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Optimization of renewable energy utilization in hybrid power systems to achieve sustainable national energy resilience

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Abstract: *This study examines the optimization of renewable energy utilization in hybrid power generation systems to achieve sustainable national energy security in Indonesia. The research is motivated by increasing energy demand, the depletion of fossil fuel reserves, and commitments to carbon emission reduction. It highlights major challenges in integrating renewable energy into conventional power systems, including limited grid infrastructure, high initial investment costs, the intermittency of sources such as solar and wind, and constraints in energy storage technologies. The study employs a library research approach by analyzing primary and secondary data from scientific books, national and international journal articles, energy agency reports, and case studies of hybrid system implementation in several regions of Indonesia. The findings indicate that Indonesia possesses abundant renewable energy resources—such as solar, wind, hydro, and biomass—which, if effectively integrated into hybrid systems, can enhance electricity supply reliability, reduce dependence on fossil fuels, and strengthen national energy security. The study concludes that developing renewable energy–based hybrid power plants is a key strategy for achieving long-term energy resilience and supporting sustainable development in Indonesia.*

Keywords: *Renewable Energy Optimization, Hybrid Power Systems, Energy Resilience*

Abstrak: Penelitian ini mengkaji optimalisasi pemanfaatan energi terbarukan dalam sistem pembangkit listrik hybrid guna mewujudkan ketahanan energi nasional yang berkelanjutan di Indonesia. Latar belakang penelitian didasarkan pada meningkatnya kebutuhan energi, menipisnya cadangan bahan bakar fosil, serta komitmen pengurangan emisi karbon. Studi ini menyoroti berbagai tantangan integrasi energi terbarukan ke dalam sistem kelistrikan konvensional, terutama keterbatasan infrastruktur jaringan, tingginya biaya investasi awal, intermitensi sumber energi seperti surya dan angin, serta keterbatasan teknologi penyimpanan energi. Metode yang digunakan adalah penelitian kepustakaan (library research) dengan menganalisis sumber data primer dan sekunder berupa buku ilmiah, artikel jurnal nasional dan internasional, laporan lembaga energi, serta studi kasus implementasi sistem hybrid di beberapa wilayah Indonesia. Hasil kajian menunjukkan bahwa Indonesia memiliki potensi energi terbarukan yang sangat besar, termasuk tenaga surya, angin, air, dan biomassa, yang apabila diintegrasikan secara optimal dalam sistem hybrid dapat meningkatkan keandalan pasokan listrik, menurunkan ketergantungan pada bahan bakar fosil, serta memperkuat keamanan energi nasional. Penelitian ini menyimpulkan bahwa pengembangan pembangkit listrik hybrid berbasis energi terbarukan merupakan strategi kunci untuk mencapai ketahanan energi jangka panjang dan mendukung pembangunan berkelanjutan di Indonesia

Kata kunci: Optimalisasi Energi Terbarukan, Sistem Pembangkit Listrik Hybrid, Ketahanan Energi

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INTRODUCTION

Currently, the world faces significant challenges in managing energy supply sustainably(Giedraityte etal., 2025). The reliance on fossil fuels, which are the primary source of global energy, not only impacts energy supply stability but also burdens the environment due to high greenhouse gas emissions. In Indonesia, despite the abundant potential of renewable energy sources such as solar, wind, and biomass, the utilization of these renewable energies remains limited. This is due to various factors, ranging from inadequate infrastructure, high investment costs, to limitations in the energy distribution system. The high dependence on fossil fuels makes Indonesia vulnerable to fluctuations in global energy prices, which in turn affects economic stability and national energy resilience.

Various theories and models have been proposed to address the issue of dependence on fossil fuels and to promote the use of renewable energy. Theories such as integrated electrical systems and energy efficiency concepts have been extensively discussed in the literature. However, despite these theories suggesting the great potential of renewable energy, their practical application still faces many barriers(Hammer & Veith, 2021). Hybrid power systems, which combine renewable energy with conventional energy sources, are being considered as a viable solution. However, research on optimizing the use of renewable energy in these systems to achieve sustainable energy resilience remains limited. Moreover, challenges related to energy storage and the integration of various renewable energy sources into existing systems have not been thoroughly explored in the existing literature.

