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Hybrid energy storage systems as a sustainable energy source

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Article Info

ABSTRACT

The use of fossil fuel power plants will contribute to emissions and environmental pollution, which has an impact on air and environmental pollution. Applying hybrid energy systems can help reduce the emission footprint and improve the stability of local electricity networks, especially in services with high energy consumption. Hybrid optimization of multiple energy resources (HOMER) is a simulator that simulates using renewable energy with the hybrid renewable energy systems (HRES). The simulation produces a system with the most appropriate combination of photovoltaic (PV), wind power (WP), and converter. The combination of PV-WP produces an economical choice for providing electrical energy in a particular location. The hybrid PV-WP model can save about 40.8% less than the current condition. The investment can be returned in 10.11 years, which is recommended for similar conditions in other areas. This positive impact can provide incentives for policymakers in the implementation of a hybrid system that can neutralize emissions and environmental pollution.

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1. INTRODUCTION

The impact of climate change will result in threats to the global economy and other impacts. Reducing the greenhouse effect on climate change is the ideal of every individual against environmental pollution in the future [1]. Fossil fuel power plants worldwide contribute to about 25% of greenhouse gas emissions. Therefore, reducing emissions in the region will have a significant impact on protecting against environmental pollution [2]. Therefore, power plants that use fossil fuels must be reduced to maintain environmental sustainability and switch to environmentally friendly energy. Indonesia still relies on electricity through thermal generation (63.4%), and the latest condition is quite adequate [3].

The use of renewable energy is being promoted as the main energy source, especially in developing countries, including Indonesia. The hybrid renewable energy systems (HRES) model is a compatible energy source because it can increase overall efficiency [4]. Hybrid optimization of multiple energy resources (HOMER) simulation provides a reliable solution for identifying approaches that have geographically varying loads [5]. HOMER simulation is a basic hourly hybrid system simulator, where the software provides consistent results by estimating system performance. The photovoltaic (PV) system simulation and software are stable, but some uncertainties arise when simulating wind power (WP) [6]. Another thing, this software works based on previous data obtained at the studied location and does not take into account other data and situations, so there is a weakness in not separating important and unimportant loads [7].

Renewable energy generation has taken over as the energy source of the future because it can reduce the impact of the greenhouse effect and emissions caused by climate change. Therefore, the change from

fossil fuel energy to renewable energy plays an important role in sustainable development. Integration of renewable energy into the electricity grid requires a comprehensive analysis of factors and availability of human resources, geography, and advanced technology [8], [9].

PV generator is one of the excellent energy sources, as its input power scale, because of its many advantages, such as being abundant, emission-free, and renewable, PV is the optimal choice as a renewable energy source. In addition, the usefulness of PV, which has high power handling capabilities, the ability to function without supervision, and fast response in output changes to changes in input radiation. Advances in PV technology have led to an overall increase in electrical efficiency and a drastic reduction in unit costs [10], [11]. In addition, this PV plant is very suitable for local renewable energy production, consisting of large open areas. Variations in power, voltage, and current will produce maximum output power [12], [13]. In addition to electromechanical methods such as trackers fixed, single, or multiple access, also maximum power point tracking (MPPT) trackers will also achieve the target [14]. The integration system in PV power plants for hybrid energy can reduce fossil fuel consumption. The contribution of this research is the proposal of a hybrid system of PV with a WP source as an economical choice for residential users.

The optimal configuration system on PV and WP hybrid power plants has made a real contribution to the provision of energy in housing. In addition, the hybrid system between PV-WP-diesel-battery is also a system that is applied to an independent system [15], while the hybrid system between PV-battery can achieve 100% from renewable energy [16], [17]. The use of the HOMER and renewable-energy and energy-efficiency technology screening (RETScreen) systems can optimize hybrid systems on renewable energy [18] because it can model standalone PV systems and PV-WP systems, but there are challenges to the openness and representation of spatiotemporal variations. Simulation models have been conducted for domestic users and energy-efficient system configurations on renewable energy in housing [19]. In addition, the design of a standalone PV-biogas system and an integrated renewable energy system using WP and PV were evaluated using HOMER [20]. A renewable energy system in rural areas that is optimally configured for PV-WP and batteries is an option for better integration to meet future energy needs [21].

