualized cost; CRF is the capital recovery factor.

$$COE\ (S) = \frac{C_{ann,tot}}{E} \tag{2}$$

$C_{ann,tot}$ is the annual total cost($); E is the total electricity consumtion (kWh/year).

1.1 Site description and load profile

This study was carried out in a boarding school about 31 kilometers from Bandung, the provincial capital of West Java, Indonesia, at coordinates -

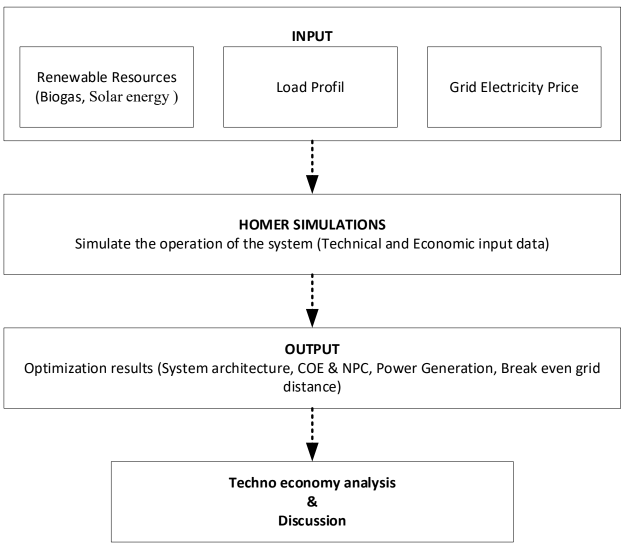

Figure 1. Method for off-grid hybrid power system optimal design and techno-economic analysis.

7.070800255723888, 107.70227220439827. There are classrooms, dorms for students, offices, and more at this school. Male student dormitory will be chosen as the load for the on-grid hybrid (PV, Biogas) power generation system in this project. Lighting is the main source of the dormitory's load, hence the peak period is from 6 p.m. to 6 a.m. The electrical energy use in buildings, monitored every hour, is depicted in Fig. 2.

2.1 Resource Assessment

Solar and biomass are regarded as the two main sources of renewable energy in this study. The annual monthly solar radiation as well as the on-site biogas production capability will be fed into HOMER. For the twelve-month inclusion of the availability of biogas. Following are the specifics for each renewable energy source.

2.1.1 Solar energy potential

According to records from the NASA database, the average clearness index was 0.49 and the annual average solar radiation was 6.69 kWh/m2/day. December has the highest sun irradiation (7.34 kWh/m2/day), while June has the lowest (5.57 kWh/m2/day) [20]. Both of these values are sufficient for PV cell power generation. Fig. 3 shows the monthly profile of the solar GHI and clarity index in the area.

2.1.2 Biogas potential

Baiturrahman boarding school has 20 cows, each cow is able to produce 10-30 kg of manure/day [21], assuming that each cow can generate 20 kg of milk per day, there are 400 kg of cow manure accessible each day for use as a biogas substrate. By using anaerobic fermentation, the cellulose and protein in cattle manure can be turned into biogas, with each kg of manure producing between 0.023 and 0.040 m^3 [6]. Therefore, between 9.2 and 16 m^3 of potential biogas might be produced at the site each day, methane has a density of 0.554 kg/m3 [22], therefore the comparable amount of biogas produced each day is about 0.4 tons as shown in fig. 4. Based on a prior study that revealed that the biogas consumption for the generator at a load of 1,047 W is 0,019 m^3/minute [23], Baiturrahman's potential for biogas will be between 8,5 and 14,69 kWh per day.

2.2 Hybrid Energy System Modelling and Specifications

The parts of a hybrid power system produce, transfer, transform, and store electrical energy. PV modules, biogas-fired generators, batteries, and converters are the four key components required because solar and biogas are the primary renewable energy sources in this situation. Since solar and wind energy are sporadic, biomass is kept on hand as a backup to help maintain a somewhat steady flow of electricity. The battery functions as a storage device and serves as an extra backup facility. A converter was added to act as an interface between the AC and DC components as there are both of them. In order to do a comparison analysis with a standalone system, the grid module is used.