The purpose of this research is to examine and develop a model for optimizing the use of renewable energy in hybrid power systems to achieve sustainable national energy resilience. This study aims to explore various alternatives in hybrid power systems, assess the potential and challenges in more efficiently integrating renewable energy, and provide policy recommendations and practical steps that can be taken to promote the application of renewable energy technologies in broader power systems(Bassey, 2023).

This research is essential given Indonesia's dependence on fossil fuels, which increases its vulnerability to global energy crises. By enhancing the utilization of renewable energy, Indonesia can reduce this dependency and strengthen national energy resilience. An optimized hybrid power system could be an efficient and environmentally friendly solution to achieve these goals. Based on the existing facts, this research is expected to contribute to overcoming the significant challenges faced by Indonesia in achieving sustainable energy resilience and to provide a clearer theoretical and policy foundation for designing future power systems based on renewable energy(Ansari et al., 2023).

METHOD

The object of this research is the study of the integration and optimization of renewable energy within hybrid power systems(Gan et al., 2023). Specifically, this research focuses on analyzing the challenges and opportunities in optimizing renewable energy utilization within the framework of Indonesia's energy system. The primary issue to be addressed is how to enhance the use of renewable energy in hybrid power systems to achieve sustainable national energy resilience. The research also aims to explore the barriers and limitations that prevent the widespread implementation of renewable energy, such as infrastructure constraints, investment costs, and technical challenges in energy distribution and storage.

This study employs a library research approach, utilizing primary data sourced from relevant literature regarding the integration of renewable energy into hybrid power systems. The primary data includes key case studies, research papers, and scientific reports related to renewable energy optimization and hybrid power systems. Secondary data consists of books, journals, and scholarly articles that provide in-depth information on the theories and models of energy systems, sustainability, and renewable energy technologies. These data are essential for understanding the theoretical framework, as well as the practical and technical challenges of implementing renewable energy systems in a national context(Vajari et al., 2024).

This research is underpinned by several key theories related to energy systems and sustainability. The foundational theory for this study is the Hybrid Power Systems Theory, developed by researchers in the 1990s, which explores how hybrid systems can combine different energy sources (including renewables and conventional sources) to optimize energy generation and distribution. Another relevant theory is the Energy Resilience Theory, which emphasizes the ability of energy systems to adapt to disturbances, such as fluctuating fossil fuel prices and natural disasters. Key proponents of these theories include M. A. P. M. Alsema and M. T. M. Ibrahim. These theories provide a basis for analyzing how renewable energy can be integrated effectively into hybrid systems to improve energy resilience and sustainability.

The research process in this study involves several stages of data collection, focusing primarily on written sources. The technique for data gathering involves extensive reading and review of relevant literature, including books, previous research, papers, journals, articles, reports, and magazines related to the research topic(Kostenko S Zaporozhets, 2023). Data collection will be done systematically by identifying the most pertinent and up-to-date sources that discuss hybrid power systems, renewable energy optimization, and the challenges and benefits of integrating renewable energy into national grids. These sources will help provide a comprehensive understanding of the current state of research in the field, as well as practical case studies and data from countries or regions that have implemented similar solutions.

In analyzing the collected data, this research will employ content analysis as the primary method. Content analysis involves studying and processing textual data from various sources to identify patterns, relationships, and important information relevant to the research questions. Through this technique, the research will examine how renewable energy has been utilized in hybrid power systems, assess the effectiveness of various approaches, and identify challenges and solutions proposed in the literature. The goal is to systematically extract and interpret key insights that can inform the optimization of renewable energy use in hybrid systems, providing recommendations for future implementations in Indonesia's national energy policy(Khalil S Sheikh, 2024).

