Designing and Analyzing a Hybrid Photovoltaic-Biomass Microgrid for Rural Communities

Herwandi*, Leonardo Kamajaya *, Fitri*‡

* Department of Electrical Engineering, State Polytechnic of Malang, Malang 65141, Indonesia

(herwandi@polinema.ac.id, leonardo42@polinema.ac.id, fitri@polinema.ac.id)

‡ Corresponding Author; Fitri, Malang 65141, Indonesia, Tel: +62 341404424, fitri@polinema.ac.id

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Abstract- In most developing countries, such as Indonesia, burning crop residues exacerbates emissions produced by coal-based thermal power plants. Agricultural residues, mainly organic components, can be effectively and sustainably exploited to produce biogas by anaerobic digestion. This paper proposes a microgrid (MG) system for reliable electricity in rural areas and effective utilization of existing renewable resources. A complete techno-economic analysis established MG systems based on solar energy and biomass. Two MG systems resulted in reliable rural electrification, MG-I with solar power (PV), and biomass-based generation units connected to an unreliable power grid. MG-II with biomass-based generation units, unstable grid, biomass, and batteries. The investigation included several performance evaluation criteria: component cost, inflation rate, project feasibility, generation response, emissions, and fuel price. This study shows that the MG-I microgrid system can provide electricity to the community for 0.0735 $/kWh, 1.37 times cheaper than MG-II. In addition, with the efficient use of abundant biomass resources, the proposed MG-I system reduces greenhouse gas emissions by more than 80 percent and can reduce atmospheric pollution.

Keywords: optimization; renewable energy integration; microgrids; hybrid energy systems; biomass.

1. Introduction

Electricity is vital to a nation's overall growth and development, particularly regarding its social and economic position. As more and more people live in cities, the energy demand increases. This problem necessitates a proportional increase in permanent energy use worldwide.

Most expanding nations, such as Indonesia, are fueled by coal-fired thermal power plants. Solar, wind, biomass, and small hydropower generate 14% of electricity, while 50% generate by coal-based thermal power facilities [1]–[3]. Coal-fired power facilities generate the majority of the nation's electricity. Between 2019 and 2021, a 73 Gigawatt (GW) Indonesian coal-fired power station utilized 32.76 metric tons (MT) of coal and created 565 MT of 2.45 μm particles, 1950 MT of NOx, 2050 MT of SO_2, 98 MT of VOCs, 1098 MT of CO, and 656 MT of CO_2[4]. Coal reserves in Indonesia concentrate in the Western and Northern regions; hence, any capacity increase in coal-based thermal lines necessitates coal delivery to the plant site, necessitating railway development [3]. Due to transmission and distribution losses of 26 to 32 percent, rural electrification is difficult in Indonesia, where coal-based thermal power facilities are in low supply.

In addition to infrastructure, there is a need to consider Indonesia's future economic growth. Indonesia will have the most rapid economic expansion. Energy demand will rise. Hence, Indonesia's installed capacity in 2030 should be 390 Terawatt (TW) [5]. Despite recent developments in the energy sector, 500 thousand homes lack electricity, and 15,000 households cook with biomass. Indonesia might meet the ESBP (Electricity Supply Business Plan) of the Paris Agreement (UNFCCC, 2015) by increasing the proportion of Renewable Energy Systems (RES) in electricity generation to 40 percent by 2022. If RES reaches 45 percent by 2030, 29 percent of greenhouse gas (GHG) emissions from the power industry can reduce, or 375 MT[5]. Renewable energy generation is essential for rural electricity supply and emission reduction goals. Unfortunately, intermittent renewable energy sources make deployment challenging. Renewable energy's intermittent nature is managed through hybrid mode.

Hybrid renewable energy systems (HRES) provide sustainable and cost-effective resource utilization, making them a superior choice for meeting the world's energy needs. The advantages of HRESs are demonstrated by research using MATLAB, Engineering Equation Solver (EES), and Hybrid Optimization Model for Many Energy Resources (HOMER).

HOMER is a popular hybrid system simulator developed by NREL [6]–[8]. The authors have assessed wind, hydro with grid [9], biomass [10]–[14], solar [15], and off-grid combinations depending on resources . To fulfill global electricity demand, researchers analyzed hybrid energy resource combinations. Thermodynamic and economic analysis of solar-biomass hybrid power-producing systems, electricity costs 74.94 dollars per megawatt-hour, and CO_2 emissions are reduced to 0.62 metric tons per megawatt-hour [16]–[21].

