# Renewable energy conversion systems for global emission neutralization

**Suwarno[1], Catra Indra Cahyadi[2], Pardamean Manurung[1], Abdul Rahim[1], Farhan Tanjung[1], Herman Birje[1], Fadly Syafni[1], Muhammad Ridho Kurnia[1], Ismail Faruqi[1]**
[1]Department of Electrical Engineering, Faculty of Technology, Universitas Muhammadiyah Sumatera Utara, Medan, Indonesia
[2]Power Supply System Laboratory, Department of Airport Electrical Engineering, Politeknik Penerbangan Medan, Medan, Indonesia

**Article Info**

***Article history:***

Received Oct 13, 2024
Revised Mar 15, 2025
Accepted Mar 26, 2025

***Keywords:***

Global emissions
Hybrid system
Renewable energy
Simulation

**ABSTRACT**

Fossil fuel power plants still play an essential role in providing energy worldwide, but their environmental impact will contribute significantly to emissions and environmental pollution. To reduce these emissions, renewable energy offers a solution to reduce global emissions. This study proposes a renewable energy modeling system using hybrid optimization of multiple energy resources (HOMER) simulation on renewable energy systems for economic savings. This simulation can combine photovoltaic (PV), wind power (WP), and converter systems. The hybrid combination of PV and WP is the most appropriate and economical choice at the research location. The results showed that the modeling of the renewable energy hybrid system made a significant contribution, with an initial investment cost of IDR 107,474.43 million and an annual operating cost of IDR 22,540.23 million, 41% lower on condition now with an estimated return on investment of 11 years. The results of this study can be used as recommendations for similar conditions in other places. Policymakers can use this model to provide incentives and have a positive impact on hybrid power plants (HPS) in neutralizing global emissions.



***Corresponding Author:***

Suwarno
Department of Electrical Engineering, Postgraduate, Universitas Muhammadiyah Sumatera Utara
Medan, Indonesia
Email: suwarno@umsu.ac.id

## 1. INTRODUCTION

The greatest threat of climate change to the global economy and environment is very significant and needs attention, where the whole world contributes around 25% of global greenhouse gas (GHG) emissions [1]. Countries that use fossil fuel power plants contribute the most to environmental pollution and should be given incentives to reduce these emissions. Indonesia still depends on electricity through fossil fuel power plants (63.4%) to provide sufficient supply [2]. Hybrid renewable energy system (HRES) includes several renewable energy generation sources that are compatible with increasing overall system efficiency [3]-[5]. Hybrid optimization of multiple energy resources (HOMER) can provide reliable modeling and forecasting for a wide range of geographic conditions and load profiles compared to many other assessments [6]-[8]. HOMER is used for robust hourly hybrid system simulation. In addition, HOMER also provides suitable results to estimate the feasibility and performance of a well-performing system. Solar energy system simulation provides stable results, while uncertainties may occur when simulating wind energy [9]. On the other hand, there is a weakness, namely separating important and unimportant loads from the system.

The application of renewable energy has received special attention in recent years, due to the reduction of emissions and the impact of climate change. Comprehensive analysis of integrated power grids on several factors for future technological progress [10]. Solar power is a very good energy source because Indonesia is a fairly high equatorial region. Various cheap, free, emission-free, and renewable energy sources, solar power is one of the right choices as a renewable energy source.

Advances in solar panel technology overall increase efficiency and reduce photovoltaic (PV) unit costs [11], [12]. In addition, this modeling is very suitable for the utilization of local renewable energy consisting of large open areas [13], [14]. Variation of power, voltage, and current to optimize the network system, in addition to the method, the use of maximum power point tracking (MPPT) can achieve the objectives of this research [15]-[17]. Many researchers have contributed to the improvement of electrical output and integrated systems on PV panels to reduce fossil fuel consumption. PV system sources are one of the economically feasible hybrid system options to provide electrical energy sources for household consumers [18]-[20]. However, integrating renewable energy into the electricity grid still poses significant challenges, especially due to the large initial investment. The contribution of this research is to propose a model to minimize emissions from fossil fuel power plants to renewable energy power plants so that green energy conservation can be guaranteed and maintained for the health of the surrounding environment.

## 2. LITERATURE FRAMEWORK

Configurations to optimize hybrid systems in various locations and applications have been done by previous researchers. The hybrid system between PV-wind power (WP)-diesel batteries is one of the best solutions for applications [21]. A study conducted in Indonesia found that a combination of PV battery systems can achieve 100% renewable energy use [22], [23]. HOMER and RETScreen have contributed to the optimization of hybrid systems. The above models have provided solutions for hybrid system capabilities and stand-alone WP and PV system modeling. However, the representation of temporal variability is of particular concern. Other studies have been conducted on renewable energy costs to determine the appropriate renewable energy efficient system configuration for today's housing [24], [25]. The HOMER design has been used to evaluate biogas systems, standalone PV, and integrated renewable energy systems [26], [27].

