JOURNAL OF ADVANCED ENGINEERING AND INNOVATION
Volume 2, Issue 2, December 2024 | pp. 52-59
https://doi.org/10.54518/jaei.2.2.2024.1295

Recent Advances in Artificial Intelligence for Renewable Energy System Optimization

Raihan Ferdinand Khairuazfa[1] ✉

Universitas Telkom, Indonesia[1]

ABSTRACT

The rapid development of renewable energy systems has increased the need for optimization methods capable of improving operational efficiency, reliability, and flexibility. The intermittent nature of renewable energy sources creates significant challenges in system management, making Artificial Intelligence (AI) a promising solution for intelligent optimization. This study aims to analyze the development of AI algorithms for renewable energy system optimization using a Systematic Literature Review (SLR) approach. The review examines scientific articles published between 2019 and 2023 that discuss the implementation of AI techniques, including Machine Learning, Deep Learning, Artificial Neural Networks, and Reinforcement Learning in renewable energy applications. The findings indicate that AI significantly improves renewable energy forecasting accuracy, optimizes system configuration, enhances energy storage management, and increases the operational efficiency and reliability of smart grids and microgrids. Furthermore, integrating AI with optimization algorithms contributes to reducing operational costs while supporting sustainable energy utilization. However, several challenges remain, including computational complexity, model generalization, and real-time implementation. Overall, this study provides a comprehensive overview of recent advances in AI-based renewable energy optimization and offers valuable insights for developing more adaptive, efficient, and sustainable energy management models.

Keywords: *Artificial Intelligence; Deep Learning; Energy Optimization; Machine Learning; Renewable Energy Systems*

CORRESPONDING AUTHOR:
Raihan Ferdinand Khairuazfa
Universitas Telkom, Indonesia

ARTICLE HISTORY
Received : July 7, 2024
Final Revised : August 23, 2024
Accepted : October 10, 2024
Published : December 30, 2024

1. | INTRODUCTION

The transition to a sustainable energy system has become a key agenda for global development in response to increasing energy demand, limited fossil fuel resources, and international commitments to reduce greenhouse gas emissions. The use of renewable energy sources, such as solar, wind, biomass, and hydropower, continues to increase due to their perceived ability to provide a more environmentally friendly energy supply than conventional energy sources. However, the characteristics of renewable energy sources, which depend on natural conditions, lead to variability in energy production, posing challenges in maintaining a balance between generation, storage, and load demand. Therefore, an optimization approach is needed that can improve the efficiency, reliability, and flexibility of renewable energy systems as a whole (Rauf, 2023).

The development of digital technology has opened up new opportunities in energy system management through the application of artificial intelligence (AI). AI enables energy systems to rapidly analyze large amounts of data to produce more accurate decisions than conventional methods. Various AI algorithms, such as Artificial Neural Networks (ANN), Machine Learning (ML), Deep Learning (DL), and Reinforcement Learning (RL), have been applied to improve energy production prediction, electricity demand estimation, operational control, and energy distribution optimization in renewable energy-based systems. AI integration provides adaptive capabilities to changing environmental conditions, thereby increasing operational efficiency and reducing uncertainty caused by energy source fluctuations (Pasaribu & Widjaja, 2022).

In addition to improving predictive capabilities, AI also plays a crucial role in energy system optimization through integration with modern optimization algorithms, such as the Genetic Algorithm (GA), Particle Swarm Optimization (PSO), Grey Wolf Optimizer (GWO), Differential Evolution (DE), and various other metaheuristic methods. This combination enables the determination of optimal system configurations based on various parameters, including energy efficiency, investment costs, operational costs, system reliability, energy storage capacity, and carbon emission levels. This approach is becoming increasingly important in modern energy systems, which are highly complex due to the integration of multiple energy sources and energy storage devices into a single network (Utamidewi, 2023).

In recent years, research on the application of AI to renewable energy systems has increased significantly. Most research focuses on solar energy production optimization, wind speed prediction, microgrid management, battery capacity optimization, predictive maintenance, and smart grid development. Furthermore, advances in deep learning have improved the accuracy of energy forecasting compared to traditional statistical methods, thereby improving the quality of decision-making in energy system management. These advances demonstrate that AI not only functions as a data analysis tool, but also as a key component in the development of intelligent energy systems capable of operating adaptively to changing operational conditions (Sulartopo et al., 2023).