Solar energy enhanced the fuel efficiency of a hybrid solar-biomass generating station without energy storage from 15% to 32% [22]. Gilutongan, a remote Philippine Island, was powered by a diesel-solar hybrid system with reliable electricity at a 70% reduced Cost [23]. In northern Bangladesh, ideal off-grid systems are significantly more expensive than grid-connected systems. The hybrid off-grid system possessed the lowest COE [24]. In faraway Algeria, a PV/diesel hybrid energy system has proven more efficient for increased loads and solar radiation with a reduced fuel storage capacity [25]. The capacity factor in the Kouhin area of Qazvin was increased to 28.8% after a techno-economic examination of a stand-alone hybrid wind/fuel cell microgrid system. The highest contribution came from wind turbines (90.59%) and fuel cells (9.41%) [26]. Ethiopia's most successful rural electrification technique is a hybrid PV/diesel generator/wind turbine/battery storage unit [27]. The most dependable solution for typical rural communities in Nigeria was a hybrid PV-diesel-battery mini-grid that decreased pollutant emissions by 97% [28]. Variations in inputs over time harm the economic performance of PV/ diesel/battery hybrid systems that reliably power Iraqi villages with multi-year modules. Diesel output increased by 25.6%, CO_2 emissions rose by 23.1%, and PV production fell by 10% [29]. Punjab, Pakistan, needed a stand-alone HRES with a capacity shortage to meet rural load requirements [30]. In another study, a PV/biomass hybrid system powered residential and agricultural loads in a remote community in Punjab, Pakistan, at the cost of energy competitive with off-grid systems [31]. The PV fuel cell-gasifier generator set-battery backup and power conditioning unit at this school in Bhopal, India, provide the school with supplemental electrical power [32]. Sharjah's ideal solar-biomass hybrid system can meet 14% of the city's electricity consumption, but its \$0.328/kWh levelized cost of electricity (LCOE) makes it unprofitable for customers [33].

In another study, decentralized power generation with RER was techno-economically viable, sustainable, and ecologically friendly for rural electrification in remote areas [34]–[36]. PV-wind-battery hybrid systems can sell excess electricity to the grid and are cost-effective for rural electrification [37]. Moving peak load, maintaining steady energy demand, and decreasing peak demand reduce COE in PV/biomass/diesel and grid-based hybrid systems. Electrification via decentralization is superior to grid extension if the community exceeds the breakeven distance [38].

Most authors who distribute power to customers in decentralized, grid-connected microgrids employ photovoltaic, wind, fuel cell, and biomass-based generation units, as evidenced by earlier research. The intermittent nature of renewable energy renders them unreliable, expensive, and ineffective as RES. Cloudy weather prevents solar power plants from supplying enough energy to fulfill demand, while intermittent fuel supplies hamper biomass power plants. Solar and biomass hybrid power plants are becoming increasingly popular due to the collaboration between the two renewable energy sources [19], [39]–[41]. Grid-connected hybrid systems are reliable and efficient. It also sells off-peak electricity. This study assesses the techno-economic viability of a solar-biomass microgrid system for an East Java community based on factors. (1) to demonstrate the importance of deploying available RER in rural East Java; (2) to create an ideal model of a grid-connected and isolated PV-biomass microgrid system; (3) to evaluate the proposed microgrid system's performance using realistic village loads, original resource data, and actual component costs; and (4) to assess the impact and suitability of the proposed microgrid system in terms of using biomass to lessen environmental impact.

The following paragraphs are included in this article: The methodology for the design of microgrids is discussed in Section 2. In the third half of this article, a hybrid system is modeled using a realistic research region load assessment. The fourth and fifth sections present the optimization outcomes, pertinent debates, and subsequent conclusions.

2. Methodology

2.1. Proposed MG system

Figure 1 illustrates a diagram of a microgrid system consisting of methane production, solar power system, battery energy storage system, converter, and associated consumer loads. The battery bank can be used as a backup to meet load needs. The bidirectional converter maintains the flow of electricity between the AC and DC buses by converting the DC from the PV panel to AC and storing the excess energy in the battery.

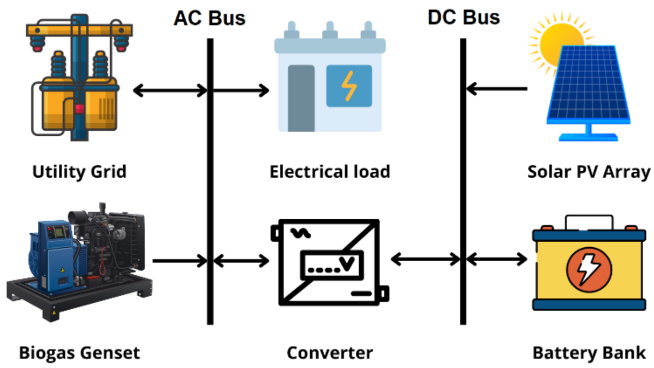

Fig. 1. Schematic Diagram of Microgrid System

2.2. Algorithm

The current work uses a specific strategy to model and improve a hybrid energy system. Figure 2 depicts the proposed algorithm for HRES. This figure also illustrates the HRES algorithm, composed of three steps: parameter input, simulation and optimization, and results. In the parameter input section, the components of each HRES variation are specified. In the simulation and optimization section, the simulation and evaluation of each component are conducted to achieve optimal results. In the results segment, the sorting process is conducted based on the lowest NPC and by analyzing the obtained outcomes.