The use of HOMER has been implemented in the Maldives to determine technical combinations in hybrid systems [22], which has been evaluated to determine several parameters such as net present cost (NPC) and levelized cost of energy (LCOE). Therefore, economic and technological exploration of hybrid systems on NPC and cost of energy (COE) related to renewable energy supply. Techno-economic studies for microgrid and economic impacts are analyzed, which are applied in housing. The scenario of electricity usage based on minimum, average, and maximum wind speed data and solar radiation data for WP and PV generators has been studied in microgrids. The result of the system configuration states that the hybrid PV and WP systems can produce 1.3 kW of power.

A simulation for a hybrid power system (HPS) system against a PV-battery can reduce NPC by about 59.6% and LCOE cost reduction by about 80.7% compared to the conventional method. In addition, the HOMER system for reliability and stability can save the cost and energy of the PV-WP hybrid system. This model has been conducted in Sudan with a PV-WP-diesel-battery configuration with LCOE $0.387/kWh with a total NPC of $24.16 million, with 40% investment and emission reduction of about 95%. PV-WP hybrid system that has been conducted in Nigeria with a payback period of 3.7-5.4 years and COE between $0.459-$0.562/kWh. A study in Colorado simulated the components for the economically optimal configuration of PV-WP-battery bank-hydrogen tank and laser systems and found that hydrogen is more economically profitable, compared to batteries, for longer energy saving, with a minimum COE of 0.78 $/kWh. The hybrid system between PV-diesel generator (DG)-battery is the best choice for the future. The above model can reduce 70% of batteries and reduce emissions by 97% compared to DG.

Illustration of renewable energy generation provided by the HRES system can provide optimal conditions for smart homes in hybrid systems. The configuration model using a hybrid system has been carried out in several countries, such as India and Victoria, with a combination scenario between PV-WP. The HOMER simulation system found a reduction in emissions with NPC of 29.7% per year compared to conventional power plants. In addition, the HOMER simulation system found an HPS of around 73.6 MW costing $180 million, and an LCOE of 0.0574 kWh. Renewable energy systems have technical-economic feasibility in some countries, but the exploration of the potential for future energy supply has not been evaluated, so the availability of literature on the most effective hybrid systems and renewable energy opportunities for relevant geographical areas is still limited, to implementation a new paradigm shift towards a more sustainable and renewable energy future. The gap in identification can be addressed by a suitable literature study on the most effective implementation of renewable energy to be integrated into the existing electricity grid.

This study aims to validate the results of other studies presented in the literature. The findings of this study can provide information to policymakers, energy planners, and governments to accelerate the adoption of renewable energy and achieve a sustainable future. The study further focuses on the importance of identifying specific renewable energy opportunities to facilitate the integration of renewable energy into the

electricity grid and contribute to mitigating the impact of climate change and promoting non-fossil energy sources in the future.

2.   METHOD

2.1. Research contributions

The HOMER device is used to validate a hybrid model of renewable energy systems for commercial scale, besides that also. This application with HOMER software to get the optimal size. This is intended to help find the most effective ways of cost-saving and to integrate hybrid energy systems that can be used in general. The impact of emissions can drive global warming and needs to be minimized. The simulation study methodology is shown in Figure 1.
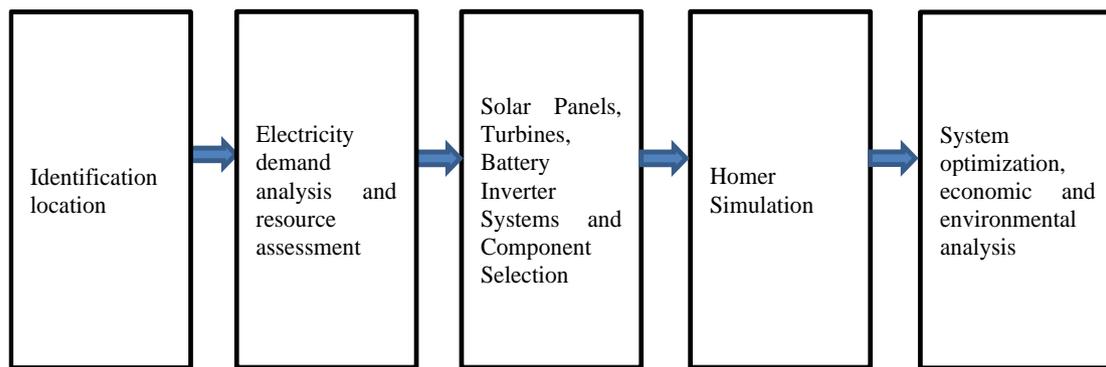
Figure 1. Simulation study methodology