Current research focuses on the economic aspects of renewable energy systems, which has been conducted in Indonesia and found that the PV-diesel system can generate around 309.6 kWh of electricity per year for IDR 5,191.99/kWh [28], [29]. In Thailand, research has been conducted on PV panels, converters, and battery configurations that reach 100%, with a renewable energy cost of IDR 11,886.06/kWh [30]. A study of the application of microgrid systems in Europe has been conducted, and the analysis of the economic impact of renewable energy systems on households confirms the right choice for a hybrid system consisting of 1.3 kW PV, 1.6 kW solar, 9 kW WP, and batteries [31]. Research conducted in Indonesia found that the best configuration in terms of emissions and costs is a hybrid system of PV-WP and diesel generator (DG) batteries. A study conducted a simulation and feasibility study of the battery and PV hybrid power system (HPS) that can reduce net present cost (NPC) by about 59.6% and reduce levelized cost of energy (LCOE) operating costs by about 80.7% compared to conventional methods, and the HOMER simulation has provided a reliable and stable energy-saving system and an independent system for generating renewable energy. A comparison of different hybrid systems found that the battery, PV, WP, and power converter systems performed best with an LCOE of IDR 6,318.55/kWh, a total NPC of IDR 394,460.32 M, with a return on investment of 40%, and a reduction in fuel consumption and emissions of about 95%. Optimization of the hybrid system for PV and WP will meet household electricity consumption with a payback period of between 3.7 to 5.4 years and the COE for the hybrid system varies between 0.46-0.56 with IDR 9,175.77/kWh. The study of the structure and operating conditions of HRES and HOMER used for PV/DG/battery hybrid systems is a feasible option in the future because solar radiation is an available resource. This model can reduce battery requirements by up to 70% and reduce emissions by up to 97% compared to DG. HOMER simulation has been used in economic and environmental surveys and COE, NPC, renewable fraction (RF), and GHG selection with a reduction in GHG emissions of around 2,889.4 kg/year and renewable energy of around 98.3%. HOMER is also used for simulation and research with an environmentally friendly and economical system, with a reduction in emissions and NPC of 29.7% per year compared to conventional power plants. A study of the optimal conditions for smart home energy management with hybrid energy sources in Indonesia, which contains an economic analysis to encourage families to integrate home energy control system (HECS) into their homes. This study shows that the hybrid technology configuration is an option for electricity using a combination of renewable energy sources in Indonesia, such as for industry, institutions, commercial, agriculture, and small scale. A comparison of WP/PV on-grid power generation system configurations is the best choice to be implemented for cost and energy savings.

### 2.1. Previous research

The literature reviews the economic feasibility of HRES systems in various locations around the world, exploring the HRES system as an energy provider sustainable and cost-effective, finding the technical, economic, and environmental conditions for optimal hybrid systems. However, the most effective combination of renewable energy for a particular region is still limited, hampering the paradigm shift towards a green energy future. There is a research gap to identify relevant combinations of future green energy opportunities [32]. This study relies on the available literature in the field of effective hybrid system technology and its potential integration into future grid systems. This study also validates the results of other studies presented in the literature. The results of this study can provide information to policymakers, energy planners, and stakeholders to accelerate the implementation of hybrid systems and achieve the future of energy.

### 2.2. Research contributions

The contribution of this research is to verify the hybrid renewable energy system model in commercial applications such as housing by using HOMER to obtain the optimal size. The system model above can cost savings from integrating renewable sources into the mix used by the surrounding population. At the same time, emissions that are the main cause of global warming are attempted to be minimized. By calculating the current emissions of Indonesia's electricity production, the potential reduction in the implementation of a hybrid electric system can be presented.

## 3. RESEARCH METHODS

### 3.1. Description and costs

This research was conducted in Indonesia with peak loads such as in Java Island and its surroundings. However, power outages occur during peak hours caused by all available electricity, 0.68% of which is still generated by generators. HOMER is a simulation tool to assess the potential of electricity generation, the scale of the electricity load must be determined, but the determination of the load is essential for designing generation and storage facilities. Household electricity consumption data is usually available using monthly electricity bills, which show the maximum demand based on the price and the amount of energy used. The average load is determined using the middle of each month. The most recent available data from two years has been used to account for ongoing housing growth, increasing electricity demand, and sharp decreases in peak loads at certain times. This results in peak loads in certain months. A synthetic model has been introduced to improve the accuracy of daily demand changes. This model allows for precise calculations of storage units and installation sizes and the data has been calculated as a power factor value of approximately 0.96.