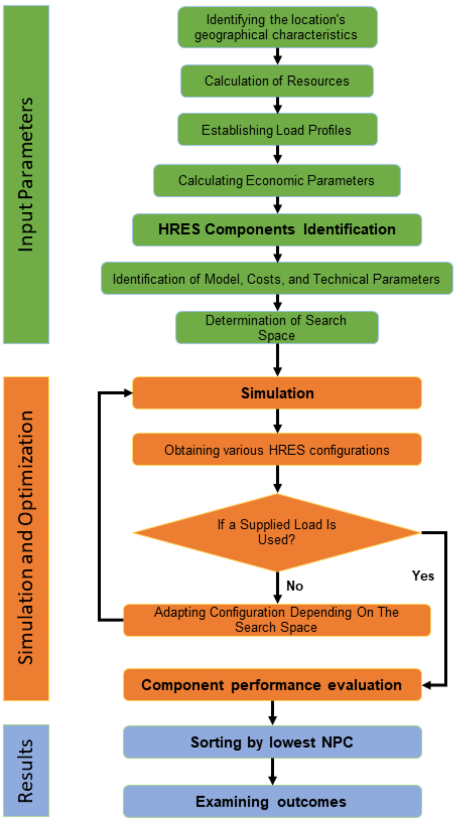

Fig. 2. Algorithm for HRES

3. Simulation Parameters

Malang, located in East Java, Indonesia, comprises 7.39% (3,530.65 km^2) of the country's total land area and is home to 887,444 people (Census, 2017). Malang is located between 7044' and 8026' south latitude and 112017' and 112057' east longitude and utilizes solar and biomass energy. 59% of Malang's rural population depends on agriculture and livestock. 17.48% of the state's gross income comes from agriculture and livestock (Census, 2018). Even though the state has finished rural electrification and Malang has a high per capita electricity consumption, Malang's electrical supply reliability remains a key concern, particularly during peak load months. Figure 3.a depicts the nation's most considerable renewable energy potential, whereas Figure 3.b depicts the RUPTL renewable energy plant development plan for 2019-2028. East Java has renewable energy potential till 2028, as shown in Figure 3.

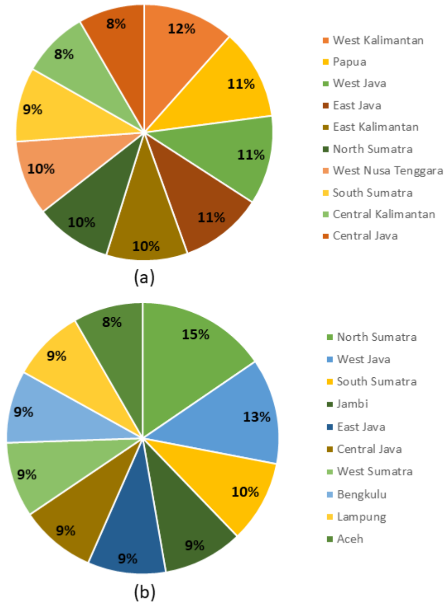

Fig. 3. (a) Largest national renewable energy potential and (b) Renewable energy plant development plan according to RUPTL 2019-2028

(Source: Indonesia clean energy status report, IESR, 2019)

3.1. Village Location

The hybrid system in Tegalweru village optimizes reliable rural electricity. Tegalweru is a small community with 225 homes and 1082 inhabitants (Census, 2015). The town has a public school and a community center. Tegalweru is 10 kilometers west of Malang City, between 112.33 and 112.35 East Longitude and 6.5775 and 7.5495 South Latitude. Tegalweru is 600 to 2,100 meters above sea level and receives 1,297 to 1,925 mm of yearly precipitation. Agriculture employs 56% of the population.

3.2. Load Profile

Simulating small power generation system loads is essential for the design process. Assess the technological, financial, and practical viability of hybrid energy production systems for public buildings. According to the Energy Efficiency and Renewable Energy Organization report, electrical equipment's electrical consumption was determined.

The first survey assessed the energy demand and community load. The village's primary loads consist of fluorescent lighting, ceiling fans, televisions, refrigerators, and air conditioning units. Moreover, mixers, phone chargers, and electric irons are examples of uncategorized loads. The dry (Mar-Oct) and rainy (Nov-Feb) seasons in the research region are evaluated independently based on different equipment, such as air conditioners in the dry season and fans and refrigerators in the wet season. The hamlet's only junior high school and community center have low daytime fan loads and nighttime light loads, as shown in Table 1.

Table 1. Load statistics for the investigated village

				Dry Season (March – Oct)		Rainy season (Nov - Feb)	
Load Type	**Number of load points**	**Power (W)**	**Load (kW)**	**Usage time (h)**	**Energy consumption/day (kWh)**	**Usage time (h)**	**Energy consumption/day (kWh)**
CFL	450	15	6.75	12	81	14	94.5
TV	125	100	12.5	4	50	4	50
Fan	200	60	12	8	96	3	36
Refrigerator	112	110	12.32	14	172.48	10	123.2
AC	5	540	2.7	6	16.2	0	0
Miscellaneous	80	100	8	4	32	7	56
School / Community facility							
CFL	35	15	0.525	4	2.1	6	3.15
Fan	10	60	0.6	6	3.6	0	0
PC	30	110	3.3	6	19.8	6	19.8
Store							
CFL	25	15	0.375	4	1.5	6	2.25
Water pump	4	275	1.1	6	6.6	6	6.6
Fan	10	60	0.6	8	4.8	0	0
Total load					**486.08**		**391.5**

According to load statistics (Table 1), During the dry season, this hamlet uses more than 486.08 kWh/day, with a peak load of 50 kW. It consumes only 391.5 kWh daily during the wet season, with a peak load of 34 kW. The survey indicates that adults work in fields while children attend school. As shown in Figure 4, schools, community centers, and irrigation pumps consume less electricity between 9:00 a.m. and 7:00 p.m. than in the afternoon and at night. The typical energy requirement during the rainy season ranges from 15 to 35 kW.