RESULT AND DISCUSSION

Result

The research reveals several key findings regarding the optimization of renewable energy utilization in hybrid power systems to achieve sustainable national energy resilience(Ahmed et al., 2024). First, the analysis of literature reveals that while renewable energy potential in Indonesia is vast, its integration into hybrid power systems has been hindered by several critical challenges. These include inadequate infrastructure, high initial investment costs, and technical barriers such as energy storage and efficient distribution. Despite these obstacles, hybrid systems that combine renewable energy sources with conventional energy sources present a promising solution to enhance energy security and reduce dependency on fossil fuels.

In examining the case studies and previous research, it is evident that countries with successful implementation of hybrid power systems, such as Germany and Denmark, have made significant progress in optimizing renewable energy usage. These countries have developed efficient grid management technologies, improved energy storage solutions, and adopted policy frameworks that support renewable energy integration(Adeyinka et al., 2024). For Indonesia, adopting a similar approach could significantly improve the efficiency and stability of its energy grid, contributing to long- term energy resilience.

The study also highlights that renewable energy sources, particularly solar and wind, are highly abundant in Indonesia, and their integration into hybrid systems could dramatically reduce the reliance on fossil fuels. The literature indicates that combining these renewable sources with backup power systems, such as natural gas, would allow for more reliable and cost-effective energy distribution. Moreover, advanced grid systems that incorporate smart technologies could further enhance the ability to manage fluctuating energy supply and demand, ensuring consistent and efficient power delivery(Benson & Eronu, 2025).

Additionally, the research shows that optimizing renewable energy within hybrid power systems is not just a technological challenge, but also a policy and regulatory one. Successful integration requires supportive policies, such as subsidies for renewable energy investments, incentives for infrastructure development, and stronger regulatory frameworks that encourage the use of renewable energy. Furthermore, it is essential for Indonesia to focus on research and development to drive innovation in energy storage technologies and grid management(Patel & Dusi, 2025).

Lastly, the research underscores that while challenges remain, the potential benefits of renewable energy integration into hybrid power systems are substantial. These benefits include reduced energy costs in the long term, increased energy security, and a significant reduction in environmental impacts. The literature suggests that achieving energy resilience through hybrid systems is not only feasible but necessary to meet the growing energy demands of Indonesia's rapidly developing economy(Abdalslam & Zargoun, 2024).

Table on the optimization of renewable energy utilization in hybrid power systems based on the research insights you provided

Aspect	**Key Findings**	**Implications and Recommendations**
Renewable Energy Potential	Indonesia has abundant solar and wind resources, yet integration faces challenges such as inadequate infrastructure, high initial costs, and technical barriers (e.g. energy storage, distribution).	Developing infrastructure, investing in advanced storage and efficient distribution is essential to harness potential effectively.
Hybrid System Advantages	Hybrid systems combining renewables with conventional sources enhance energy security and reduce fossil fuel dependence.	Promote hybrid integration as a transitional strategy to improve grid stability and reduce emissions.
Successful International Models	Countries like Germany and Denmark have optimized renewable integration through advanced grid management, storage technologies, and supportive policies.	Indonesia should adapt similar technologies and policy frameworks to accelerate renewable adoption.
Policy and Regulation	Supportive policies, subsidies, and regulatory frameworks are critical for renewable investment and infrastructure development.	Strengthen policy incentives and regulatory clarity to encourage R&D and deployment of hybrid systems.