2.2. Research location

The selected location is Medan City, the capital of North Sumatra, Indonesia, with a population of around 2,494,512 people, with a population density of around 9,413 people/km (2022). Medan was originally founded by Guru Patimpus in 1590 and in 1909 became the center of government of the East Sumatra Residency. Currently, Medan is a major growth center in Indonesia. A fairly large population requires electrical energy to meet its economic needs.

However, peak-hour power outages still occur frequently with all the electricity available, of which around 0.68% is still generated by DG addition. Before assessing the power generation opportunities, the scale of the electrical load must be determined. However, a more accurate determination of the load is essential for designing generation and storage facilities. Data for the electricity consumption of large entities such as trading markets and others are usually available using monthly electricity bills, which state the maximum load against rate request arrangement and the total energy used. Use with the average load is determined using the last load for the middle day of each appropriate month. Data at the most recent point available for the last two years is used to calculate load growth from trading areas and increasing power demand. This resulted in a peak load of 4,400 kW, with an average of 2,160 kW. The model was introduced to accommodate varying demands from day to day. This step is important to allow for the proper calculation of the storage units and the appropriate installation size.

2.3. PV and WP sources

The non-existence of a single source for energy production, renewable energy caused by climate change in the area requires different energy sources, during different months of the year. This is due to the ever-changing and intense nature of the environment in coastal areas, where warm summers, followed by windy, rainy seasons, increase the opportunities for multiple PV and WP sources to be installed to generate efficient electricity. The active rainy season phase in Indonesia, which is characterized by strong convection and high rainfall, where WP equipped with PV is an alternative energy source in the use of electrical energy. The active and resting phases can be predicted using pre-defined monsoon indices that capture intraseasonal variance dynamics, but NASA wind energy data are somewhat optimistic, with average wind speeds much higher when compared to other sources.

2.4. Biomass potential

The Medan City community, with a large population, will produce unused food waste, and if this can be managed properly, it will produce energy that is useful as an additional power plant. It is estimated that the amount of household waste is around 39.9%. At that location, there is a total potential to convert 1,600-2,000 tons of food waste can be converted into electricity. Converting biomass into biogas for further use in household appliances or cars would be more adequate.

2.5. Design and simulation of the HOMER system

An HRES system will indirectly reduce greenhouse gas emissions and improve grid stability for additional storage capacity of electrical energy. HRES system consisting of compatible renewable energy generation sources to improve overall efficiency. HOMER system is a system that has proven to be a reliable and suitable solution for identifying approaches to specific applications for varying geographical areas and load profiles. The HOMER system has been used for various previous assessments because it has a common load profile for residential, industrial, and other uses. This method can be used for other projects in renewable electricity production, such as for evaluation. Several factors must be taken into account, such as taxation of emissions caused by the combustion of fossil fuels. PV and WP generation are the most realistic options of all the proposed system components. Implementing renewable energy is depicted in Figure 2.
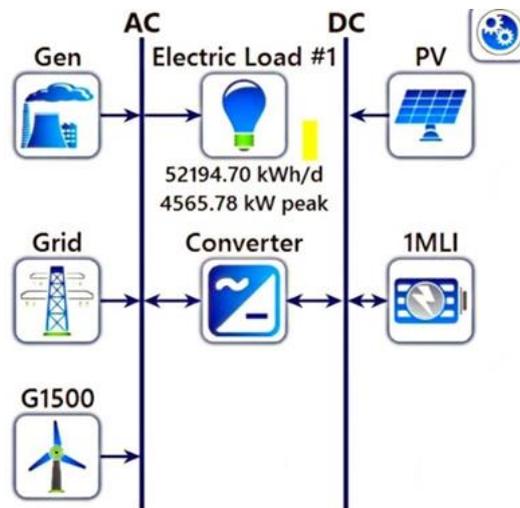