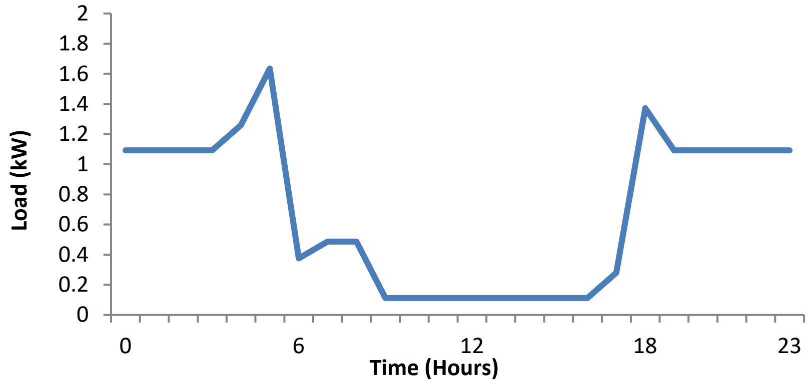

Figure 2. The daily load curve for the Baiturrahman male student dormitory

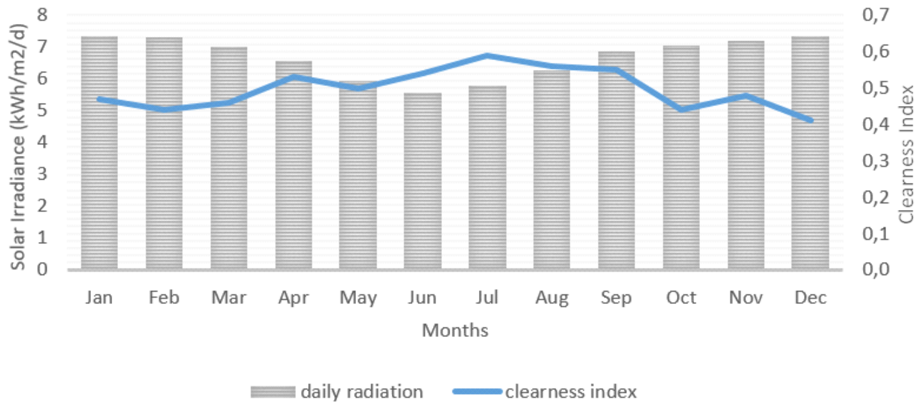

Figure 3. Solar radiation and cleanliness on an annual basis

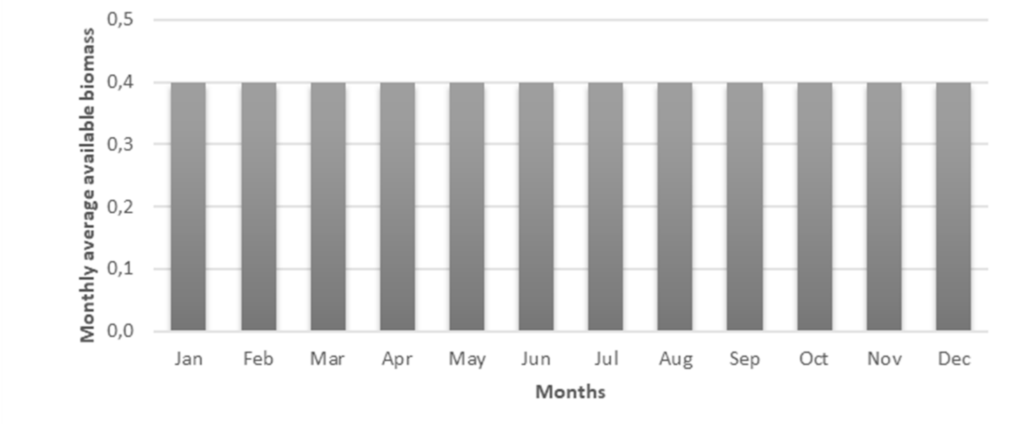

Figure 4. Monthly average available biogas

2.2.1 PV module

PV modules with a 10 kW capacity and a 25-year lifespan were employed in this investigation. Using site data, solar radiation serves as the PV's input. For every 1 kW of common flat plate PV, capital expenses are approximately \$500, while replacement costs are \$950. The O&M expense is estimated to be \$10/year/kW due to the fact that PV panels require less maintenance [24]. In the sentences that follow, the cost per kW is also taken into account, along with.

2.2.2 Biogas-fueled generator

A biogas generator (BG) is required as a backup energy supply because solar panels are a renewable energy source with intermittent properties. However, as previously said, the school's location has numerous biogas sources with cheap capital, replacement, and O&M expenses. The off-grid hybrid power system's stability and dependability will be guaranteed by BG's existence energy source with intermittent properties. However, as previously said, the school's location has numerous biogas sources with cheap capital, replacement, and O&M expenses. The off-grid hybrid power system's stability and dependability will be guaranteed by BG's existence. A BG with a capacity of 5 kW and a capital and replacement cost of \$250 was chosen for this study. \$0.05/hour is the cost of running [25][26]. Market-based generators are connected to an AC output and have a lifetime of up to 15,000 hours of operation [27] and 30% is the minimum load ratio.

2.2.3 Converter

A converter system is required to convert the output to AC because it is known that the PV module provides DC electrical energy. The converter, which is the most crucial part of the hybrid AC-DC system and may provide controlled energy conversion among various components and systems at various voltage levels, has high future prospects [28]. For one KW, \$820 is assumed to be the capital cost, \$750 for replacement, and \$750 for operations and maintenance. The cost of O&M is minimal and is taken to be zero [29]. The inverter's efficiency is set at 95%, while the rectifier's efficiency is set at 100% to take into account the fact that, despite being necessary for the HOMER implementation, the rectifier is absent in the actual system. Ten years of converter life are taken into account.

