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An Empirical Study on Hybrid Renewable Energy (PV & Wind): A Special reference to Ranchi (Jharkhand) and Kochi (Kerala)

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ABSTRACT: This study explores the potential of hybrid renewable energy systems, specifically combining photovoltaic (PV) and wind energy, in Ranchi, Jharkhand, and Kochi, Kerala. These two locations offer distinct climatic conditions that impact their renewable energy capacities, with Ranchi experiencing a humid subtropical climate and Kochi a tropical monsoon climate. The research aims to evaluate the feasibility, performance, and optimization of hybrid renewable energy systems in these regions. With integrating solar and wind resources, the study seeks to identify effective strategies for maximizing energy production and ensuring reliability. Solar irradiance data was obtained from meteorological stations and satellite sources, while wind data was collected from local weather stations. Optimization algorithms were applied to design hybrid systems, considering factors such as cost, efficiency, and reliability. Comparative analysis highlights the benefits and challenges associated with deploying hybrid renewable energy systems in varying environmental contexts. The findings from this study are intended to inform the development of sustainable energy solutions that are tailored to regional characteristics, ultimately contributing to the reduction of fossil fuel dependency and the mitigation of climate change. This paper mainly explored the hybrid Renewable energy (PV and Wind) in context with Ranchi (Jharkhand) and Kochi (Kerala).

KEYWORDS: Hybrid Renewable Energy, Solar Photovoltaic, Wind Energy, Solar Photovoltaic, Ranchi, Kochi.

I. INTRODUCTION

The transition to renewable energy sources is crucial for achieving sustainable development and mitigating climate change. This study focuses on the estimation and optimization of hybrid renewable energy systems comprising solar photovoltaic (PV) and wind energy for Ranchi, Jharkhand, and Kochi, Kerala. These regions present distinct climatic conditions that influence their renewable energy potential. Ranchi's humid subtropical climate contrasts with Kochi's tropical monsoon climate, leading to differences in solar irradiance and wind speeds. The objectives of this research are to assess the feasibility of deploying hybrid systems in these locations, compare their performance, and provide recommendations for optimizing energy production. By integrating solar and wind resources, this study aims to identify the most effective strategies for harnessing renewable energy in varying environmental contexts. The insights gained will aid in advancing sustainable energy solutions tailored to regional characteristics [1-3].

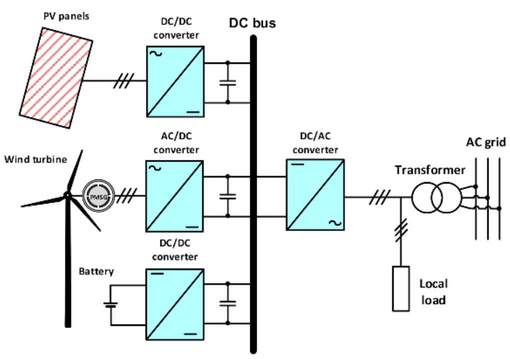

Fig 1: Hybrid Renewable Energy
Source: Energies | Free Full-Text | Control of the Hybrid Renewable Energy System with Wind Turbine, Photovoltaic Panels and Battery Energy Storage (mdpi.com)

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1.1 Renewable Energy Sources

Renewable energy sources are vital for sustainable development and reducing reliance on fossil fuels. These sources include solar, wind, hydro, geothermal, and biomass energy. They are characterized by their ability to regenerate naturally and provide a continuous supply of energy without depleting resources. Solar energy harnesses the power of the sun, wind energy captures wind flow, hydro energy utilizes water flow, geothermal energy taps into Earth's heat, and biomass involves converting organic materials into energy. Each source has unique characteristics and applications, contributing to a diversified energy mix that can address global energy demands while minimizing environmental impact [4].

1.2 Photovoltaic (PV) Systems: Principles and Applications

Photovoltaic (PV) systems convert sunlight directly into electricity using semiconductor materials. The basic principle involves the photovoltaic effect, where light photons excite electrons in a semiconductor material, creating an electric current.

PV systems consist of solar panels, inverters, and other components. Panels are made of silicon or other materials that absorb sunlight and generate direct current (DC). Inverters convert DC to alternating current (AC) for use in the electrical grid or local applications. PV systems are widely used in residential, commercial, and industrial applications, offering a clean and renewable source of electricity with minimal environmental impact [5].