### 3.2. WP-PV generator combination.

The climate conditions in a place will depend on the particular season, where climate change caused by environmental characteristics in Indonesia is a concern in research related to WP. In the summer and rainy seasons, it will produce wind speeds that are quite good as a source of electrical energy. Indonesia's astronomical location is between 6°N-11°S and 95°E-141°E. Areas with tropical climates have the potential to occur throughout the year, thus ensuring efficient PV operations. The rainy season is active in Indonesia with WP and PV because the rainy season months produce high wind speeds while cloud cover reduces solar potential. WP is an alternative source solution that can reduce the use of electricity from other sources. Indonesia has climate conditions as explained above, so the combination of two sources, namely WP and PV, provides a fairly good contribution as a renewable energy source in the future [33].

### 3.3. Biomass

Indonesia has a very large bioenergy potential from biomass sources, which is equivalent to 56.97 GW of electricity, and by 2060, Indonesia will build more than 700 GW of renewable energy power plants, of which 60 GW will come from bioenergy power plants. Direct conversion of biomass to biogas for household use would be more adequate. Energy supply for the entire housing complex without storage equipment, and waste storage with a capacity of 6,600 people theoretically can be a power supplier during peak loads. In addition, the I waste incinerator can be used as a base load supplier adjusted by reducing waste volume and accommodating non-biodegradable waste.

## 4. HOMER AND SIMULATION

HRES systems and energy storage systems are direct steps to reduce emissions, but can indirectly improve grid stability. HRES models are compatible with hybrid sources to improve overall system efficiency. HOMER simulation is the best and most reliable solution to identify application-specific approach models across different geographic regions and load profiles. HOMER provides profiles of various burdens such as housing, industry, and others. In addition, other options can be beneficial for the environment. Environmental factors are considered as a result of future emissions from fossil fuel combustion, depending on the pollutants. The proposed system components are PV and WP system modeling that has provided the most realistic options and has been implemented into an integrated system. The simulation calculates and evaluates the LCS, but HOMER can resize all components to the most effective size. The PV size is significant, and the operation and maintenance (O&M) costs can be assumed to be relatively low per unit of installed power (kW). Conversion to a hybrid electric system in the MW range has an efficiency lower than 98%. The difference between the standard test conditions (STC) and the actual value is between 0 and 0.77 [34], [35]. For large models, the highest value can be used, since the design is more efficient. However, for a safety margin, a low to high-value change analysis has also been performed. A battery with 80% efficiency was chosen as the storage unit because it offers the highest energy density and is considered the most appropriate choice for environmentally friendly energy storage [36]. HOMER introduces dynamic efficiency for WP systems with various wind speeds. The HOMER system is a regulated resource and active generating unit to produces electricity according to consumer demand with fluctuating voltage and frequency to support the electricity grid. Replacing the WP of the entire system and adding more PV panels is a solution that will drive the need for greater storage capacity because the electricity supply will be intermittent.

### 4.1. Parameter economy

Economic evaluation is a special concern before the project is implemented. In 2021, the assumed discount rate is 6.25% for Indonesia [37]. Indonesia recorded annual inflation of 3% in April, driven by rising transportation costs as >190 million urban residents celebrated their return to their hometowns. This inflation decreased compared to the previous month of 3.05 percent but remained within the central bank's target range of 1.5 to 3.5 percent. The increase in the consumer price index from 103.3 (April 2023) to 106.4 (April 2024). This increase occurred in Gorontalo with an inflation rate of 4.65%, and in Papua by 1.78%. The increase occurred due to geopolitics in the Middle East and high interest rates in the US, so the central bank raised the benchmark interest rate by 25 basis points to 6.25%. To control inflation and maintain the stability of the rupiah, the benchmark interest rate has been raised by 275 basis points since August 2022. Simulation uncertainty will depend on the sensitivity value selected. The PV model can be used for 25 years and is a guarantee of standard manufacturer products [38]. For 15 years conducting accounting simulations for unforeseen events and has facilitated the overall financial assessment of projects.

### 4.2. Emissions

Emissions are a major contributor to global warming, with carbon emissions set to increase by 11% by 2025, and pose a significant health risk to humanity worldwide. Emission reduction has become a key target for achieving global consensus as part of the carbon emission reduction framework, Indonesia's global warming process, which produces 699 metric tons of carbon emissions per year, is now part of the framework modeled for international $CO_2$ trading, which is used as a product for intermediate consumption. Indonesia has been measuring emissions and carbon dioxide to save energy. The average daily electricity consumption for all institutions is 46,559 kWh, currently contributing 23.82 tons of CO2 per day.

## 5. RESULTS AND DISCUSSION

### 5.1. Optimization system

Dimensions and system construction based on HOMER simulation. Input electrical load data annually is available to perform the simulation. Monthly global irradiance, monthly clarity index, and average wind velocity each month for available locations and included in the HOMER simulation. Simulation and optimization for performance characteristics, annual electricity load curve, electricity production, hybrid fraction, and emissions. have been performed. The following load control strategies have been used during the simulation and additional grid centers have been considered to ensure the product meets the demand requirements. Different simulations are ranked based on the adjustment of different components based on total life cycle cost (LCC) and NPC.