3.3. Resource Assessment

The NASA surface metrology and solar energy database supplied data on solar irradiance for the research region, "Tegalweru". The site has over 300 sunny days per year, an annual average of 5.44 kWh/m^2/day of solar radiation, and an average clarity index of 0.63. This community depends on agriculture and livestock. The neighborhood cultivates rice, wheat, corn, potatoes, and vegetables. Moreover, the survey discovered 800 cattle, 100 buffalo, and 100 chickens in the neighborhood. One cow produces 5.5 kilograms (kg) of manure daily, generating 0.6 to 0.8 cubic meters of biogas and 1.5 kilowatt-hours of power [42]. So, 4400 kg of cow manure can provide 6600 kWh of electricity in the hamlet. One ton of rice straw produces 240 m^3 of biogas and 2 kWh of energy via anaerobic digestion. 1 MW per hour can be produced from 50 tons of straw. Digesting 5 tons of agricultural waste with animal manure improves biogas output [43]. Therefore, the village's biomass is limited to 8 tons each month (Figure 7), except for the wheat and rice harvests in April and September to November, respectively.

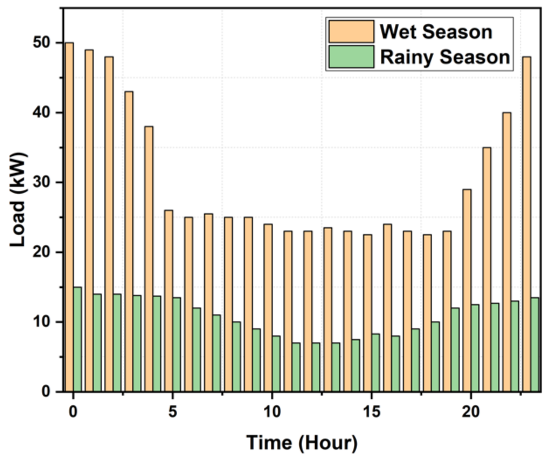

Fig. 4. Load profile for each day in Tegalweru, Malang, Indonesia

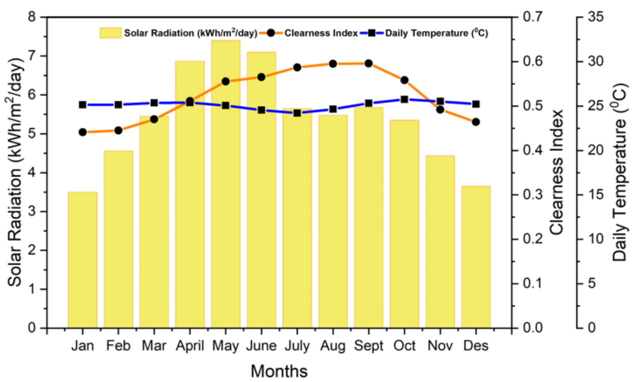

Fig. 5. Profile of the village's solar energy

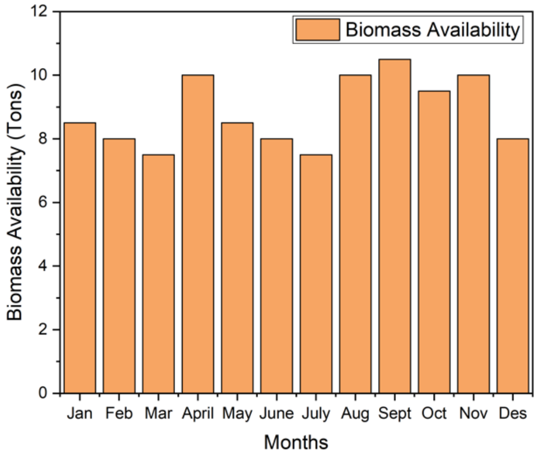

Fig. 6. Biomass Availability

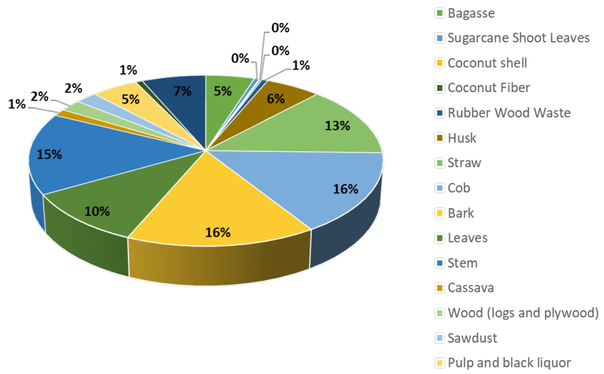

Fig. 7. Biomass Potential of East Java Province

(Source: ESDM Sector Facilities and Resources Map (ESDM One Map Indonesia))

3.3.1. Biomass potential

Indonesia has untapped RES Indonesia makes 650 MT of agricultural waste every year. Cereal crops like rice, corn, and wheat comprise 64.06 % of this waste, while sugarcane and cotton biomass account for 24.60% and 10.68% of total biomass, respectively. Indonesia produces 650 MT of agricultural waste annually, with cereal crops such as rice, wheat, and corn accounting for 63.06 percent and biomass from sugarcane and cotton accounting for 23.60 percent and 10.48 percent, respectively [44]. Depending on collection and heating efficiency, agricultural leftovers have an energy potential of 3.72 Exajoule (EJ) and can generate between 23-53 GW of electricity [45]. Malang's agricultural production comprises 54% rice and 39% maize. Straw, leaves, stems, and roots form biomass following harvest (Figure 7) [46], [47].