1.3 Wind Energy Systems: Principles and Applications

Wind energy systems convert the kinetic energy of wind into electrical power using wind turbines. The fundamental principle is that wind causes the blades of a turbine to rotate, driving a generator that produces electricity. Wind turbines consist of blades, a rotor, a gearbox, and a generator. As wind flows over the blades, it creates lift and drag forces, causing the rotor to spin. The gearbox increases the rotational speed, and the generator converts this mechanical energy into electrical energy. Wind energy systems are used in various scales, from small residential turbines to large wind farms, providing a significant source of renewable energy with low operational costs [6].

1.4 Hybrid Renewable Energy Systems: Concepts and Benefits

Hybrid renewable energy systems combine multiple renewable sources, such as solar and wind, to enhance energy reliability and efficiency. By integrating different energy sources, these systems capitalize on their complementary characteristics. For example, solar energy is often plentiful during the day, while wind energy can be more available at night or during different weather conditions. Combining these sources helps balance energy production and reduces dependence on any single source. Benefits include increased energy reliability, improved system efficiency, and reduced storage needs. Hybrid systems can also lower overall costs and provide a more stable energy supply, making them an attractive option for diverse applications [7].

1.5 Feasibility Studies and Optimization in Renewable Energy

Feasibility studies assess the practicality of implementing renewable energy systems by evaluating technical, economic, and environmental factors. These studies involve analysing resource availability, system performance, and potential impacts to determine the viability of renewable projects. Optimization in renewable energy focuses on enhancing system performance and efficiency through advanced technologies and methods. Techniques such as resource mapping, cost-benefit analysis, and system modelling are employed to identify the most effective configurations and operational strategies. Optimizing renewable energy systems ensures that they meet energy needs while minimizing costs and environmental impacts, ultimately contributing to the success of sustainable energy projects [8-11].

II. LITERATURE REVIEW

Gusain et al. (2023) indicated that exponentially rising hydrocarbon fuel consumption had created several environmental issues, necessitating the integration of renewable energy systems (RES) into the grid. They stated that solar photovoltaic and wind energy constituted the most mature hybrid renewable energy system (HRES) alternative to conventional fossil fuels, being pollution-free, easily available, low-cost, and abundant. However, the intermittent nature of solar irradiation and fluctuations in wind speed made system design either oversized or undersized, leading to increased costs or inefficiencies in deploying solar PV-Wind-based HRES. They emphasized the immediate requirement for optimization problem-solving methodologies to minimize HRES costs. Their paper focused on a critical comparative analysis of various applied and promising optimization methodologies. These methodologies, used to design the optimal capacity of HRES, were categorized as traditional, modern, and hybrid based on identified

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objective functions, decision variables, and evaluation indicators. They observed that while most present studies were based on the technical reliability and economic perspective of HRES, their paper gave major emphasis to environmental indicators. The study revealed that the application of hybrid meta-heuristic optimization techniques for engineering applications was growing significantly due to their flexibility and efficiency. They also found that economic indicators were more prevalent compared to other reliability and environmental indicators, although the percentage of multi-objective functions of economic and reliability indicators was a growing trend for the optimal design process of HRES.

Agajie et al. (2023) discussed that renewable energy solutions were appropriate for both on-grid and off-grid applications, supporting utility networks or rural locations without the need for costly and difficult grid infrastructure development. As a result, hybrid renewable energy sources had become a popular option for grid-connected or standalone systems. Their paper examined hybrid renewable energy power production systems with a focus on energy sustainability, reliability due to irregularities, techno-economic feasibility, and environmental friendliness. They highlighted the crucial challenge of sizing optimal hybrid renewable energy sources (HRES) to achieve reliable, clean, and cost-effective systems. They outlined the best sizing approaches that could be used in HRES, considering key components, parameters, methods, and data. Furthermore, they highlighted goal functions, design constraints, system components, optimization software tools, and meta-heuristic algorithm methodologies in available studies. Current issues resulting from scaling HRES were identified and discussed, and the latest trends and advances in planning problems were thoroughly addressed. Finally, they provided suggestions for further research into appropriate component sizing in HRES.

Bouaouda & Sayouti (2022) reported that the hybrid renewable energy system (HRES) had been presented as the most studied solution for improving the sustainability of energy production infrastructures in isolated areas. With the rapid growth of HRES markets, various issues and aspects had to be considered when major work on the hybridization of renewable energy sources was undertaken, making optimization problem-solving a requirement. Their paper presented a state-of-the-art review of hybrid meta-heuristic algorithms applied for the optimal size of HRES. They first presented the relevant literature sources and their distribution, then reviewed the literature from two viewpoints: existing applied hybrid meta-heuristic algorithms for single-objective and multi-objective design. Finally, they outlined promising paths ranging from improving algorithms to technical applications to encourage researchers to conduct research in related fields.