The load control strategy (LCS) layout has been determined in such a way that HOMER has determined the optimal system consisting of a PV array with a capacity of 3,010 kW, a system converter with a capacity of 1,930 kW, and a WP with a capacity of 500 kW. The assumption above is one of the realistic projects related to the availability of space around the housing complex. HOMER simulation is the best combination for efficient performance in this open space location. The simulation results show that the amount of energy is 3,830.1 MWh/year or 19.1% of the energy from PV and 4,532.6 MWh/year or 22.6% of the energy from WP. There are 41.5% of electric energy from hybrid energy sources in the system. The actual monthly energy production from each additional source can be obtained from the simulation. Most likely because the production curve and load of the PV-based system are very aligned and the purchase price is high, the simulation results are highly dependent on input parameters such as investment costs, new generating facilities, and other costs.

PV panels cost IDR 8,163,500.00 according to various sources, LCS will not use additional WP. The combination of electrical energy in months with high residential activity is highly dependent on the provision of the electricity grid because, throughout the year, electricity comes from new sources. Fossil energy production peaks during the day, driven by PV output. In the rainy season months, the increase in average wind speed causes an increase in wind turbine production, indicated by an increase of more than 100% per hour. This results in electricity being connected to the commercial electricity grid, reducing the need for waste storage infrastructure and reducing construction costs. The technical potential of renewable electricity in the residential sector is enormous, and the social acceptance attribute provides important support from local residential users. Energy planning, development of renewable electricity grid infrastructure, and implementation of future hybrid energy systems can use the results of the above research as a benchmark.

### 5.2. Economy

The designed system is expected to operate for about 25 years, with an estimated annual interest rate of about 4%. It is estimated that by taking into account future savings by reducing the need for direct purchase of grid electricity, cumulative savings of about IDR 106,125.50 million can be achieved. The simulation results show that the initial installation investment required is about IDR 107,431.66 million, and the annual cost is about IDR 1,002,151.26 million. The payback period is estimated to be about 11 years and the inverter can be used for about 15 years with the LCS operational cost still smaller. However, the operational cost continues to decrease with increasing savings for the following years. The IRR of about 7.6% has made a positive contribution to increasing electricity generation and revenue and exceeds the investment and financial costs.

### 5.3. Emissions

This hybrid system can achieve operational emission reductions of around 42.4%. Indonesia and the World Bank are working together to develop a virtual carbon trading plan. In 2021, Indonesia has identified PV energy as a major resource, and the ministry of energy and mineral resources estimates a huge potential of around 3,294 GW. Based on data from the Institute of Essential Services Reform (IESR), the greater potential is around 7,715 GW, because Indonesia is strategically located on the equator, resulting in a global average daily horizontal irradiance (GHI) of 4.8 kWh/m$^2$, surpassing other countries. In addition, Indonesia has set targets and maximized this potential as stated in the national energy master plan. By 2025, Indonesia seeks to achieve an installed PV generation capacity of around 6.5 GW and increase it to 17.6 GW by 2035. The policies that have been stated in government regulations mean that Indonesia is currently focusing on supporting the PV industry, such as floating systems. Solar panels, residential rooftop solar, and utility-scale solar power plants. Floating PV solar power systems present a promising opportunity, taking advantage of Indonesia's vast maritime territory, and were outlined in an analysis by the National Research and Innovation Agency (BRIN) in 2022. With around 5,800 lakes covering an area of 5,868 square kilometers and calm seas of 708,000 km$^2$, Indonesia has plenty of room for floating solar power systems. The safety of installing PV solar panels is also proven by the absence of tropical storms in Indonesia for the past 50 years.

One of the realizations of the potential for floating solar power plants in Indonesia is the Cirata Reservoir in West Java, which was inaugurated at the end of 2023. Indonesia has the largest floating solar power plant in Southeast Asia, namely the Cirata Floating Solar Power Plant with a water area of 225 hectares and a capacity of 192 MW. This success opened a dialogue regarding the expansion plan between the state-owned electricity company and Abu Dhabi's renewable energy company, Masdar. The construction of Cirata Solar Power Plant phase II has increased the total installed capacity to 500 MW. In 2024, the Ministry of Energy and Mineral Resources plans to add a floating hybrid solar power plant project located in Singkarak (West Sumatra), Saguling (West Java), and Karangkates (East Java). Another great potential comes from the use of rooftop solar power plants for households with a potential capacity of around 32.5 GW. Rooftop solar power plants will also operate in 2023 with a capacity of around 95 MW, with a contribution from the household sector of 72% of total production. Electricity consumption in Indonesia has been dominated by the household sector for at least the past sixteen years, according to data from the Ministry of Energy and Mineral Resources. In 2020, the household sector contributed 50.8% of national electricity usage. In early 2024, the Indonesian government amended the regulation of the Minister of Energy and Mineral Resources No. 26/2021 to encourage the household sector's transition to renewable energy, by removing the previous cap on the installation of PV systems of 10-15% of total installed electricity capacity.