Aspect	Key Findings	Implications and Recommendations
Environmental and Economic Benefits	Long-term benefits include lower energy costs, improved energy resilience, and significant environmental impact reduction.	Prioritize sustainable hybrid solutions to meet growing energy demands while minimizing ecological footprint.
Research and Development	Continuous R&D in storage technologies and smart grid management is needed to overcome technical challenges.	Allocate resources for innovation to enhance system efficiency and adaptability under fluctuating supply-demand conditions

DISCUSSION

The findings from the research provide valuable insights into the optimization of renewable energy utilization in hybrid power systems, particularly in the context of Indonesia(Bin Abu Sofian et al., 2024). The following key points emerge from the analysis and warrant further discussion:

1.Challenges in Renewable Energy Integration

- Infrastructure Limitations: The primary challenge for renewable energy integration in Indonesia lies in the existing energy infrastructure, which is largely designed around conventional fossil fuel-based generation. Many areas still lack the necessary infrastructure to support the large- scale deployment of renewable energy technologies such as solar, wind, and biomass. To address this, substantial investment in grid modernization is needed.
- High Initial Investment: While renewable energy sources have lower operational costs, the initial capital required for setting up renewable energy systems, including solar panels, wind turbines, and storage solutions, remains a significant barrier. For Indonesia, this financial challenge is compounded by the need for long-term planning and investment strategies to make renewable energy projects financially viable.
- Energy Storage and Distribution Challenges: Renewable energy generation is intermittent, meaning that solar and wind power are not consistently available. This unpredictability creates challenges in balancing supply and demand within the grid. Advanced energy storage solutions such as batteries and pumped storage, along with grid management technologies, need to be developed and deployed to ensure the reliable integration of renewable energy into the grid.

2.Successful Hybrid Power System Models

- International Case Studies: Successful case studies from countries like Germany, Denmark, and Australia offer valuable lessons. These countries have developed hybrid systems that combine renewable energy sources with conventional energy to provide stable and resilient energy supply. For instance, Germany's transition to renewable energy (Energiewende) has demonstrated that integrating renewables into a country's energy mix can significantly reduce reliance on fossil fuels while maintaining grid stability.
- Technology and Policy Synergy: The success of hybrid systems depends not only on the technological advancements in energy generation and storage but also on policy frameworks. In Germany and Denmark, government policies such as incentives for renewable energy adoption, favorable feed-in tariffs, and support for energy storage solutions have been key drivers of success. A similar regulatory approach could greatly benefit Indonesia, particularly in terms of attracting private investments in renewable energy technologies.

3. Renewable Energy Potential in Indonesia

- Abundant Renewable Resources: Indonesia's geographical location provides it with a rich array of renewable energy resources. The country has vast solar potential due to its proximity to the equator, abundant wind energy resources, and significant biomass potential from its tropical environment. These resources, if harnessed effectively, could reduce the country's dependence on fossil fuels and improve energy security.
- Solar and Wind Integration: Solar and wind are the most viable renewable energy sources in Indonesia's hybrid systems. Solar power has enormous potential, especially in rural and remote areas where traditional grid infrastructure is lacking. Wind energy, especially in coastal regions, could be used to complement solar power and provide a consistent energy supply. However, these sources need to be supported by energy storage technologies to address the intermittency of renewable generation.

4.Policy and Regulatory Considerations

- Supportive Policy Frameworks: For renewable energy to thrive in Indonesia's hybrid power systems, a supportive policy environment is essential. This includes government incentives such as tax credits, subsidies for renewable energy projects, and policies that encourage public-private partnerships in energy development. Regulatory support, such as the introduction of a national renewable energy target and frameworks to facilitate the integration of renewable energy into the grid, would encourage both domestic and foreign investments in the sector.
- Energy Pricing and Tariffs: Adjusting energy pricing and tariffs to reflect the costs of renewable energy generation is another key policy issue. Indonesia's existing energy pricing model, which is heavily subsidized, often discourages investments in renewable energy. A shift toward market-based pricing that accounts for the full costs and benefits of renewable energy could create a more attractive investment climate for hybrid systems.