Lian et al. (2019) noted that due to continuously increasing electricity consumption and concerns for environmental issues, renewable energy sources had been widely utilized to generate electricity, presenting advantages such as cleanliness, easy availability, low cost, and abundance. In 2017, the installed capacity of solar and wind power worldwide amounted to 903.1 GW, representing 41.4% of the total installed capacity of renewable energy. Hybrid renewable energy systems were proposed to overcome the variability and randomness of single renewable energy sources such as solar and wind power, with more than 80% being off-grid systems. They emphasized the necessity of determining the size of each component to design a reliable and cost-effective hybrid renewable energy system. Their paper mainly reviewed the recent classification, evaluation indicators, and sizing methodologies of hybrid renewable energy systems (stand-alone and grid-connected). They called for further optimization research to improve the overall performance of hybrid renewable energy systems. They suggested that decision-makers explore and develop hybrid systems including hydropower and/or pumped hydro storage based on their superiority and pay attention to the development of hybrid energy storage. In addition to reliability and economic indicators, which had applications above 80%, they suggested giving more attention to environmental and social indicators to determine system capacity and disseminate some new indicators. They assessed the features of traditional, artificial intelligence, and hybrid methods, along with software tools. They concluded that hybrid methods with high accuracy and fast convergence, capable of overcoming the defects of single methods, were the most promising sizing method compared to other sizing methods. This review was valuable for understanding the current status and development trends of optimal sizing for hybrid renewable energy systems.

Anoune et al. (2018) identified solar and wind energy as promising electrical generating sources due to their omnipresence, free access, and friendly environmental impact. They noted that integrating these sources remained technically and economically advantageous for electrical generation in isolated areas (IS). They found that the separate use of solar and wind energy sources often resulted in considerable over-sizing, making single renewable energy sources costly to implement. They concluded that using one of the optimization sizing techniques could help guarantee maximum power reliability and minimum system cost for future hybrid implementation. Their paper provided an updated literature review of the most applied methods and techniques used in sizing and optimizing PV-Wind based

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hybrid systems (PWHS) for isolated areas, aiming to reach the best compromise between power reliability and hybrid system costs. They compared the most common topologies used for implementing PWHS, presented a mathematical model of the hybrid system components, and emphasized the importance of power reliability and system cost. Finally, they provided an extensive analysis of software tools and algorithm approaches used in sizing optimization.

Khan et al. (2018) highlighted that electrical energy had become necessary for human beings, with generation mostly dependent on fossil fuels, which are limited and responsible for environmental pollution. They argued that renewable energy resources provided a better alternative for the future, with the economic aspect being a major issue in comparison to conventional energy resources. They noted that these limitations were being addressed by deploying hybrid renewable energy resources. Their paper focused on hybrid energy systems based on solar photovoltaic (PV) and wind resources, shedding light on various parameters of economic feasibility, sizing strategies, and logical advancements to enhance utilization and future prospects. They also presented strategies for developing an effective storage system and reviewed developments in optimization techniques, reliability indices, and cost-analyzing techniques for hybrid renewable energy systems.

Al-Falahi et al. (2017) discussed that electricity demand in remote and island areas was generally supplied by diesel or other fossil fuel-based generation systems. However, due to increasing costs and harmful emissions of fossil fuels, there was a growing trend to use standalone hybrid renewable energy systems (HRESs). They noted that hybrid systems with solar and wind energy had become popular due to their complementary characteristics, matured technologies, and availability in most areas. However, they identified challenges associated with the intermittency and high net present cost of solar and wind energy systems. They emphasized that optimal sizing was key to attaining a reliable supply at low cost through these standalone systems. Their paper presented a comprehensive review of recent developments in size optimization methodologies, critically comparing single algorithms, hybrid algorithms, and software tools used for sizing standalone solar and wind HRES. They also evaluated all possible combinations of standalone solar and wind energy systems, considering economic, reliability, environmental, and social aspects.