Figure 2. System architecture before optimization

Based on calculations and evaluations lowest cost system (LCS), HOMER can resize all components to the most effective size. The selection of 1 MWh is the best recommendation from the software because the size of the PV system is estimated to be quite significant, with a relatively low cost of US$900 installed in power units (kW), assumed for operation and maintenance (O&M) costs. Other researchers that configuration using the converter is estimated to have an efficiency of around 98%. This model is a basic concept of generator, power electronics, speed control, or aerodynamic power constraints. The dermatology factor value is the difference between stanniocalcin (STC) and the actual value, which is between 0.0-0.77. For high dermatology factors applied to large modules, sensitivity analysis is based on financial safety margin. Lithium-type batteries having an efficiency of around 80% are selected for energy storage. A study with a dynamic efficiency range for a WP generator has been implemented with the HOMER system. The resources are arranged to produce generating units to serve the load with voltage and frequency according to consumer needs.

2.6. Parameter economic

Economic parameters must be considered in the system evaluation, where a discount rate of approximately 6.25% was assumed in July 2021 alongside 3% inflation. Varying sensitivity values are selected for the uncertainty simulation, while the PV model can operate for 25 years as per the manufacturer's warranty. However, simulations generally use a 15-year lifespan to account for unexpected events in the best project financial scenarios.

2.7. Carbon dioxide

Carbon dioxide (CO_2) contributes globally to environmental warming changes; previous research has shown that CO_2 contributes about 11% of emissions in 2025, and this will have an impact on the health of living things on this planet. A significant reduction in these emissions is needed. Reducing CO_2 emissions is a worldwide consensus as part of the framework to reduce global warming process. To estimate direct emission savings and similar financial benefits, the current level of CO_2 production from the electricity sector needs to be measured. Daily electricity consumption is expected to reduce emissions so that the environment remains comfortable and safe.

3.   RESULTS AND DISCUSSION

3.1. Optimization system

The HOMER simulation system has been used for the selection and determination of dimensions. The electrical load is obtained from one year of data used in the simulation. The monthly average radiation, the coolness index, and the monthly average wind speed at the research location are obtained from the Agency for Meteorology, Climatology, and Geophysics (BMKG) data of Medan City. The optimization assessment of the characteristics, electricity production, annual electrical load, renewable energy, emissions, and others has been simulated. A load control strategy is the addition of the network that has been considered as consumer demand. In addition to the above, simulations have also been carried out for the benefit of using components such as life cycle cost (LCC) and NPC.

HOMER identification is the best hybrid model for efficiency in a specific geographical location. The simulation shows the amount of annual energy use of around 3830,081 MWh/year (19%) for PV generators, while WP generators use around 4532,579 MWh/year (22.5%). Around 41.5% of energy source electricity is generated by renewable sources in the system. Actual monthly energy production from each source is summed so that in the peak production month of March, solar power produces a higher amount of energy; however, in the rainy months of June, July, and August, wind is seen to provide a higher percentage of energy. The introduction of chemical storage units proved to be unprofitable, probably due to the congruent production and load curves of the PV-based system and the high purchase price. It should be noted that the actual results of this simulation depend strongly on input parameters such as the investment cost of new generating facilities and the cost [23]. To find potential for further improvements, it may be helpful to choose a period with high grid electricity demand.

The PV array model costs $500 according to various sources; LCS will not use additional wind turbines. This hybrid model for the months with high consumer activity, such as March and October are still very dependent on grid supply. It should be noted that throughout the year, electricity from newly introduced sources follows two patterns. First, the peak of non-conventional energy production during the day is driven by the output of the PV array. During the monsoon months (from one day to the next, i.e., from June to mid-August), the increase in the average wind speed causes an increase in wind turbine production, indicated by an increase of more than 100% per hour. This creates conditions where the power can be directly connected to the commercial electricity grid. In addition, the temporary part of the renewable power generation is also assessed. The technical potential of energy renewable electricity is very large, and the social acceptance attribute provides important support from local users. Based on the above data, the planning and development of hybrid power grids can be implemented.