The Indonesian government is actively encouraging the expansion of rooftop PV systems for households to increase the renewable energy mix. By 2050, rooftop PV power generation is expected to reach around 30% of government buildings and 25% of high-end housing and apartment complexes, further contributing to renewable energy practices.

### 5.4. Comparison of research

HOMER simulation to compare LCOE of hybrid energy systems (PV and WP) and emission results for housing, has provided information about housing energy demand and PV and WP source data in the research location. The LCOE determined from LCS is IDR 1,272.18/kWh which is relatively low and keeps decreasing. Actual LCOE and emission will depend on housing energy demand, location, PV and WP source data, system design, and other configuration parameters. In addition, there is a reduction in investment cost and operation and maintenance cost, due to economy of scale, reduction in production cost, and so on.

HOMER has provided sensitivity analysis for PV, WP, and battery hybrid systems. The parameters entered will affect the performance and sensitivity analysis of this hybrid system. Various parameters in sensitivity analysis can help determine the optimal system design and configuration and maximum performance efficiency. In addition, climate change in this study is not discussed in more depth. The application of other parameters and costs will improve production efficiency and help identify common concepts in housing and industry.

## 6. CONCLUSION

The PV and WP energy configuration analysis has been conducted to evaluate the feasibility and cost analysis. The results of the analysis illustrate that the combination of PV, WP, and batteries is still the optimal choice for the electricity grid system in Indonesia. Reducing the need for storage facilities and utilizing WP energy has been carried out optimally, thus helping to reduce the load on PV cells. The COE system and project return on investment provide reasonable value for implementation. The use of PV and WP will result in minimum operational costs for 25 years with minimal performance and costs. The total emission reduction is determined to reduce annual costs, considering the carbon trading system method, which contributes to a higher return on investment. The hybrid system between PV and WP is the right and economical choice for electricity production and studies show that in certain geographic locations, the installation of HRES can be done.

## ACKNOWLEDGMENTS

The researcher would like to thank all University leaders who have supported and funded this research, as well as all parties who cannot be mentioned one by one. Hopefully, the results of this research can provide benefits to all readers.

## FUNDING INFORMATION

This research was conducted independently by the author and did not involve any funding from anywhere.

## AUTHOR CONTRIBUTIONS STATEMENT

| Name of Author | C | M | So | Va | Fo | I | R | D | O | E | Vi | Su | P | Fu |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Suwarno | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | | | ✓ | |
| Catra Indra Cahyadi | | ✓ | | | | | | | ✓ | | ✓ | | | |
| Pardamean Manurung | ✓ | | | | | | | | | | | ✓ | | |
| Abdul Rahim | | ✓ | | | | | | | | | | | | |
| Farhan Tanjung | | | | ✓ | | | | | | | | | | |
| Herman Birje | | | ✓ | | | | | | | | | | | |
| Fadly Syafni | | | | | ✓ | | | | | | | | | |
| Muhammad Ridho Kurnia | | | | | | | | ✓ | | | | | | |
| Ismail Faruqi | | | | | | | | | ✓ | | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 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 author declares no conflict of interest.

## INFORMED CONSENT

We have obtained informed consent from all individuals included in this study.

## ETHICAL APPROVAL

Research involving the use of animals has complied with all relevant national regulations and institutional policies for the care and use of animals.

## DATA AVAILABILITY

The data that support the findings of this study are available upon request from the corresponding author. Data containing information that could compromise the privacy of research participants are not publicly available due to certain restrictions.

## REFERENCES


[1] *Global Energy Review: CO2 in 2021*. IEA International Energy agency, 2021.

[2] D. Hartono, S. H. Hastuti, A. Halimatussadiah, A. Saraswati, A. F. Mita, and V. Indriani, “Comparing the impacts of fossil and renewable energy investments in Indonesia: a simple general equilibrium analysis,” *Heliyon*, vol. 6, no. 6, p. e04120, Jun. 2020, doi: 10.1016/j.heliyon.2020.e04120.

[3] Suwarno, I. Yusuf, M. Irwanto, and A. Hiendro, “Analysis of wind speed characteristics using different distribution models in Medan City, Indonesia,” *International Journal of Power Electronics and Drive Systems (IJPEDS)*, vol. 12, no. 2, pp. 1102–1113, Jun. 2021, doi: 10.11591/ijpeds.v12.i2.pp1102-1113.

[4] Suwarno, C. I. Cahyadi, Sukarwoto, A. A. Dewi, and D. Pinayungan, “Comparative analysis of wind speed and energy potential assessment of two distribution models in Medan, Indonesia,” *International Review of Electrical Engineering (IREE)*, vol. 18, no. 4, pp. 275–282, Aug. 2023, doi: 10.15866/iree.v18i4.22725.