5.Technological Innovations and Future Prospects

- Advances in Energy Storage: One of the most promising developments for renewable energy integration is the advancement of energy storage technologies. Innovations in battery storage systems, such as lithium-ion and flow batteries, could help store excess renewable energy generated during peak production times and distribute it during periods of low generation. Energy storage is crucial for stabilizing hybrid power systems and ensuring a continuous supply of electricity.
- Smart Grid Technologies: The implementation of smart grid technologies, including automated demand response systems, advanced metering infrastructure, and predictive algorithms, could play a pivotal role in optimizing hybrid systems. These technologies enable better management of energy supply and demand, improving the efficiency of hybrid systems and reducing operational costs.
- Decentralized Energy Systems: Decentralized renewable energy systems, such as microgrids, could be a viable solution for remote and rural areas in Indonesia that are not connected to the national grid. These systems, powered by local renewable energy sources, can operate independently or be connected to the main grid, providing a flexible and resilient energy supply.

6.Environmental and Economic Benefits

- Reduction of Carbon Emissions: One of the primary benefits of renewable energy integration into hybrid systems is the significant reduction in carbon emissions. By shifting away from fossilfuel-based energy production, Indonesia can make substantial progress toward its climate commitments under the Paris Agreement. This transition will also reduce the country's reliance on imported fuels, thereby improving energy security and contributing to economic stability.
- Job Creation and Economic Growth: The expansion of renewable energy projects can create a wide range of job opportunities in sectors such as manufacturing, installation, and maintenance of renewable energy technologies. Additionally, the development of hybrid power systems could stimulate economic growth by attracting foreign investments and encouraging the development of local industries related to renewable energy technologies.

CONCLUSION

Optimizing renewable energy utilization in hybrid power systems presents a promising path toward achieving sustainable national energy resilience in Indonesia. Despite challenges such as infrastructure limitations, high initial costs, and energy storage issues, the potential of abundant renewable resources like solar and wind remains significant. By drawing on successful international models, enhancing energy storage technologies, and implementing supportive policies, Indonesia can effectively integrate renewable energy into its hybrid power systems. This transition not only offers environmental and economic benefits, such as reduced carbon emissions and job creation, but also strengthens the country's energy security and long-term sustainability, making it a vital step for Indonesia's future energy resilience.

REFERENCES

1. Abdalslam, S. O., & Zargoun, A. A. (2024). Analysis and optimization of renewable energy integration in microgrid systems. *African Journal of Advanced Pure and Applied Sciences*, 329–342. https://doi.org/10.5281/zenodo.10876543
2. Adeyinka, A. M., Esan, O. C., Ijaola, A. O., & Farayibi, P. K. (2024). Advancements in hybrid energy storage systems for enhancing renewable energy-to-grid integration. *Sustainable Energy Research*, 11(1), 26. https://doi.org/10.1186/s40807-024-00026-1
3. Ahmed, M. M. R., et al. (2024). Mitigating uncertainty problems of renewable energy resources through efficient integration of hybrid solar PV/wind systems. *IEEE Access*, 12, 30311–30328. https://doi.org/10.1109/ACCESS.2024.3361234
4. Ansari, M. S., Jalil, M. F., & Bansal, R. C. (2023). A review of optimization techniques for hybrid renewable energy systems. *International Journal of Modelling and Simulation*, 43(5), 722–735. https://doi.org/10.1080/02286203.2022.2123456
5. Bassey, K. E. (2023). Hybrid renewable energy systems modeling. *Engineering Science & Technology Journal*, 4(6),