3.2. Economic analysis

Economically, the project is predicted to be used for 25 years, and the interest rate is 4% per year. For future energy savings and a reduction in direct purchases from the network, an initial investment of around $6.5 million can be saved. In addition, the simulation can save an annual cost of $1.38 million with a predicted return on investment of around 10.9 years. However, the cost of LCS is still low for the following year's use. This increase contributes to an internal rate of return (IRR) of around 7.5%, and this is a profitable investment [24].

3.3. Emission analysis

The use of hybrid systems can reduce emissions by around 42.4%. The world bank plans to provide incentives to countries that can minimize emissions from the construction of power plants in the future. This is intended to reduce emissions and environmental pollution caused by the construction of fossil power plants. Future power plant projects can contribute to the construction of renewable power plants such as PV, WP, and geothermal [25]. Comparison of LCOE for hybrid energy and emission results from fossil power plants are simulated against energy needs for consumers. The simulation results provide information that LCOE from LCS is lower than the fossil power plant. LCOE and emissions will depend on consumer needs,

location, and hybrid energy. This will depend on investment costs and other management costs, with economies of scale, decreasing production costs.

3.4. Data limitations

The results of the analysis with HOMER for the hybrid system (PV-WP-battery) provide information that the hybrid model is more profitable and environmentally friendly when compared to fossil power plants. The performance of the hybrid system will depend on the size of the PV, WP, battery, load, and climate at the location [26]. The PV-WP-battery hybrid system provides important parameters for planning and optimal system configuration to produce maximum efficiency.

The limitations of data obtained at a location will affect the results of the hybrid system including the local climate. The capital cost for the use of technology will vary substantially, and these costs are predicted to decrease due to the economic effects and product efficiency. Numerical parameters are implemented with appropriate results for identifying trends and concepts to be applied to industrial areas or residential areas.

4. CONCLUSION

Evaluation and configuration for hybrid systems against the costs used will provide good value for future renewable energy generation. Some of the results of the evaluation and configuration include the PV-WP-battery combination is the best choice at this time because the load characteristics change for each time, such as in the morning, afternoon, evening, and night. For COE around $0.087 kWh, with a return on investment of around 4.1% and an annual operating cost of $1.38 million. This is because PV-WP project can operate for around 25 years with minimal costs. Emission reduction of around 42% as a consideration of government incentives. PV-WP hybrid is an ideal configuration used as a profitable combination model. The research results are operated on a techno-economic system to convince decision-makers.

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AUTHOR CONTRIBUTIONS STATEMENT

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Suwarno	✓		✓	✓	✓		✓		✓		✓			✓
Catra Indra Cahyadi		✓				✓		✓		✓		✓	✓	

C	: **C**onceptualization	I	: **I**nvestigation	Vi	: **Vi**sualization
M	: **M**ethodology	R	: **R**esources	Su	: **Su**pervision
So	: **So**ftware	D	: **D**ata Curation	P	: **P**roject administration
Va	: **Va**lidation	O	: Writing - **O**riginal Draft	Fu	: **Fu**nding acquisition
Fo	: **Fo**rmal analysis	E	: Writing - Review & **E**diting		

CONFLICT OF INTEREST STATEMENT

The authors declare that they have no known conflicts of interest, whether financial or non-financial, that could have influenced the conduct or outcomes of this research. The study was carried out independently, and all analyses, interpretations, and conclusions are based solely on the data obtained and the methodologies applied by the authors.

DATA AVAILABILITY

The dataset used in this study to develop and evaluate the extreme gradient boosting (XGBoost)-based diabetes risk prediction model consists of anonymized patient health records derived from historical health data. All personal identifiers were removed prior to analysis to ensure compliance with ethical and privacy standards. Due to institutional and privacy restrictions, the raw data are not publicly available, but

they may be obtained from the corresponding author, [MA], upon reasonable request and with permission from the relevant data owner.

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