Khare et al. (2016) noted that the demand for electricity was increasing daily, which could not be fulfilled by non-renewable energy sources alone. They stated that renewable energy sources such as solar and wind were omnipresent and environmentally friendly. They argued that renewable energy sources were emerging options to fulfil energy demand, but unreliable due to their stochastic nature. They proposed that a hybrid renewable energy system (HRES), combining two or more renewable energy sources like wind turbines and solar systems, was the solution. Their paper presented a comprehensive review of various aspects of HRES, discussing prefeasibility analysis, optimum sizing, modelling, control aspects, and reliability issues. They also presented the application of evolutionary techniques and game theory in hybrid renewable energy.

Sinha & Chandel (2015) provided an updated literature review on trends in optimization techniques used for designing and developing solar photovoltaic–wind-based hybrid energy systems. Their main objective was to identify the latest promising techniques for optimizing these systems. They reviewed different techniques used by researchers for optimization and presented a PV–wind-based hybrid system sizing methodology. They analysed optimization studies from the last 2.5 decades, noting that new generation artificial intelligence algorithms were mostly used during the last decade due to their lower computation time, better accuracy, and good convergence compared to traditional methods. They suggested using hybridization of two or more algorithms to overcome the limitations of single algorithms. They identified additional techniques for follow-up research in designing PV–wind hybrid systems, providing valuable insights for researchers facing complexity and challenges in renewable energy-based hybrid system research.

Mahesh & Sandhu (2015) argued that renewable energy sources were certain to play a key role in future energy generation due to the rapid depletion of conventional energy sources. They noted that solar and wind energy, as major renewable energy sources, had the potential to meet the energy crisis to some extent. However, when explored independently, these sources were unreliable due to their unpredictable nature. They proposed that hybrid energy systems, combining solar and wind, were more reliable and cost-effective due to the complementary nature of these resources. Their paper presented a systematic review of hybrid PV/wind energy systems with battery storage, helping researchers explore such systems for further improvements in design, analysis, and integration into the power network.

Nugent & Sovacool (2014) critically screened 153 lifecycle studies on wind and solar photovoltaic (PV) electricity generation technologies to identify 41 of the most relevant, recent, rigorous, original, and complete assessments to determine the dynamics of their greenhouse gas (GHG) emissions profiles. They found that both wind and solar systems were tied to and responsible for GHG emissions when viewed holistically, including initial materials

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extraction, manufacturing, use, and disposal/decommissioning. By spotlighting the lifecycle stages and physical characteristics most responsible for emissions, they suggested improvements to lower the carbon footprint. Their in-depth examination uncovered best practices in wind and solar design and deployment to better inform climate change mitigation efforts in the electricity sector.

Kubiszewski et al. (2010) reviewed and synthesized literature on the net energy return for electric power generation by wind turbines, defining Energy Return on Investment (EROI) as the ratio of energy delivered to energy costs. They examined 119 wind turbines from 50 different analyses, spanning publication dates from 1977 to 2007. Their survey showed an average EROI for all studies (operational and conceptual) of 25.2, and an average EROI for just the operational studies of 19.8. They concluded that wind power had a favourable position relative to fossil fuels, nuclear, and solar power generation technologies in terms of EROI.

Table 1. Comparative Analysis of Reviews

This table summarizes methodologies, research areas, and meta-analyses from various studies on hybrid renewable energy systems, highlighting optimization techniques, system sizing, sustainability, economic feasibility, and environmental impact across different energy sources.

Author(s) (Year)	Methodology	Research Area	Meta Analysis
Gusain et al. (2023)	Comparative analysis of optimization methodologies	Hybrid Renewable Energy Systems (HRES)	Hybrid meta-heuristic optimization techniques growing due to flexibility and efficiency
Agajie et al. (2023)	Examination of hybrid renewable energy power systems	On-grid and off-grid applications	Focus on energy sustainability, reliability, techno-economic feasibility, and environmental friendliness
Bouaouda & Sayouti (2022)	State-of-the-art review of hybrid meta-heuristic algorithms	HRES in isolated areas	Promising paths for research, improvement in algorithms, technical applications
Lian et al. (2019)	Review of classification, evaluation indicators, and sizing methodologies	Hybrid Renewable Energy Systems (stand-alone and grid-connected)	Optimization research needed to improve performance; hybrid methods most promising
Anoune et al. (2018)	Updated literature review on sizing and optimization	PV-Wind based hybrid systems (PWHS) in isolated areas	Emphasis on power reliability and system cost, analysis of software tools and algorithm approaches
Khan et al. (2018)	Review of economic feasibility, sizing strategies, and storage systems	Hybrid Renewable Energy Systems (solar PV and wind)	Developments in optimization techniques, reliability indices, and cost-analyzing techniques
Al-Falahi et al. (2017)	Comprehensive review of size optimization methodologies	Standalone solar and wind HRES	Critical comparison of single algorithms, hybrid algorithms, and software tools
Khare et al. (2016)	Comprehensive review of HRES aspects	Hybrid Renewable Energy Systems	Prefeasibility analysis, optimum sizing, modelling, control aspects, reliability issues
Sinha & Chandel (2015)	Literature review on optimization techniques	Solar PV–Wind based hybrid energy systems	Hybridization of algorithms to overcome limitations of single algorithms
Mahesh & Sandhu (2015)	Systematic review of hybrid PV/wind systems with battery storage	Hybrid Renewable Energy Systems	Further improvements in design, analysis, and integration into power networks
Nugent & Sovacool (2014)	Critical screening of lifecycle studies on GHG emissions	Wind and solar photovoltaic electricity generation	Best practices in design and deployment to lower carbon footprint
Kubiszewski et al. (2010)	Review and synthesis of literature on EROI	Wind power generation	Wind power favourable compared to fossil fuels, nuclear, and solar power in terms of EROI