The anaerobic digestion of second-generation biofuel crop leftovers generates biogas. Primarily composed of methane and carbon dioxide, biogas is combustible. Biogas derived from the anaerobic digestion of organic materials is a diverse renewable energy source. Methane can generate energy and heat instead of fossil fuels, lowering greenhouse gas (GHG) emissions and climate change.

3.3.2. Energy production from solar PV

With more than 300 sunny days each year, Indonesia could create 5 trillion kW of clean solar energy. MEMR has taken advantage of solar energy. Malang gets 4–7 kWh/m2 of annual solar insolation. PLN provides solar energy to 4,794 consumers in Indonesia with a capacity of 48.79 MW (until December 2021). In addition to these solar power plants, PLN has implemented rooftop photovoltaic solar systems. Realizing the benefits of hybrid technology, PLN has promoted phase-2 hybrid power generation with solar energy as the primary or secondary renewable energy source in decentralized off-grid or grid-connected hybrid systems.

3.4. Solar photovoltaic generation

Photovoltaic systems convert sunlight into electricity using solar cells. Solar photovoltaic modules generate hourly energy (P_{PV}) calculated using Eq. 1 [48]:

$$P_{PV} = C_{PV} + D_{PV}\left(\frac{I_T}{I_{T,STC}}\right)[1 + \alpha_P(T_C - T_{C,STC})] \qquad (1)$$

where C_{PV} is the power output of the PV system in kilowatts, D_{PV} is the power drop factor, and I_T is the solar radiation in kW/m^2, $I_{T,STC}$ represents the incident solar radiation in kW/m^2, P represents factor of thermal power in %/C, T_C represents the cell temperature in Celsius, and $T_{C,STC}$ represents the cell temperature under standard testing conditions. This hybrid microgrid employs a standard multi-crystalline flat-plate PV panel with an efficiency of 14.5% [38]. Tree cover, dust, age, temperature, and wire losses diminish the efficiency of PV arrays by 80 percent—twenty-year photovoltaic panels [48].

3.5. Biogas generator

Biogas generators utilize biogas produced by the anaerobic digestion of organic materials. P_A (kWh), the yearly power output of a biogas generator set is derived from Eq. 2:

$$P_A = P_M + CUF[365 \times (\text{operating hours/day})] \qquad (2)$$

where P_M is the maximum capacity of the biomass gasifier system, and CUF is the capacity utilization factor. Based on biomass [24], equation 3 calculates the maximal biogas generator rating (kW):

$$P_M = B_T \times 1000 \times CV \times \eta_{BG} \qquad (3)$$

where B_T is biomass in tons per year, CV is the calorific value of biomass in MJ/kg, and η_{BG} is the efficiency of biogas generator set conversion [49]. This research optimized biogas generator sets ranging from 0 to 100 kW at a minimum load ratio of 0.5. The lifespan of biogas generators is 20,000 hours.

3.6. Converter

Figure 1 depicts a bidirectional converter that maintains energy transfer between AC and DC buses. Equation 4 determines the power value of the converter [48]:

$$P_{con} = P_L/\eta_{con} \tag{4}$$

where P_L denotes peak load demand and η_{con} is the efficiency of the converter. In this investigation, the converter has a 20-year lifespan and a 90% round-trip efficiency.

3.7. Battery

Microgrids utilize batteries to store excess generation and discharge energy during peak load demand when RER is insufficient to meet the load demand. Equation 5 determines the battery's maximum power:

$$P_{bat}^{max} = \frac{N_{bat}V_{bat}I_{bat}^{max}}{1000} \tag{5}$$

where N_{bat} represents the number of batteries, V_{bat} represents the battery's voltage, and I_{bat} represents the battery's maximum charging current in amps. This investigation utilized 40 flat-plate Li-ion batteries charged at 100% and 10% capacity. The return frequency was 90% [48].

3.8. Microgrid system economics

Capital, replacement, operating, and maintenance expenses for microgrid system components comprise the economics of hybrid systems. The system's fixed assets include installation labor and land. Biomass is $25 per ton. A 20-year project has zero percent annual capacity [48]. In HOMER simulations, the dispatch mechanism is load following, and the time step is one hour. COE is the average annual system cost per produced kWh of electricity. The cost of grid COE was $0.01/kWh [50]. Table 2 component prices explain from the current literature. The exchange rate was 15,278 IDR per 1 USD.

Table 2. Cost summary of different components of a microgrid system

Module	Investment Price ($/kW)	Substitute price ($/kW)	O & M price	References
Photovoltaic (Flat Plate)	820	780	9.5$/year	[50]
Biogas Genset	560	500	0.035 $/hour	[41], [48]
Battery (Li-Ion)	610	580	0.65$/hour	[48]
Converter	125	125	1.25 $/year	[35], [48]

3.9. The Microgrid system assessment criteria

The economic viability of the proposed microgrid system is evaluated based on the system's total net present cost (TNPC) and cost of energy per unit. $TNPC$ and COE are determined by Eq. 6:

$$TNPC = \frac{C_A}{CRF(i,n)} \tag{6}$$

where C_A is the total annual cost ($/year), and $CRF(i,n)$ is the expected capital recovery factor which is explained in Eq. 7 [48]:

$$CRF(i,n) = \frac{i(1+i)^n}{(1+i)^n - 1} \tag{7}$$

where i is the nominal interest rate (percent), which is based on annual inflation, and n is the project's expected lifespan in years.