Although numerous studies have demonstrated the successful application of AI in various aspects of renewable energy systems, several challenges remain that require further attention. Some studies only evaluate a single type of algorithm without comparing it to other optimization methods. Other studies focus more on improving prediction accuracy but fail to integrate aspects of energy efficiency, operational costs, system reliability, and environmental sustainability simultaneously. Furthermore, most studies are focused on specific applications, making their results not fully generalizable to various renewable energy system configurations. This situation indicates the need for a more comprehensive study on the use of AI as an integrated optimization approach in renewable energy systems (Edinov et al., 2023).

Based on these conditions, this study aims to analyze the development of the application of artificial intelligence algorithms in renewable energy system optimization through a Systematic Literature Review (SLR) approach (Hidayat et al., 2021). The study focuses on identifying the most widely used AI algorithms, the optimization parameters applied, the benefits achieved in improving system efficiency, and the implementation challenges still faced. The results of the study are expected to provide a comprehensive overview of the development of AI technology in renewable energy systems and serve as a basis for developing more adaptive, efficient, and sustainable optimization models to support the transformation of modern energy systems.

2. | RESEARCH METHOD

This study employed the Systematic Literature Review (SLR) method to systematically identify, evaluate, and synthesize research findings on the application of artificial intelligence algorithms to renewable energy system optimization. The SLR approach was chosen because it produces a transparent, structured, and replicable scientific synthesis, making it suitable for mapping research progress, identifying research gaps, and formulating technological development directions in the renewable energy sector. The literature review process adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines, which include identification, screening, eligibility assessment, and determining articles that met the inclusion criteria (Utami et al., 2021).

The literature search was conducted using Google Scholar as the primary database using a combination of keywords, including artificial intelligence, machine learning, deep learning, renewable energy, renewable energy system, energy optimization, smart grid, microgrid, genetic algorithm, particle swarm optimization, and hybrid renewable energy system. Selected articles were limited to publications published between 2019 and 2023, in English, peer-reviewed, and published in reputable scientific journals relevant to the fields of engineering, energy, and artificial intelligence. Conversely, articles in the form of proceedings, editorials, short reports, books, theses, and publications outside the specified year range were excluded from the selection process to maintain the quality and consistency of the research data (Bernardi et al., 2023)

Next, each article meeting the inclusion criteria was analyzed based on several key aspects: the type of artificial intelligence algorithm used, the renewable energy system studied, the optimization method applied, the performance evaluation parameters, and the reported implementation results. This information was then grouped and compared to identify research trends, the advantages of each algorithm, implementation challenges, and opportunities for technological development in renewable energy systems (Utami et al., 2021). The synthesis results were then presented descriptively and analyzed comparatively to gain a comprehensive understanding of the contribution of artificial intelligence algorithms to improving the efficiency, reliability, and sustainability of renewable energy systems.

3. | RESULTS AND DISCUSSION

A literature synthesis indicates that the application of artificial intelligence (AI) algorithms has become a key approach to improving the efficiency, reliability, and flexibility of renewable energy systems. Based on various scientific publications from 2019–2023, research developments are no longer solely focused on improving the accuracy of energy generation predictions, but have shifted toward integrated optimization encompassing capacity planning, energy storage management, load regulation, microgrid control, and real-time decision-making. This shift is driven by the increasing complexity of modern energy systems, which integrate multiple renewable energy sources with intermittent characteristics, necessitating optimization methods that adapt to changing operational conditions.

One key finding from the study is the dominant use of Machine Learning (ML) and Deep Learning (DL) algorithms in the energy production prediction process. The ability of these two approaches to recognize nonlinear patterns in historical data allows for improved forecast accuracy for solar radiation, wind speed, and electricity load demand. Compared to conventional statistical methods, models based on Artificial Neural Networks (ANN), Long Short-Term Memory (LSTM), and Convolutional Neural Networks (CNN) are capable of producing more stable predictions under dynamic data conditions, thereby supporting more effective operational decision-making (Ajeng, 2023). Improved prediction accuracy directly contributes to reducing the imbalance between energy generation and consumption, ultimately improving overall system efficiency.