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III. METHODOLOGY

The methodology used to evaluate and design hybrid renewable energy systems for Ranchi and Kochi. The approach integrates data collection, estimation techniques, optimization methods, and comparative analysis to assess feasibility and efficiency.

3.1 Study Areas

- ✓ **Ranchi, Jharkhand:** Located on the Chotanagpur Plateau, experiencing a humid subtropical climate with seasonal variations in solar irradiance and wind speeds.
- ✓ **Kochi, Kerala:** Positioned on the southwestern coast, with a tropical monsoon climate providing consistent solar irradiance and variable wind conditions.

3.2 Data Collection and Sources

- ✓ **Solar Data:** Obtain historical solar irradiance data from meteorological stations and satellite sources to estimate daily and seasonal variations.
- ✓ **Wind Data:** Collect wind speed and direction data from local weather stations and meteorological agencies to understand wind patterns and potential.

3.3 Estimation Techniques

Solar Energy: Use solar irradiance data and PV panel specifications to estimate potential energy output using standard formulas, accounting for panel efficiency and local weather conditions.

3.3 Optimization Methods

- ✓ **Hybrid System Design:** Utilize optimization algorithms to determine the optimal size and configuration of PV panels, wind turbines, and energy storage systems. Consider cost, efficiency, and reliability.
- ✓ **Cost-Benefit Analysis:** Perform economic assessments to compare initial investment, operating costs, and potential savings for both locations.

3.4 Comparative Feasibility Analysis

- ✓ **Criteria:** Evaluate the systems based on energy output, cost, environmental impact, and reliability. Compare the performance metrics of both Ranchi and Kochi to determine the most effective configuration for each location.

IV. SOLAR ENERGY POTENTIAL IN RANCHI AND KOCHI

Solar energy potential varies significantly between different geographical locations due to differences in solar radiation levels, climate, and other environmental factors. This section provides an analysis of the solar energy potential in Ranchi, Jharkhand, and Kochi, Kerala, highlighting the key factors influencing their solar energy capacities.

4.1 Ranchi, Jharkhand

Ranchi, situated in the eastern part of India, experiences a humid subtropical climate with distinct seasons. The region receives an average annual solar insolation of approximately 4.5 to 5.5 kWh/m²/day. The city enjoys over 250 sunny days annually, making it a viable location for solar energy generation. However, the presence of the monsoon season, which spans from June to September, reduces the effective solar radiation due to increased cloud cover and rainfall. Despite this, the dry months from October to May offer ample sunshine, contributing significantly to the overall solar energy potential. The high solar irradiance during these months can be effectively harnessed using photovoltaic (PV) systems to generate substantial amounts of electricity, making solar energy a promising option for Ranchi.

4.2 Kochi, Kerala

Kochi, located on the southwestern coast of India, has a tropical monsoon climate characterized by high humidity and significant rainfall. The region receives an average annual solar insolation of around 5 to 5.5 kWh/m²/day, which is relatively high. Kochi experiences abundant sunshine for a substantial part of the year, with over 300 sunny days

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annually. The monsoon season, from June to September, brings heavy rainfall, leading to reduced solar radiation during these months. However, the rest of the year, particularly from October to May, provides excellent solar energy conditions. The coastal location of Kochi also ensures a relatively stable and high level of solar irradiance, making it highly suitable for solar PV installations.