2.2.4 Battery

The battery will be used in this hybrid system as a backup. This battery can store energy from both PV and BG, which may be used anytime the energy produced by the two energy sources is used to satisfy the available load. A generic battery is chosen with a nominal capacity of at least 6 kWh and a nominal voltage of 12 V. The battery has a 12-year lifespan.

The breakdown of system component costs and performance is the primary factor, which is provided as follows, for system design and techno-economic analysis. Technical specifications and component costs are calculated based on Indonesian assumptions, data from privately held sources of manufacturers, and information from previously published publications. Table 1 displays the summarized primary components and their specifications. These elements help HOMER determine the best setup to handle the electrical demand. A configuration plan for a hybrid energy system is shown in Fig. 5.

3. RESULTS AND DISCUSSION

The outcomes of the HOMER simulation for hybrid systems and optimization will be examined in this part, along with their implications. The optimization analysis is presented first, followed by the findings from the sensitivity analysis. Data for each component, including production of the diesel and biogas components as well as expenditures classified by category, are also provided. In order to validate the results, the simulation results were compared to those of other hybrid systems in related studies.

3.1 System optimization results

With a renewable energy source in the form of solar power, the presence of biogas at the Baiturrahman school location, and the simulation's choice of one of the male dorms with a load demand of 11.26 kWh per day on average and a peak load of 2.09 kW. Three ideal configurations are found using Homer's simulation

Table 1. Component Specifications PV-Biogas Hybrid Simulation

Component	Technical Description	Rated Capacity	Capital cost ($)	Replacement cost ($)	O&M cost ($)	Life Time
Photovoltaic panel (PV)	Monocrystalline	0,5 kW	500/kW	400	10 per year	25 years
Biogas Generator (BG)	Generic Genset	5 kW	250/kW	250/kW	0.05 per hours	15.000 hours
Converter	Generic Converter	1 kW	820/kW	750/kW	0 per years	10 years
Battery (Bat)	Generic 1kWh Lead Acid	5 kWh	1000	900	15 per years	12 years