The COE calculates by dividing the system components' annual cost by the energy output. In the cost calculation, only demand-supply energy is considered. The formula for COE which is explained in Eq. 8:

$$COE = \frac{C_A}{E_T} \tag{8}$$

where E_T is the total annual electricity consumption in kWh. Eq. 9 computes financing based on the payback period:

$$Payback\ period = \frac{I}{R-E} \tag{9}$$

where I, E, and R indicate investment, expenditure, and return, respectively.

4. Results and Discussion

In this section, evaluation of the microgrid system designed to meet the load requirements of a hamlet. MG-I is the microgrid system with PV and biomass-based generation units connected to an unreliable power grid, whereas MG-II is the microgrid system with battery storage and no power grid connection. The simulation results indicate the generation response of various components, cost analysis, emissions, and the influence of various sensitivity variables on TNPC and COE. The HOMER-2019 (Ver. 13.11.3) Pro edition software was used to build and test the system. Simulations of the microgrid system use a load-following (LF) dispatch technique. In several case studies, the proposed microgrid systems (MG-I and MG-II) are evaluated:

4.1. MG-I

The grid-connected microgrid system (MG-I) must consist of a 50-kW available generator, a 50-kW biogas generator, a 100-kW PV-Array, and a 73.9-kW system converter with an LF dispatch mechanism. The TNPC, per kWh COE, and operational expenses are $281,225.30, $0.0735, and $43,997, respectively, with an 81.5% share of renewable energy [39]–[41]. With net metering, the proposed MG-I system can sell excess electricity supplied by renewable energy sources (PV and biomass) to the grid to satisfy the village's load requirement. MG-I demonstrates that the suggested system can generate more electricity and satisfy the load demand in the hamlet. PV-Biogas Genset-grid electricity contributions are shown in Figure 8.

Anaerobic digestion generates mesophilic temperatures of biogas (35^0C to 42^0C). Biogas production in the research area peaked from May to July, when temperatures ranged between 32^0C and 44^0C. As shown in Figure 9, the biogas generator consumes more fuel during peak load months, optimizing its contribution to electricity output. MG-I consumes 232 tons of fuel annually and 0.63 tons of feedstock daily. In January and February, biogas generators consume less gasoline. During the rainy season, load demand is minimal; thus, the grid can handle it.

4.2. MG-II

To enhance the MG-II, a 50-kW generic biogas generator, a 63-kW generic flat-plate PV, a 46-kW system converter, 85-kW generic Li-ion batteries, and an LF dispatch method were incorporated. MG-100% II's RES-contributed TNPC, COE per kWh, and operating running costs are $466,858, $0.156, and $96,908. The microgrid's biogas and photovoltaic (PV) generators met the village's load demand throughout the year [39]–[41]. Besides, renewable energy excess charges and discharges battery packs to provide load electricity.

According to Figure 11, biogas and PV producers accounted for 52.5 and 47.5 percent of the total monthly power, respectively. Each power source contributes to the grid depending on the current conditions and the weather forecast. Due to optimal mesophilic temperatures for biogas generation, the biomass generator produces the most significant electricity in May–July (35^0C–42^0C). Figure 10 depicts the PV generator that supplies the remaining energy.

Figure 11 depicts the annual fuel usage of the biomass generator in bars. The results indicate that the facility has sufficient fuel to operate the biogas generator throughout the year. The MG-II biomass production unit consumed 372 tons of raw materials daily, or 1.02 tons. During the dry season's peak loading months, the biogas generator produced 30–50 kW, close to its maximum capacity (May-July). Due to insufficient solar energy, the biomass production unit operates primarily at night, increasing the microgrid's dependability.

4.3. Analyzing pollutant emissions

Although greenhouse gas emissions (GHG) are a worldwide concern, MG-II is more eco-friendly than MG-I because it can meet the village's linked load requirement with almost no emissions (Table 3). Nonetheless, TNPC and COE are cheaper than MG- II's, and MG-I is preferable since the hamlet is already connected to the grid. Table 3 demonstrates that MG-I employs 232 tons of sustainable biomass to generate electricity, which, if burned openly, would release greenhouse gases. Thus, the MG-I system reduces 85% of CO_2 emissions, 86.5% of NO emissions, and 76% of SO_2 emissions with an 82.5% renewable energy system component [39]–[41].

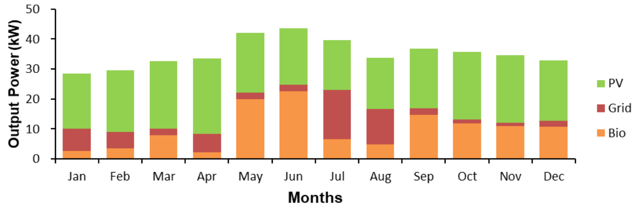

Fig. 8. MG-I generating unit power output throughout the year

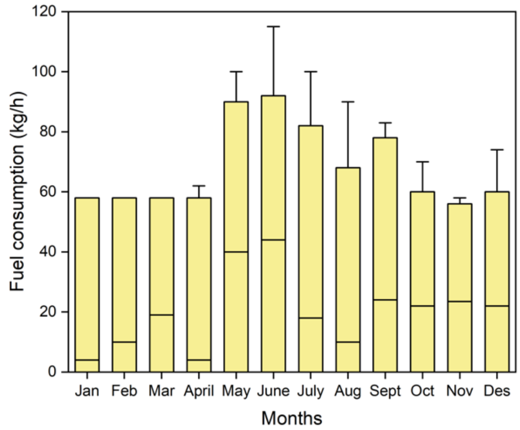

Fig. 9. Annual fuel consumption (in kilograms per hour) of the MG-I biogas generator