V. WIND ENERGY POTENTIAL IN RANCHI AND KOCHI

Wind energy potential is influenced by various factors including wind speed, wind direction, and the frequency of high-wind conditions. This section assesses the wind energy potential in Ranchi, Jharkhand, and Kochi, Kerala, considering their distinct geographical and climatic characteristics.

5.1 Ranchi, Jharkhand

Ranchi, located on the Chotanagpur Plateau, has a moderately elevated terrain that can impact wind patterns. The region experiences moderate to low wind speeds, with average annual wind speeds ranging from 3 to 5 m/s. Wind speeds tend to be higher during the pre-monsoon season, particularly from March to May, while the monsoon period brings variable wind conditions due to shifting weather patterns. The overall wind energy potential in Ranchi is somewhat limited compared to other regions with higher wind speeds. However, with advancements in turbine technology and suitable site selection, harnessing wind energy remains feasible, particularly in areas with more consistent wind flow [13].

5.2 Kochi, Kerala

Kochi, situated on the southwestern coast of India, benefits from its coastal location, which generally enhances wind speeds. The region experiences average annual wind speeds ranging from 5 to 7 m/s, with higher speeds during the monsoon season from June to September due to strong onshore winds. The coastal breeze and seasonal wind patterns contribute to a more favourable wind energy environment compared to inland areas. The higher wind speeds and more consistent wind patterns in Kochi make it a more attractive location for wind energy projects. Coastal areas often have better wind resource availability, making wind energy a promising option for the region [13].

VI. HYBRID ENERGY SYSTEM DESIGN FOR RANCHI AND KOCHI

Designing hybrid energy systems for Ranchi and Kochi involves integrating solar photovoltaic (PV) and wind energy sources to optimize energy production and reliability based on each region's unique conditions.

Ranchi: With a solar energy potential of 4.5 to 5.5 kWh/m²/day and moderate wind speeds of 3 to 5 m/s, the hybrid system components include:

- Photovoltaic Panels: Sized to maximize output during high solar irradiance from October to May.
- Wind Turbines: Small to medium-sized turbines optimized for higher wind speeds in pre-monsoon months.
- Energy Storage: Batteries to store excess energy for stable supply during low generation periods.
- Hybrid Controller: Manages energy distribution, ensuring efficient operation [8, 13-17].

Kochi: Benefiting from 5 to 5.5 kWh/m²/day solar insolation and wind speeds of 5 to 7 m/s, especially during monsoons, the components are:

- Photovoltaic Panels: Robust arrays to maximize energy capture year-round.
- Wind Turbines: Designed for higher wind speeds, harnessing strong onshore winds.
- Energy Storage: Advanced batteries for steady supply during low generation.
- Hybrid Controller: Optimizes energy from solar, wind, and storage for reliability.

These designs ensure a balanced and continuous energy supply, maximizing renewable resource utilization for both regions [8, 13-17].

VII. ESTIMATION OF ENERGY OUTPUT

Estimating the energy output of a hybrid renewable energy system involves calculating the contributions from both solar photovoltaic (PV) and wind energy sources and then combining these estimates to determine the overall system performance. For both Ranchi and Kochi, the process includes the following steps:

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7.1 Determine PV Panel Efficiency

$$E_{solar} = G \times A \times \eta \times H$$

where $E_{solar}$is the daily energy output (kWh), A is the area of PV panels (m²), and H is the number of operating hours per day **[9,13-17]**.

7.2 Wind Energy Output Estimation

$$E_{wind} = \frac{1}{2} \times \rho \times A \times v^3 \times \text{CF} \times H$$

where $Ewind$ is the daily energy output (kWh), ρ is the air density (typically 1.225 kg/m³), A is the swept area of the turbine blades (m²), v is the average wind speed, and CF is the capacity factor of the turbine. **[9,13-17]**

7.3 Hybrid System Output

Combine Energy Outputs: Sum the energy outputs from both solar and wind systems to estimate the total energy generation:

$$E_{total} = E_{solar} + E_{wind}$$

Adjust for System Losses: Factor in losses due to system inefficiencies, such as energy conversion losses and storage losses, typically around 10-15% **[9,13-17]**.