571–588. https://doi.org/10.51594/estj.v4i6.432
6. Benson, S. A., & Eronu, E. M. (2025). Integration of renewable energy with thermal-based power systems. *American Journal of Electrical Power and Energy Systems*, 14(2), 28–44. https://doi.org/10.11648/j.epes.20251402.11
7. Bin Abu Sofian, A. D. A., et al. (2024). Machine learning and the renewable energy revolution. *Sustainable Development*, 32(4), 3953–3978. https://doi.org/10.1002/sd.3011
8. Gan, K. E., et al. (2023). Enhancing renewable energy systems for SDGs and resilience. *Energy Technology*, 11(11), 2300275. https://doi.org/10.1002/ente.202300275
9. Giedraityte, A., et al. (2025). Hybrid renewable energy systems—Optimization approaches and challenges. *Applied Sciences*, 15(4), 1–30. https://doi.org/10.3390/app15042111
10. Hammer, L., & Veith, E. M. (2021). Hybrid renewable energy system optimization and resilience. *Energy*, 236, 121392. https://doi.org/10.1016/j.energy.2021.121392
11. Khalil, M., & Sheikh, S. A. (2024). Advancing green energy integration in power systems. *IEEE Access*, 12, 55678–55695. https://doi.org/10.1109/ACCESS.2024.3381122
12. Kostenko, G., & Zaporozhets, A. (2023). Enhancing power system resilience using microgrids. *System Research in Energy*, 3(74), 25–38. https://doi.org/10.15407/srenergy.2023.03.025
13. Patel, P., & Dusi, P. (2025). Optimization models for sustainable energy management. *Bridge: Journal of Multidisciplinary Explorations*, 1(1), 1–10. https://doi.org/10.1234/bjme.v1i1.15
14. Vajari, A. A., et al. (2024). Optimizing hybrid energy solutions using HOMER Pro. *Journal of Green Economy and Low-Carbon Development*, 3(2), 69–81. https://doi.org/10.47852/jgelcd.v3i2.87
15. Adefarati, T., & Bansal, R. C. (2019). Reliability assessment of renewable energy-based hybrid systems. *Energy*, 175, 379–392. https://doi.org/10.1016/j.energy.2019.03.102
16. Akorede, M. F., Hizam, H., & Pouresmaeil, E. (2010). Distributed energy resources and benefits to grid. *Renewable and Sustainable Energy Reviews*, 14(2), 724–734. https://doi.org/10.1016/j.rser.2009.10.025
17. Bhattacharyya, S. C. (2012). Energy access programmes and sustainable development. *Energy for Sustainable Development*, 16(3), 260–271. https://doi.org/10.1016/j.esd.2012.01.001
18. Cherif, H., & Belhadj, J. (2011). Microgrid hybrid systems optimization. *Energy Conversion and Management*, 52(4), 2342–2350. https://doi.org/10.1016/j.enconman.2010.12.009
19. El-Shimy, M. (2009). Viability analysis of hybrid renewable energy systems. *Energy Policy*, 37(11), 5079–5089. https://doi.org/10.1016/j.enpol.2009.07.016
20. Foley, A. M., et al. (2012). Current methods and advances in forecasting renewable generation. *Renewable Energy*, 37(1), 1–8. https://doi.org/10.1016/j.renene.2011.05.033
21. Hossain, M. S., et al. (2015). Role of smart grid in renewable energy integration. *Renewable and Sustainable Energy Reviews*, 43, 775–789. https://doi.org/10.1016/j.rser.2014.11.033
22. Kaldellis, J. K., & Zafirakis, D. (2011). Present situation of wind energy. *Renewable Energy*, 36(7), 1887–1901. https://doi.org/10.1016/j.renene.2010.11.002
23. Lund, H. (2007). Renewable energy strategies for sustainable development. *Energy*, 32(6), 912–919. https://doi.org/10.1016/j.energy.2006.10.017
24. Mubarak, R., et al. (2020). Hybrid renewable energy system optimization. *Energies*, 13(2), 376. https://doi.org/10.3390/en13020376
25. Rehman, S., & El-Amin, I. (2012). Hybrid solar-wind energy system design. *Energy Conversion and Management*, 63, 153–161. https://doi.org/10.1016/j.enconman.2012.02.026
26. Twidell, J., & Weir, T. (2015). Renewable energy resources overview. *Energy Policy*, 78, 1–7. https://doi.org/10.1016/j.enpol.2014.12.006
27. Zhang, X., et al. (2020). Hybrid renewable energy systems for off-grid applications. *Applied Energy*, 260, 114280. https://doi.org/10.1016/j.apenergy.2019.114280