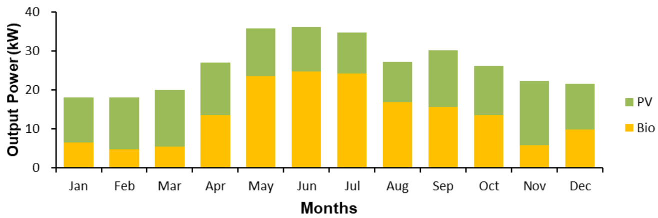

Fig. 10. MG-II generating unit power output throughout the year

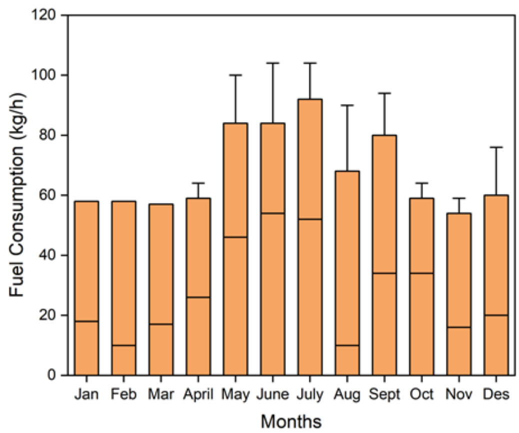

Fig. 11. Annual fuel consumption (in kilograms per hour) of the MG-II biogas generator

Based on the above techno-economic analysis of microgrid systems, the MG-I microgrid is the superior option for providing reliable and high-quality electricity to rural consumers, as it can provide electricity to villages at a COE of 0.0735 $/kWh, which is less than the average tariff rate of purchasing electricity from the grid, which is 0.1 $/kWh. As indicated in Table 4, the TNPC and COE are 1.67 and 2.1 times more in MG-II than in MG-I, despite MG-II utilizing 100% renewable energy. The annual energy sold to the grid by the MG-I system is 1.96 times greater than the energy purchased from the grid since the MG-I system generates 1.30 times more power (kWh/year). Additionally, the MG-I system generates a small profit and has a payback period of 3.83 years, with a shortened payback length of 4.16 years. In order to estimate the microgrid's COE and TNPC, a sensitivity analysis of the MG-I system (PV/biomass/grid) was conducted.

Table 3. Cost summary of different components of the microgrid system

Emissions	Grid-only	Burning of crop waste	MG-I	MG-II
CO_2 (kg/year)	94560	115019	31714	69.1
CO (kg/year)	-	6963.2	0.563	0.845
SO_2 (kg/year)	457	159.2	153	0
NO (kg/year)	209	275.718	67.3	0.565

4.4. Analysis of sensitivity

Sensitivity analysis assesses optimal system behavior when unpredictable characteristics such as biogas generator cost, biomass fuel price, solar radiation availability, and location-specific inflation rate are present. This study investigated the effects of various sensitivity variables on the MG-I hybrid system (Table 5).

4.4.1. Dependence on the biogas capital cost multiplier

Figure 12 compares COE and TNPC capital cost multipliers ranging from 0.8 to 2 for biogas. COE increases from 0.0719 to 0.0814 dollars per kilowatt-hour, while TNPC increases from $295,225 to $315,225.

4.4.2. Dependence on the cost of biomass fuel

COE and TNPC are also affected by the cost of biomass. According to studies, biomass particle size reduction speeds up anaerobic digestion. Also, the costs associated with biomass size reduction affect biomass pricing. Biomass prices increased from 22 to 30 dollars per ton, causing the COE to fluctuate between 0.0710 and 0.0777 dollars per kilowatt-hour, and the TNPC to range between $291,650 and $297,185 (Figure 13).

4.4.3. Dependence on the solar radiation

Solar radiation between 4.47 and 6.01 kW/m2 per day impacted COE and TNPC (Figure 14). The intensity of solar radiation decreases COE and TNPC. COE is lowered by solar radiation from 0.0843 to 0.0671 dollars per kilowatt-hour and TNPC from $295,305 to $269,164.