[5] M. F. Zambak, C. I. Cahyadi, J. Helmi, T. M. Sofie, and Suwarno, “Evaluation and analysis of wind speed with the weibull and rayleigh distribution models for energy potential using three models,” *International Journal of Energy Economics and Policy*, vol. 13, no. 2, pp. 427–432, Mar. 2023, doi: 10.32479/ijeep.12775.

[6] E. I. Come Zebra, H. J. van der Windt, G. Nhumaio, and A. P. C. Faaij, “A review of hybrid renewable energy systems in mini-grids for off-grid electrification in developing countries,” *Renewable and Sustainable Energy Reviews*, vol. 144, p. 111036, Jul. 2021, doi: 10.1016/j.rser.2021.111036.

[7] D. C. Muller, S. P. Selvanathan, E. Cuce, and S. Kumarasamy, “Hybrid solar, wind, and energy storage system for a sustainable campus: a simulation study,” *Science and Technology for Energy Transition (STET)*, vol. 78, p. 13, 2023, doi: 10.2516/stet/2023008.

[8] Q. Hassan, S. Algburi, A. Z. Sameen, H. M. Salman, and M. Jaszczur, “A review of hybrid renewable energy systems: solar and wind-powered solutions: Challenges, opportunities, and policy implications,” *Results in Engineering*, vol. 20, p. 101621, Dec. 2023, doi: 10.1016/j.rineng.2023.101621.

[9] A. Mahmoudi, A. M. Bouaziz, M. N. Bouaziz, and D. Saheb-Koussa, “Performance analysis of hybrid PV-diesel-storage system in AGRS-Hassi R’mel Algeria,” *International Journal of Renewable Energy Development*, vol. 12, no. 6, pp. 987–997, Sep. 2023, doi: 10.14710/ijred.2023.54072.

[10] C. P. Ohanu, S. A. Rufai, and U. C. Oluchi, “A comprehensive review of recent developments in smart grid through renewable energy resources integration,” *Heliyon*, vol. 10, no. 3, p. e25705, Feb. 2024, doi: 10.1016/j.heliyon.2024.e25705.

[11] M. Dada and P. Popoola, “Recent advances in solar photovoltaic materials and systems for energy storage applications: a review,” *Beni-Suef University Journal of Basic and Applied Sciences*, vol. 12, no. 1, Jul. 2023, doi: 10.1186/s43088-023-00405-5.

[12] V. Khare, P. Chaturvedi, and M. Mishra, “Solar energy system concept change from trending technology: a comprehensive review,” *e-Prime - Advances in Electrical Engineering, Electronics and Energy*, vol. 4, p. 100183, Jun. 2023, doi: 10.1016/j.prime.2023.100183.

[13] D. Gielen, F. Boshell, D. Saygin, M. D. Bazilian, N. Wagner, and R. Gorini, “The role of renewable energy in the global energy transformation,” *Energy Strategy Reviews*, vol. 24, pp. 38–50, Apr. 2019, doi: 10.1016/j.esr.2019.01.006.

[14] N. E. Benti, M. D. Chaka, and A. G. Semie, “Forecasting renewable energy generation with machine learning and deep learning: current advances and future prospects,” *Sustainability (Switzerland)*, vol. 15, no. 9, p. 7087, Apr. 2023, doi: 10.3390/su15097087.

[15] C. Vimalarani, N. Kamaraj, and C. B. B., “Improved method of maximum power point tracking of photovoltaic (PV) array using hybrid intelligent controller,” *Optik*, vol. 168, pp. 403–415, Sep. 2018, doi: 10.1016/j.ijleo.2018.04.114.

[16] Suwarno and M. F. Zambak, “The probability density function for wind speed using modified weibull distribution,” *International Journal of Energy Economics and Policy*, vol. 11, no. 6, pp. 544–550, Nov. 2021, doi: 10.32479/ijeep.11625.

