



ADVANCES IN AI MODELING TECHNIQUES FOR RENEWABLE ENERGY SYSTEMS: EFFICIENCY, ACCURACY, AND COMPUTATIONAL OPTIMIZATION

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ABSTRACT:

Artificial intelligence (AI) included into renewable energy systems has greatly improved predictive power, efficiency, and optimization. This work evaluates several theoretical and experimental artificial intelligence approaches extensively used in renewable energy applications in terms of forecasting, control, and optimization tasks. The main goal is to find with little computing overhead the most effective, accurate, and generalizable AI-based modelling method. Performance of current AI techniques—counting machine learning (ML), deep learning (DL), and hybrid models—is assessed in a thorough assessment. The results emphasize the fact that all these hybrid artificial intelligence methods have produced results by lowering the computing complexities while achieving excellent accuracies. The results referenced here are such as inform policymakers, engineers, and researchers interested in pursuing strategies for enhancing the integration of renewable energy sources (RESs) and sustainability into practices. This research improves intelligent energy management through more extensive optimization of AI-driven modelling methodology while improving renewable energy systems regarding their operational performance, reliability, and scalability.

Keywords: AI Modelling; Renewable energy; Energy Systems; Efficiency, Accuracy, Computational Optimization.

INTRODUCTION:

The growing reliance on renewable energy sources worldwide calls for sophisticated plans for effective control, forecasting, and optimization. The intermittent and unpredictable character of RESs like solar and wind presents a challenge for conventional energy modelling approaches, which results in inefficiencies in power generating and grid stability (Krzywanski et al., 2024; Bennagi et al., 2024). Also, leveraging ML,

DL, and hybrid models to boost accuracy and operational efficiency, AI has become a potent tool to meet these difficulties. Particularly with regard to computational complexity and real-time applicability, the choice of the most effective, accurate, and generalizable AI modelling technique still begs unresolved research questions (Zhou, 2022; Hamdan et al., 2024). This work intends to find and evaluate several theoretical and experimental artificial intelligence solutions used in renewable energy systems, thereby evaluating their predictive accuracy, flexibility, and processing efficiency. The results will promote more intelligent and environmentally friendly energy management systems, therefore helping to advance AI-driven renewable energy solutions. The following section elaborates the past literatures related to this study.

LITERATURE REVIEW:

With an emphasis on efficiency, accuracy, and computational optimization, the prior literatures on this research of advances in AI modelling techniques for renewable energy systems are discussed in following part.

Table 1: Related Works

AUTHORS AND YAER	METHODOLOGY	FINDINGS
Mauludin et al., (2025)	The goal is to create a comprehensive database matrix covering several categories, such as component configurations, methods, and software infrastructures. Additionally, the socio-economic, environmental, and ecological implications of these systems are assessed to determine their importance. Additionally, this study explores utilizing artificial intelligence to optimize these systems.	Hybrid energy harvesting systems are expected to grow due to their potential as clean, and sustainable, along with eco-friendly energy sources.
Ukoba et al., (2024)	This study reviewed current renewable energy and AI research, identifying major techniques, problems, and successes.	Finally, the review examined field potential and trends. Explainable AI, reinforcement learning, and edge computing may optimize RES.

Yousef et al., (2023)	This review paper summarized AI strategies for variable renewable energy (VRE) system management and predicted future research.	AI has been used to enhance power generation forecasts and integrate VRE into power networks, including performance monitoring, demand forecasting, system optimization, energy storage, and cost management.
Abualigah et al., (2022)	This report used learning-based methods to review the most prominent renewable problem researchers.	Hybrid learning methods outperform single methods because they use two or more strategies to predict accurately.

Research Gap: Although artificial intelligence is being used in renewable energy systems, a major research gap exists in determining the most effective and generalizable modeling method that blends high predicted accuracy with lowest computational complexity. Deep learning models can demand large data and processing capability, therefore restricting real-time applications even if they provide better accuracy. On the other hand, conventional ML models could lack the adaptability required for complicated energy systems even if they are computationally efficient. Although hybrid artificial intelligence techniques show promise, their relative efficacy across many renewable energy uses is nevertheless understudied. This work fills in the need by carefully evaluating several artificial intelligence approaches to identify the most suitable one for improving control, efficiency, and forecasting of renewable energy.