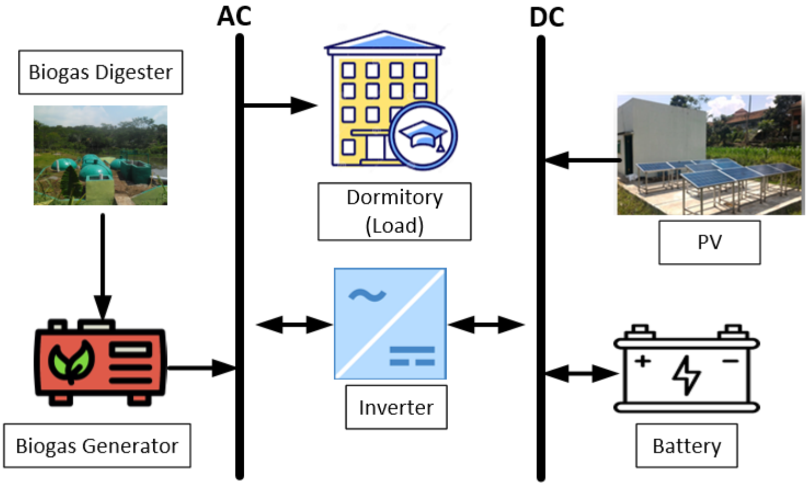

Figure 5. The configuration of the hybrid system.

findings, with the first order being a PV/Biogas-fueled generator/Battery and Converter combo. As seen in Table 2, the second sequence does not employ a generator powered by biogas. A 7.54 kW PV module, a 5.00 kW biogas-powered generator, an 18.78 kWh battery, and a 4 kW converter make up the ideal system, as shown in the table. These combinations, which total $17,769, $0,216/kWh, and $387.50/year, respectively, combine NPC, COE, and the lowest initial investment. These numbers are suitable for a hybrid power plant powered by renewable energy.

Table 3 provides the total annual electricity produced by the overall system as well as by each producing system. It is clear that solar power dominates the generation of 9.989 kWh/year, or 98.13% of all generation. Only about 190 kWh/year, or 1.87%, of biomass is used in the production of power. It is clear from the system's overall electrical energy output that a hybrid renewable energy system can fully satisfy the load. Furthermore, the storage system is unable to store all of the electricity produced by the PV modules throughout the day, resulting in 5,947 kWh/year, or 58.4% of production, being excess electricity. This can

Table 2. Optimization result for the hybrid system based on categorized.

Rank	Architecture				Costs		
	PV (kW)	Biogas fueled generator (kW)	Battery (kWh)	Converter (kW)	NPC ($)	COE ($/kWh)	O&M ($/yr)
1	7.54	5.00	18.78	4	17,769	0,216	387.50
2	9.17	NA	18.78	4	18,293	0,227	392.89

Table 3. Optimization result for the hybrid system.

Electric Production (kWh/year)			Consumption (kWh/year)	Excess electricity (kWh/year)
PV	Biogas fueled generator	Total		
9,989 kW	190 kW	10,179	4,109	5,947
98.13 %	1.87 %	100 %	100 %	58.4 %

involve a conversation and additional study on how to boost storage capacity in order to prevent electricity surpluses or by raising the load on the school's site.

The COE value generated by this approach is equivalent to the value of research that has been carried out previously; the COE value generated is $ 0.202 for research in the Philippines [30] and $ 0.286 for research on Sebesi Island, Indonesia [31]. This is corroborated by data from Table 4 showing that the COE values generated from other studies are in the same range for similar studies [27][32][33][34][35].