In addition to energy forecasting, AI is also widely used in optimizing renewable energy system configurations. Various studies have shown that the combination of machine learning algorithms with metaheuristic methods, such as Genetic Algorithm (GA), Particle Swarm Optimization (PSO), Grey Wolf Optimizer (GWO), and

Differential Evolution (DE), can produce more optimal system configurations than conventional approaches. This optimization includes determining solar panel size, wind turbine capacity, battery capacity, energy storage operating strategies, and power distribution scheduling in hybrid renewable energy systems. This multi-objective approach allows simultaneous optimization of energy efficiency, investment costs, operational costs, system reliability, and carbon emissions (Dwi, 2023).

A literature review also shows that the integration of AI with smart grids and microgrids is a rapidly growing research trend during the 2019–2023 period. In these systems, AI is used to predict electricity loads, regulate energy flows between generation sources, optimize battery charging and discharging processes, and control load response (demand response). AI's ability to process sensor data in real time enables the system to automatically adjust operations when weather conditions change or electricity consumption fluctuates. This allows for a continuous energy supply without increasing energy consumption from conventional power plants.

Other findings indicate that Deep Learning is increasingly being used to solve problems previously difficult for traditional prediction models. Architectures such as LSTM, Gated Recurrent Unit (GRU), and CNN have the ability to learn temporal and spatial relationships from energy data, improving prediction performance in solar and wind energy systems. These models have proven effective in handling data fluctuations due to changing atmospheric conditions, supporting a more adaptive energy system operation optimization process (Supari et al., 2022). The use of Deep Learning also contributes to improving the quality of decision-making in Internet of Things (IoT)-based energy systems and smart energy management.

From an operational efficiency perspective, most studies report that the application of AI can reduce energy consumption, reduce power losses, improve the capacity factor of generating plants, and extend the lifespan of energy storage systems through smarter control strategies. AI not only optimizes the energy generation process but also determines the most efficient operating strategy based on environmental conditions, load characteristics, and the status of energy storage devices (Gao & Lu, 2021). This approach results in more effective energy use while reducing long-term operating costs.

The synthesis results also indicate that research is beginning to move toward the application of Reinforcement Learning (RL) as an adaptive decision-making method. Unlike supervised algorithms, RL enables systems to learn autonomously through a reward mechanism based on the results of previous actions. This approach is considered highly suitable for optimizing microgrid control, energy storage scheduling, and power distribution in renewable energy systems with high levels of uncertainty (Putra, 2019). Although the number of studies on RL remains smaller than those on ANNs and LSTMs, the publication trend shows a significant increase due to its ability to solve dynamic optimization problems in real time.

Nevertheless, the study identified several challenges that remain of concern. First, most research still focuses on a single type of energy source, such as solar or wind power, so implementation in more complex hybrid energy systems requires further development. Second, some studies use datasets with limited characteristics, so the generalizability of the models to different operational conditions has not been fully tested. Third, the computational complexity of some Deep Learning algorithms results in high computational resource requirements, especially for real-time applications. In addition, the issue of model interpretability (explainable AI) remains a challenge because most modern algorithms work as black boxes, making the decision-making process difficult to explain technically.

Based on the overall analysis results, it can be concluded that the integration of AI with modern optimization algorithms makes a significant contribution to improving the performance of renewable energy systems. AI is able to increase the accuracy of energy predictions, optimize system configurations, improve energy storage management, increase the reliability of smart grid operations, and support the achievement of higher energy efficiency. On the other hand, future research needs to develop AI models that are computationally lighter, easier to interpret, and able to optimize various energy sources simultaneously through a multi-objective approach. The integration of AI with technologies such as IoT, digital twins, edge computing, and intelligent control systems is expected to be the next research direction in supporting the transformation towards a more efficient, resilient, and sustainable energy system.