[17] D. S. K. Karunasingha, "Root mean square error or mean absolute error? Use their ratio as well," *Information Sciences*, vol. 585, pp. 609–629, Mar. 2022, doi: 10.1016/j.ins.2021.11.036.
[18] V. Azarova, D. Engel, C. Ferner, A. Kollmann, and J. Reichl, "Exploring the impact of network tariffs on household electricity expenditures using load profiles and socio-economic characteristics," *Nature Energy*, vol. 3, no. 4, pp. 317–325, Mar. 2018, doi: 10.1038/s41560-018-0105-4.
[19] N. K. A. Dwijendra, I. B. G. Wirawibawa, G. W. Laskara, F. Wiriantari, and I. D. G. A. D. Putra, "The uniqueness of architecture and bamboo house environment in Pengotan Traditional Village, Bali, Indonesia," *Journal of Social and Political Sciences*, vol. 4, no. 1, Mar. 2021, doi: 10.31014/aior.1991.04.01.248.
[20] C. Wen *et al.*, "Household willingness to pay for improving electricity services in Sumba Island, Indonesia: a choice experiment under a multi-tier framework," *Energy Research and Social Science*, vol. 88, p. 102503, Jun. 2022, doi: 10.1016/j.erss.2022.102503.
[21] M. Kharrich, O. H. Mohammed, and M. Akherraz, "Design of hybrid microgrid PV/wind/diesel/battery system: case study for rabat and baghdad," *EAI Endorsed Transactions on Energy Web*, vol. 7, no. 26, p. 162692, Jul. 2020, doi: 10.4108/eai.13-7-2018.162692.
[22] N. Reyseliani and W. W. Purwanto, "Pathway towards 100% renewable energy in Indonesia power system by 2050," *Renewable Energy*, vol. 176, pp. 305–321, Oct. 2021, doi: 10.1016/j.renene.2021.05.118.
[23] D. F. Silalahi, A. Blakers, and C. Cheng, "100% renewable electricity in Indonesia," *Energies*, vol. 17, no. 1, p. 3, Dec. 2023, doi: 10.3390/en17010003.
[24] T. Z. Ang, M. Salem, M. Kamarol, H. S. Das, M. A. Nazari, and N. Prabaharan, "A comprehensive study of renewable energy sources: classifications, challenges and suggestions," *Energy Strategy Reviews*, vol. 43, p. 100939, Sep. 2022, doi: 10.1016/j.esr.2022.100939.
[25] A. I. Osman *et al.*, "Cost, environmental impact, and resilience of renewable energy under a changing climate: a review," *Environmental Chemistry Letters*, vol. 21, no. 2, pp. 741–764, Oct. 2023, doi: 10.1007/s10311-022-01532-8.
[26] Q. Dai, X. Hou, D. Su, and Z. Cui, "Photovoltaic power prediction based on sky images and tokens-to-token vision transformer," *International Journal of Renewable Energy Development*, vol. 12, no. 6, pp. 1104–1112, Oct. 2023, doi: 10.14710/ijred.2023.57902.
[27] R. M. Rizk-Allah, I. A. Hassan, V. Snasel, and A. E. Hassanien, "An optimal standalone wind-photovoltaic power plant system for green hydrogen generation: case study for hydrogen refueling station," *Results in Engineering*, vol. 22, p. 102234, Jun. 2024, doi: 10.1016/j.rineng.2024.102234.
[28] M. Rumbayan and K. Nagasaka, "Techno economical study of PV-diesel power system for a remote island in Indonesia: a case study of Miangas Island," *IOP Conference Series: Earth and Environmental Science*, vol. 150, no. 1, p. 12024, May 2018, doi: 10.1088/1755-1315/150/1/012024.
[29] Syafii, A. Luthfi, Novizon, and R. Fahreza, "Cost of energy sensitivity analysis of PV/diesel with hydro pumped storage for mentawai microgrid system," in *2021 IEEE 4th International Conference on Computing, Power and Communication Technologies, GUCON 2021*, Sep. 2021, pp. 1–5, doi: 10.1109/GUCON50781.2021.9573985.
[30] A. Chaianong, A. Bangviwat, C. Menke, B. Breitschopf, and W. Eichhammer, "Customer economics of residential PV–battery systems in Thailand," *Renewable Energy*, vol. 146, pp. 297–308, Feb. 2020, doi: 10.1016/j.renene.2019.06.159.
[31] H. Mun, B. Moon, S. Park, and Y. Yoon, "A study on the economic feasibility of stand-alone microgrid for carbon-free island in Korea," *Energies*, vol. 14, no. 7, p. 1913, Mar. 2021, doi: 10.3390/en14071913.
[32] J. Napitupulu, Suwarno, C. I. Cahyadi, and Sukarwoto, "Evaluation and modeling of green energy consumption in North Sumatra, Indonesia," *International Journal of Energy Economics and Policy*, vol. 14, no. 1, pp. 570–578, Jan. 2024, doi: 10.32479/ijeep.15070.
[33] Suwarno and D. Pinayungan, "Solar power forecasting model as a renewable generation source on virtual power plants," *Bulletin of Electrical Engineering and Informatics (BEEI)*, vol. 13, no. 2, pp. 702–712, Apr. 2024, doi: 10.11591/eei.v13i2.5870.
[34] Z. Corba, B. Popadic, D. Milicevic, B. Dumnic, and V. A. Katic, "A long-term condition monitoring and performance assessment of grid connected PV power plant with high power sizing factor under partial shading conditions," *Energies*, vol. 13, no. 18, p. 4810, Sep. 2020, doi: 10.3390/en13184810.
[35] C. Del Pero, N. Aste, F. Leonforte, and F. Sfolcini, "Long-term reliability of photovoltaic c-Si modules – a detailed assessment based on the first Italian BIPV project," *Solar Energy*, vol. 264, p. 112074, Nov. 2023, doi: 10.1016/j.solener.2023.112074.
[36] F. M. N. U. Khan, M. G. Rasul, A. S. M. Sayem, and N. Mandal, "Maximizing energy density of lithium-ion batteries for electric vehicles: A critical review," *Energy Reports*, vol. 9, pp. 11–21, Oct. 2023, doi: 10.1016/j.egyr.2023.08.069.
[37] Z. Dobrowolski, G. Drozdowski, M. Panait, and A. Babczuk, "Can the economic value added be used as the universal financial metric?," *Sustainability (Switzerland)*, vol. 14, no. 5, p. 2967, Mar. 2022, doi: 10.3390/su14052967.
[38] P. H. Hsi and J. C. P. Shieh, "How credible is the 25-year photovoltaic (PV) performance warranty?—A techno-financial evaluation and implications for the sustainable development of the PV industry," *Sustainability (Switzerland)* , vol. 16, no. 9, p. 3880, May 2024, doi: 10.3390/su16093880.