VIII. CONCLUSION

The empirical study of hybrid renewable energy systems for Ranchi and Kochi reveals significant benefits from integrating solar PV and wind energy. Ranchi demonstrates considerable solar potential during dry months, while Kochi benefits from consistent solar irradiance and favourable wind conditions throughout the year. This study emphasizes the importance of designing region-specific hybrid renewable energy systems to optimize the use of local renewable resources. Such systems can play a crucial role in meeting regional energy demands sustainably while reducing environmental impacts. Future research should focus on advanced optimization techniques and assessing economic feasibility to further refine these hybrid systems. The insights gained from this research underscore the potential for hybrid renewable energy systems to significantly contribute to sustainable development and climate change mitigation efforts.

REFERENCES

1. Gusain, C., Tripathi, M. M., & Nangia, U. (2023). Study of meta-heuristic optimization methodologies for design of hybrid renewable energy systems. *Thermal Science and Engineering Progress*, *39*, 101711.
2. Agajie, T. F., Ali, A., Fopah-Lele, A., Amoussou, I., Khan, B., Velasco, C. L. R., & Tanyi, E. (2023). A comprehensive review on techno-economic analysis and optimal sizing of hybrid renewable energy sources with energy storage systems. *Energies*, *16*(2), 642.
3. Bouaouda, A., & Sayouti, Y. (2022). Hybrid meta-heuristic algorithms for optimal sizing of hybrid renewable energy system: a review of the state-of-the-art. *Archives of Computational Methods in Engineering*, *29*(6), 4049-4083.
4. Lian, J., Zhang, Y., Ma, C., Yang, Y., & Chaima, E. (2019). A review on recent sizing methodologies of hybrid renewable energy systems. *Energy Conversion and Management*, *199*, 112027.
5. Anoune, K., Bouya, M., Astito, A., & Abdellah, A. B. (2018). Sizing methods and optimization techniques for PV-wind based hybrid renewable energy system: A review. *Renewable and Sustainable Energy Reviews*, *93*, 652-673.
6. Khan, F. A., Pal, N., & Saeed, S. H. (2018). Review of solar photovoltaic and wind hybrid energy systems for sizing strategies optimization techniques and cost analysis methodologies. *Renewable and Sustainable Energy Reviews*, *92*, 937-947.
7. Al-Falahi, M. D., Jayasinghe, S. D. G., & Enshaei, H. J. E. C. (2017). A review on recent size optimization methodologies for standalone solar and wind hybrid renewable energy system. *Energy conversion and management*, *143*, 252-274.
8. Khare, V., Nema, S., & Baredar, P. (2016). Solar–wind hybrid renewable energy system: A review. *Renewable and Sustainable Energy Reviews*, *58*, 23-33.

| e-ISSN: 2278 – 8875, p-ISSN: 2320 – 3765| www.ijareeie.com | Impact Factor: 8.317|| A Monthly Peer Reviewed & Referred Journal |