3.2 PV modules performance

The PV module serves as the load's primary source of electricity in this hybrid system. Fig. 6 displays the output of the PV modules over the course of the year. The PV modules have a capacity factor of 16.3% and produce 28.2 kWh of power per year. Between 6:00 and 17:00 is when electrical energy is produced. Between 10:00 and 14:00, electricity output is at its highest.

This is consistent with the idea that PV has operational hours to produce power for that time. According to research by PascalinTiam Kapen et al., most of the electrical energy produced by PV modules happened between 9 and 16, with a peak output at 12 [36].

3.3 Biogas fueled generator performance

Fig. 7 depicts the biogas generator's performance over the course of the year; it is clear from the figure that the generator runs around 18.00. When the demand was high and the PV module was no longer able to generate electricity that was the time. The biogas plant generates 190 kWh of electricity annually, which equals a capacity factor of 0.434%. The typical generator works for 130 days a year and uses 146 tons of biogas. The generator actually works fewer hours than is typical, which results in a greater remaining life at the end of the project's life and allows for high salvage values to be acquired under the current economic climate. Therefore, a low capacity factor for this generator is preferred because the optimization is dependent on NPCs.

Table 4. The COE of various HOMER-simulated hybrid energy systems

Architecture	Location	Year	COE	Ref
PV/BG/DG/bat	China	2022	$0.24	[32]
PV/BG/bat	India	2022	$0.36	[33]
PV/Wind/DG	Saudi Arabia	2022	$0.25	[34]
PV/Wind/Biogas	Cameroon	2018	$0,27	[27]
PV/Biogas/DG/ Battery/Grid	Saudi Arabia	2019	$0,21	[35]

3.4 Sensitivity analysis results

To find out the economic indicators of the hybrid system, including the relationship between the discount rate and inflation on NPC and COE. For this reason, a sensitivity analysis was carried out with discount rates and inflation rates varying between 10% and 20%, respectively, while the project time was chosen to be between 20 and 25 years. The NPC and COE systems based on discount rates (X axis) and inflation (Y axis) are depicted in Fig. 8 and Fig. 9. When can be seen, the NPC value rises as the inflation rate rises, while the discount falls. In contrast, the COE value rises as the inflation rate falls and discounts rise. Sensitivity tests conducted in other research reveal that PV, biogas, and battery systems are susceptible to discounts and capital subsidies [37].

The optimal results for a hybrid system with a projected life of 20 years with variations in inflation and discount rates are shown in Table 5. It can be seen that when the inflation rate is 10% and the discount is 10%, the NPC and COE values are $17.769 and $0.216, respectively. with the same condition as the project age and the same discount but an increased inflation rate of 15% and 20%, the NPC value increased to, respectively, $ 21.368 and $ 23.04, while the COE value was $ 0.158 and $ 0.099. This shows that the possibility of decreasing the inflation rate can change the optimal system configuration.

Table 5. Optimum results for different inflation and nominal discount rates (project lifetime of 20 year).

Architecture	Project lifetime (year)	Inflation rate (%)	Nominal Discount Rate (%)	NPC ($)	COE ($/kWh)
PV/ Biogas fueled Generator/ Battery/ Converter	20	10	10	17,769	0,216
	20	15	10	21,368	0,158
	20	20	10	23,041	0,099
	20	10	15	15,303	0,287
	20	15	15	17,769	0,216
	20	20	15	21,276	0,161
	20	10	20	13,581	0,363
	20	15	20	15,401	0,284
	20	20	20	17,769	0,216