4. | CONCLUSION

This research demonstrates that the application of artificial intelligence (AI) algorithms has become an effective approach to optimizing renewable energy systems. Based on a Systematic Literature Review of scientific publications from 2019–2023, various AI algorithms, such as Machine Learning, Deep Learning, Artificial Neural Networks, Long Short-Term Memory, and Reinforcement Learning, have been utilized to improve the accuracy of energy production predictions, optimize system configurations, manage energy storage, and support smart grid and microgrid control. The integration of AI with metaheuristic optimization algorithms has also been shown to increase operational efficiency, lower operational costs, improve system reliability, and support carbon emission reduction through more adaptive and intelligent energy management.

However, the study findings indicate that several challenges remain in implementing AI in renewable energy systems, including high computational complexity, limited model generalization across various system configurations, and the limited application of models capable of integrated optimization across multiple energy sources. Therefore, further research needs to be directed at developing more efficient, easily interpretable AI models capable of performing real-time multi-objective optimization. Furthermore, the integration of AI with supporting technologies such as the Internet of Things, edge computing, and digital twins has the potential to enhance the capabilities of renewable energy systems in dealing with increasingly complex operational dynamics. Thus, the application of AI is expected to be a crucial foundation for realizing a more efficient, reliable, intelligent, and sustainable energy system.

Acknowledgment

We gratefully acknowledge the contributions of individuals who supported the completion of this article.

Funding Information

This research did not receive any funding.

Conflict of Interest Statement

The authors declare that there is no conflict of interest.

Ethical Approval and Originality Statement

Ethical approval was obtained for this study. The manuscript represents original work and has not been previously published, nor is it under consideration by another journal.

Data Disclosure Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

REFERENCES

Ajeng, P. K. (2023). Recurrent Neural Network (Rnn) Berbasis Long-Short Term Memory (Lstm) Untuk Peramalan Inflasi Di Indonesia.

Bernardi, F. A., Alves, D., Crepaldi, N., Yamada, D. B., Lima, V. C., & Rijo, R. (2023). Data Quality In Health Research: Integrative Literature Review. *Journal Of Medical Internet Research*, *25*, E41446.

Dwi, K. (2023). Optimasi Adopsi Pembangkit Listrik Tenaga Surya Skala Rumah Tangga 1.300 Va Dengan Pendekatan Stakeholder Menggunakan Metode Multi-Objective Genetic Algorithm.

Edinov, S., Rancak, G. T., Wahyudi, R., Wiyani, L., & Prabasari, I. G. (2023). Carbon Capture and Storage dan Circular Economy: Tinjauan Sistematis dan Arah Penelitian di Masa Depan. *Nusantara Technology and Engineering Review*, *1*(1), 19-30.

Gao, T., & Lu, W. (2021). Machine learning toward advanced energy storage devices and systems. *Iscience*, *24*(1)

Hidayat, D. J., Fathiyana, R. Z., & Dharmawan, G. B. (2021). Systematic Literature Review: Pengembangan Sistem Intelijen untuk Prediksi Suhu. *Journal of Informatics and Communication Technology (JICT)*, *3*(2), 94-107.

Pasaribu, M., & Widjaja, A. (2022). *Manajemen strategis di era kecerdasan buatan*. Kepustakaan Populer Gramedia

Putra, J. (2019). Penentuan Kapasitas BESS (Battery Energy Storage System) Dengan Pendekatan Multiperiod Optimal Power Flow Pada Sistem Microgrid.

Rauf, R. (2023). Optimalisasi Pembangkit Listrik Tenaga Surya di Daerah Kepulauan.

Sulartopo, S., Kholifah, S., Danang, D., & Santoso, J. T. (2023). Transformasi proyek melalui keajaiban kecerdasan buatan: mengeksplorasi potensi ai dalam project management. *Jurnal Publikasi Ilmu Manajemen*, *2*(2), 363-392.

Supari, S., Satria, P., Syndu, Y. P., & Lantar, B. A. (2022). Optimalisasi Listrik Tenaga Surya Dalam Mobilitas Perahu (Metode Dan Analisanya).

Utamidewi, D. (2023). *Optimasi Pembangkit Hibrida (PV, Baterai, dan Generator) pada Daerah Off-Grid dengan Pendekatan Multi Objective Optimization* (Doctoral dissertation, Universitas Hasanuddin).

Utami, M. C., Jahar, A. S., & Zulkifli, Z. (2021). Tinjauan scoping review dan studi kasus. *Radial*, *9*(2), 152-172.