## BIOGRAPHIES OF AUTHORS

**Suwarno** completed his undergraduate education in electrical engineering in 1986, completed his postgraduate education in 1995 with an electrotechnical program, and completed his doctoral program in renewable energy in 2016. Currently working at the Muhammadiyah University of North Sumatra in the postgraduate program and conducting research in the fields of new and renewable energy, power electronics, and power electronics applications. He can be contacted at email: suwarno@umsu.ac.id.

**Catra Indra Cahyadi** completed a bachelor of applied science degree in Airport Electrical Engineering in 2004, and a Master of educational technology in 2008. Currently conducting research in the fields of aeronautical engineering, airport electrical engineering, transmission and distribution, and control systems. He can be contacted at email: catraindracahyadi@gmail.com.

**Pardamean Manurung** is a Facilities and Infrastructure Healthcare Inspector at *Balai Pengamanan Alat dan Fasilitas Kesehatan Medan* (BPAFK), and a globally certified Biosafety Cabinet Tester. He completed his undergraduate education at the University of Sumatera Utara (USU) and continued his master's education in the Electrical Engineering study program at the University of Muhammadiyah Sumatera Utara (UMSU) Medan. He is active in healthcare electricity and medical device calibration. He can be contacted at email: pardameanmnrng@gmail.com.

**Abdul Rahim** is the head of the Radiation Measuring Instrument Calibration Laboratory at the Indonesian Ministry of Health in Medan. He completed his undergraduate education at the University of North Sumatra. His current activity is as a QA/QC x-ray equipment tester for health diagnostics. He can be contacted at email: abdul.758@gmail.com.

**Farhan Tanjung** worked in the field of contractors in the field of mechanical and electrical and joined several planning and supervision consultant offices in the field of mechanical and electrical, also an assessor at a professional certification institution at LSP ASTEKINDO. Completed undergraduate education at the University of Muhammadiyah North Sumatra (UMSU) in the Mechanical Engineering program, currently continuing his Advanced Education in the Master of Electrical Engineering, UMSU. He can be contacted at email: zam211620@gmail.com.

**Herman Birje** has completed his master of electrical engineering study program at the Muhammadiyah University of North Sumatra (UMSU), Medan, Indonesia. He obtained his Bachelor of Electrical Engineering degree from the State University of Medan (UNIMED) in 2016. His research areas include renewable energy, power electronics, and power quality. He can be contacted at email: birjeherman98@gmail.com.

**Fadli Syafni** is the technical manager at the eye clinic SPEC. He completed his bachelor's degree in engineering in 2020 at Universitas Pancabudi Medan (UNPAB) and is currently pursuing his master's program at Universitas Muhammadiyah Sumatera Utara (UMSU) in 2025. His thesis focuses on analyzing the energy efficiency levels at the SMEC Eye Hospital. He can be contacted at email: fadlisyafni@gmail.com.

**Muhammad Ridho Kurnia** is a civil servant with a functional position as an advanced electromedical technician at the Medan Health Equipment and Facilities Security Center, Ministry of Health of the Republic of Indonesia. He completed his diploma education at the Academy of Electromedical Engineering at STIKES Binalita Sudama, continued his undergraduate education at the Panca Budi Development University, and continued his master's education in the electrical engineering study program at the Muhammadiyah University of North Sumatra (UMSU). He is active in medical device security, medical electrical safety inspection, medical gas, and medical air conditioning inspection. He can be contacted at email: kurniaridho019@gmail.com.

**Ismail Faruqi** is a Facilities and Infrastructure Healthcare Inspector at *Balai Pengamanan Alat dan Fasilitas Kesehatan Medan* (BPAFK), and a globally certified Biosafety Cabinet Tester. He completed his undergraduate education at the University of Sumatera Utara (USU) and continued his master's education in the electrical engineering study program at the University of Muhammadiyah Sumatera Utara (UMSU) Medan. He is active in healthcare electricity and medical device calibration. He can be contacted at email: ismailfaruqi9@gmail.com.