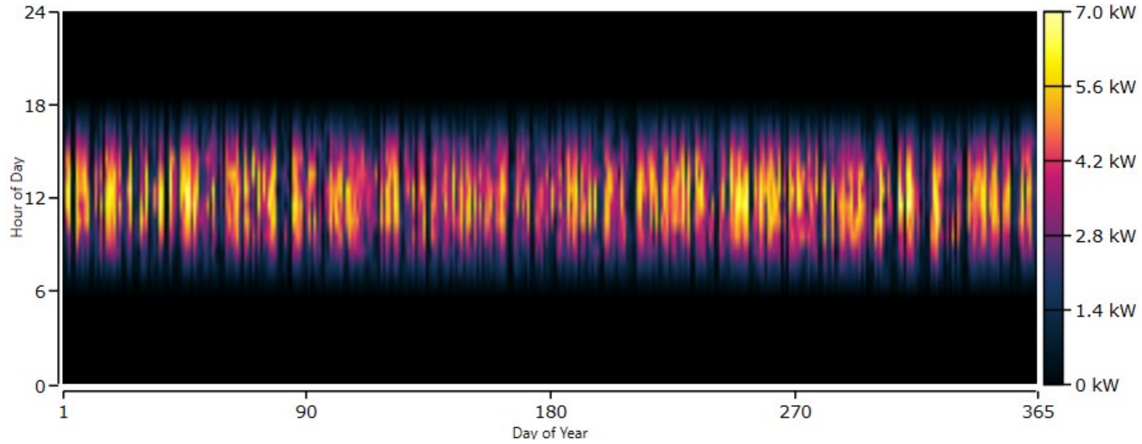

Figure 6. Power Output of PV modules

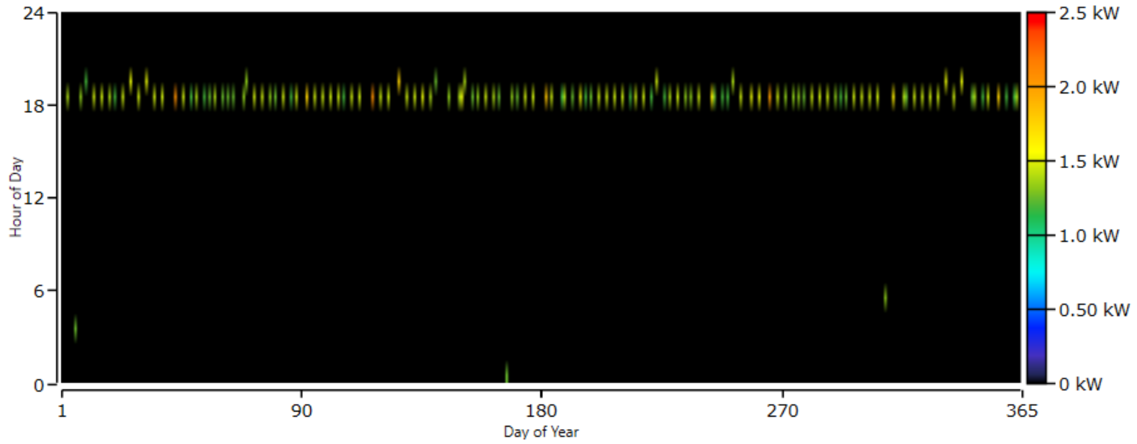

Figure 7. Power output of biogas fueled generator

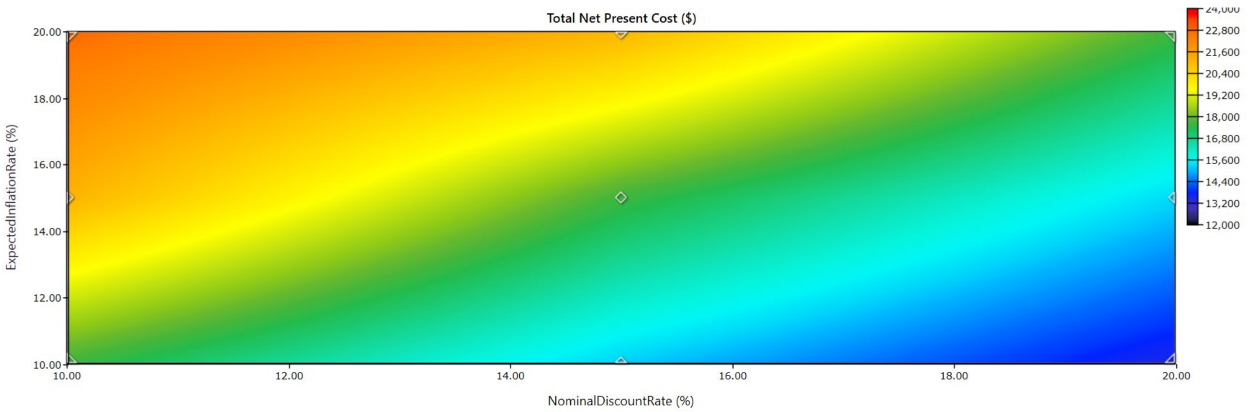

Figure 8. Sensitivity analysis of the system's NPC by inflation and discount rate

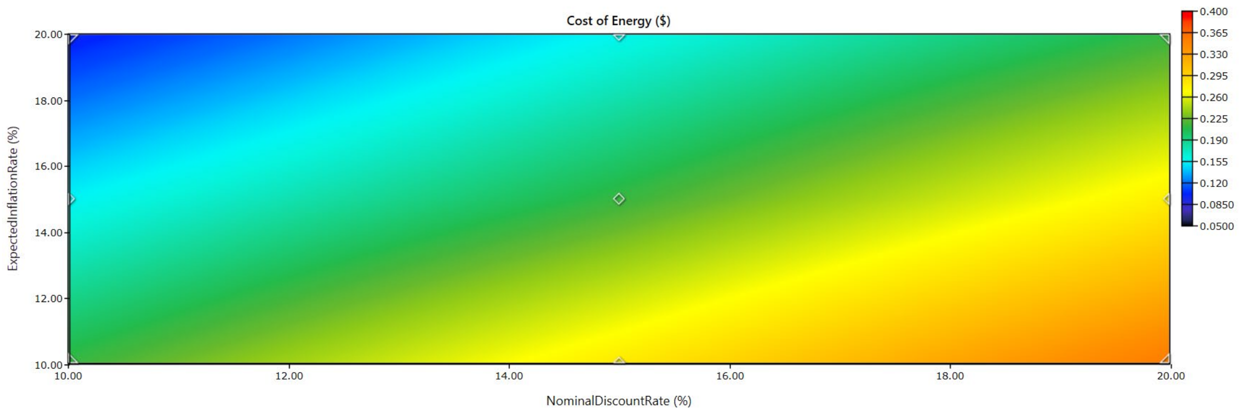

Figure 9. Sensitivity analysis of the system's COE by inflation and discount rate

4. CONCLUSION

This paper has demonstrated the techno-economic viability of a photovoltaic-biogas hybrid system at the Baiturrahman boarding school in Indonesia, using HOMER simulations and sensitivity analysis. The proposed hybrid system, consisting of a 7.54 kW PV, a 5 kW biogas-fueled generator, an 18.78 kWh battery, and a 4 kW converter, showcased a remarkable performance in providing cost-effective and reliable electrical energy services to the school.

The sensitivity analysis conducted in this study highlighted the impact of changes in the discount rate and variations in the value of inflation on the net present cost (NPC) of the hybrid system. It revealed that fluctuations in these parameters significantly influenced the NPC, indicating the importance of considering economic uncertainties when designing and implementing renewable energy hybrids. This finding reinforces the need for careful financial planning and policy frameworks to ensure the long-term sustainability and profitability of such systems.

Overall, the hybrid system's economic analysis resulted in a favorable NPC of $17.769 and a cost of energy (COE) of $0.216, which aligned well with previous literature. While the system provided reliable electricity services, it also generated surplus electricity due to storage limitations. As a future consideration, enhancing the system's storage capacity or finding ways to increase electricity demand at the school could effectively utilize the surplus energy and further optimize the system's performance.

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Author Contributions

All authors contributed equally as the main contributor of this paper. All authors read and approved the final paper.

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Competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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