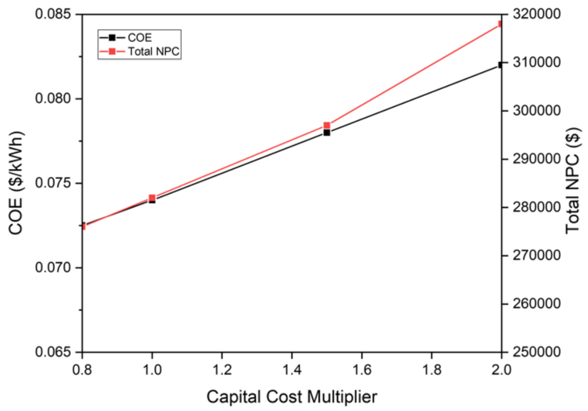

Fig. 12. COE and NPC impact of biogas generating capital cost

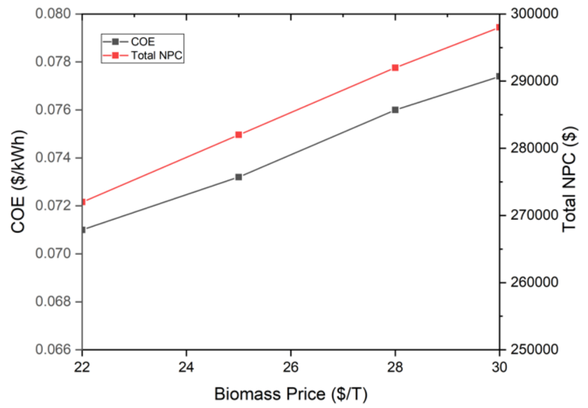

Fig. 13. Impact of Biomass Expense on COE/NTPC

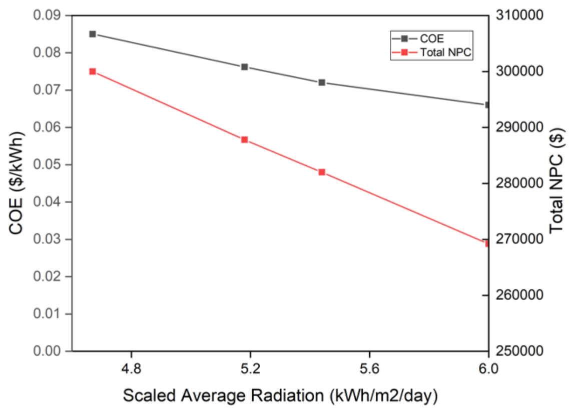

Fig. 14. Effects on COE and TNPC of scaled average solar radiation

Table 4. Comparisons suggested different ways to set up microgrid systems

Descriptions	Parameters	MG-I	MG-II
Finances	NPC ($)	280,225.30	466,758.
	COE ($/kWh)	0.0735	0.156
	Initial investment ($)	122,400.38	140,303
	Cost of operation ($)	43,997	95,903
Production of electricity	Total power generated (kWh/year)	305,002	226,596
	PV generation (kWh/year)	171,222	106,595
	Production of biogas generators (kWh/year)	84,248	119,052
Grid	Grid auction (kWh/year)	94,183	-
	Grid investment (kWh/year)	47,532	
	AC load (kWh/year)	181,500	181,450
	Electricity surplus (kWh/year)	19,477	38,416
Renewable percentage (%)		81.5	100

Table 5. Various sensitivity variables

Parameter	Values	Sensitivity variable
Solar	4.66; 5.1; 5.39; 6	Scaled average radiations
Biogas generator set	0.8; 1; 1.5; 2	Capital cost multiplier
Biomass	22; 25; 28; 30	Fuel price ($/ton)
Inflation rate	2.64; 3.55; 4.35; 5.51	Expected inflation rate

4.4.4. Dependence on the inflation value

Inflation in project commissioning affects capital costs. The expected variance in the inflation rate between 2.64 and 5.51 percent is included, and as shown in Figure 15, when inflation rises, the COE decreases from 0.0788 to 0.0755 dollars per kilowatt-hour. The TNPC increases from $252,484 to $283,225 when inflation increases.

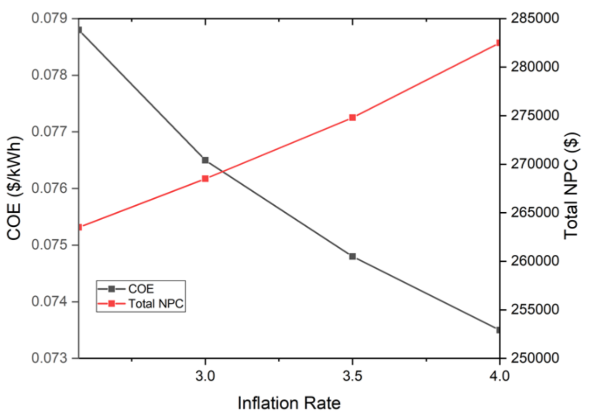

Fig. 15. Inflation's effect on COE and TNPC

The proposed microgrid HRES in Malang's "Tegalweru" community produced the following results:

- The PV/biomass resources fully satisfied the highest power consumption, with the Daily power from photovoltaic cells and the biogas generator meeting demand at night.
- Compared to grid-purchased COE, the grid-connected PV/biomass/microgrid MG-I system offers the least expensive unit COE at 0.0735 $/kWh.
- A net metering system permits the MG-I system to sell surplus energy to the grid.
- The MG-I system cuts greenhouse gas emissions by 7% by utilizing 230 tons of biomass yearly.
- The necessary payback period of the MG-I system is 3.8 years, making it a viable alternative for increasing the proportion of renewable energy in the energy mix.
- By spreading digestate across fields, biogas production from anaerobic digestion creates clean energy for electricity generation and improves soil health.
- The sensitivity analysis indicates that the system's TNPC and COE increase as the cost of producing biomass and biogas increases.
- As inflation increases, COE decline, and TNPC incline.

5. Conclusion

This study shows that Malang's PV/biomass microgrid system can reliably utilize biomass as a rural electricity source. The MG-I microgrid system can provide electricity to the community for 0.0735 $/kWh, 1.37 times cheaper than a grid-only system. By sustainably using biomass through anaerobic digestion, the MG-I system reduces greenhouse gas emissions by more than 80 percent, enabling the development of a clean and green community in Malang. Inflation also lowers the energy cost per unit of the MG-I system. This planned system provides employment and electricity to the community. Based on the study's results, the authorities should develop hybrid solar power plants to supply safe and reliable electricity to rural areas.

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