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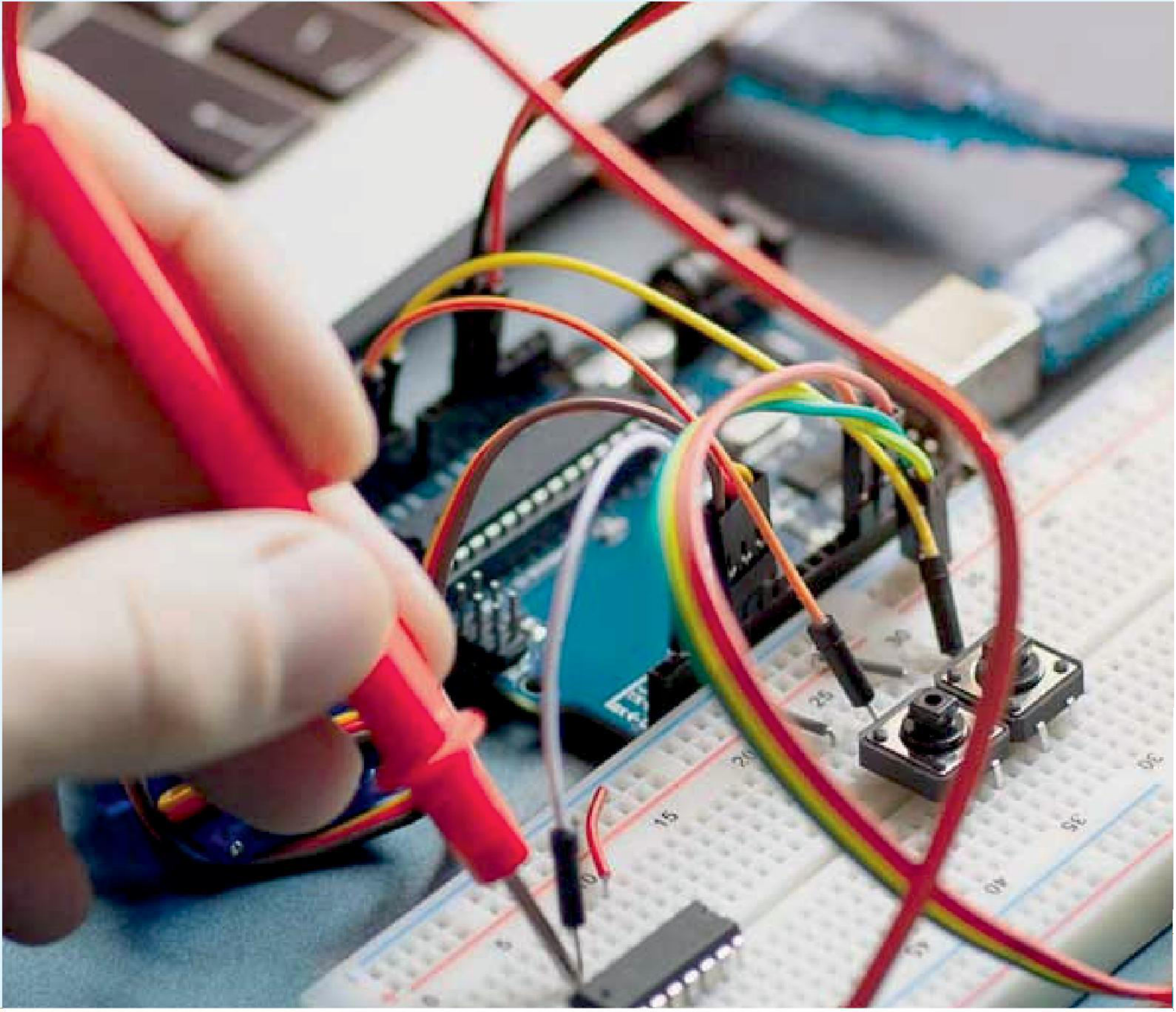
|DOI:10.15662/IJAREEIE.2024.1303049 |

9. Sinha, S., & Chandel, S. S. (2015). Review of recent trends in optimization techniques for solar photovoltaic–wind-based hybrid energy systems. *Renewable and sustainable energy reviews*, *50*, 755-769.
10. Mahesh, A., & Sandhu, K. S. (2015). Hybrid wind/photovoltaic energy system developments: Critical review and findings. *Renewable and Sustainable Energy Reviews*, *52*, 1135-1147.
11. Nugent, D., & Sovacool, B. K. (2014). Assessing the lifecycle greenhouse gas emissions from solar PV and wind energy: A critical meta-survey. *Energy Policy*, *65*, 229-244.
12. Kubiszewski, I., Cleveland, C. J., & Endres, P. K. (2010). Meta-analysis of net energy return for wind power systems. *Renewable energy*, *35*(1), 218-225.
13. Gusain, C., Tripathi, M. M., & Nangia, U. (2023). Study of meta-heuristic optimization methodologies for design of hybrid renewable energy systems. *Thermal Science and Engineering Progress, 39*, 101711. https://doi.org/10.1016/j.tsep.2023.10171
14. Agajie, T. F., Ali, A., Fopah-Lele, A., Amoussou, I., Khan, B., Velasco, C. L. R., & Tanyi, E. (2023). A comprehensive review on techno-economic analysis and optimal sizing of hybrid renewable energy sources with energy storage systems. *Energies, 16*(2), 642. https://doi.org/10.3390/en16020642
15. Bouaouda, A., & Sayouti, Y. (2022). Hybrid meta-heuristic algorithms for optimal sizing of hybrid renewable energy system: a review of the state-of-the-art. *Archives of Computational Methods in Engineering, 29*(6), 4049-4083. https://doi.org/10.1007/s11831-022-09714-4
16. Lian, J., Zhang, Y., Ma, C., Yang, Y., & Chaima, E. (2019). A review on recent sizing methodologies of hybrid renewable energy systems. *Energy Conversion and Management, 199*, 112027. https://doi.org/10.1016/j.enconman.2019.112027
17. Anoune, K., Bouya, M., Astito, A., & Abdellah, A. B. (2018). Sizing methods and optimization techniques for PV-wind based hybrid renewable energy system:



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