METHODOLOGY:

This study used secondary data taken from reliable online databases like Scopus, IEEE Xplore, ScienceDirect, and Springer using a qualitative research methodology. Emphasizing their efficiency, accuracy, and computational performance, a thorough literature study is done to examine several AI-based approaches used in renewable energy systems. Published throughout the past ten years, peer-reviewed journal articles, and conference proceedings, along with technical reports are methodically examined to find trends, difficulties, and developments in artificial intelligence-driven renewable energy modelling. Evaluating their relevance in forecasting, optimization, and energy management, the paper uses a theme analysis approach to contrast machine learning, deep learning, and hybrid artificial intelligence systems. This approach offers a thorough knowledge of the strengths and constraints of various artificial intelligence models by combining present research results, thereby directing the choice of the most successful way for improving renewable energy systems.

RESULTS AND DISCUSSIONS:

Particularly in forecasting, control, and optimization, the results of this study underline the efficiency of certain AI approaches in uses related to renewable energy. Although ML models include random forests, support vector machines (SVMs), and decision trees offer modest accuracy with quite low computing cost, the study finds that they often struggle with complicated, non-linear interactions in renewable energy datasets. DL models—counting recurrent neural networks (RNNs) and convolutional neural networks (CNNs)—show better accuracy in time-series forecasting and pattern recognition, therefore rendering them rather useful for estimating solar and wind energy outputs. Real-time applications, particularly in resource-limited settings, find difficulty with the computational intensity of DL models, nevertheless. By using the advantages of both approaches, hybrid artificial intelligence solutions—which combine ML and DL techniques—offer promise. These models fit for large-scale energy management since they maximize computing efficiency and enhance accuracy, hence optimizing computational economy. Table 1 presents a comparison of artificial intelligence approaches for uses in renewable energy. These results underline the requirement of ongoing model efficiency and flexibility as they support the increasing relevance of AI in developing renewable energy solutions.

Table 1: Comparative Analysis of AI Techniques in Renewable Energy Applications

AI Approach	Accuracy	Computational Efficiency	Real-time Applicability
Machine Learning (SVM, Random Forest)	Moderate	High	Limited in complex scenarios
Deep Learning (CNN, RNN)	High	Low	Challenging due to processing demands
Hybrid AI Models	High	Moderate	Suitable for large-scale applications
Transfer Learning & Federated Learning	Very High	Varies (Optimized for knowledge transfer)	Effective for adaptive energy systems

Furthermore, the results show that artificial intelligence models developed on high-quality datasets with varied environmental conditions show higher generalization, therefore guaranteeing consistent forecasts over several geographical areas. Improving model performance mostly depends on feature selection and data preparation since redundant or unnecessary elements could cause overfitting and higher computational overhead. By enabling knowledge transfer across several datasets, hence lowering the demand for lengthy retraining, transfer learning and federated learning techniques further improve the adaptability of artificial intelligence models.

Apart from the technical necessity, the paper brings forth the need for including artificial intelligence in energy management into smart grid systems, enabling predictive maintenance, anomaly detection, demand-response systems driven by artificial intelligence to make the grids and energy economy more robust. The intelligent collection of real-time data through a combination of AI and the Internet of Things (IoT) improves energy operating decisions on utilization and allocation. Nonetheless, aspects like data security, model interpretability, and scalability should be worked out to ensure public acceptance of artificial intelligence in renewable energies. Future research will concentrate on the development of lightweight artificial intelligence models with reduced processing requirements so that these can be implemented on edge computing environments and distributed inside distributed energy networks.

CONCLUSION:

This paper describes very well how artificial intelligence is an important tool for improving forecasts in the control and management functions so that renewable energy systems can be maximised. The deep learning methods offer higher accuracy but involve great processing resources, while the efficiency of machine learning models has to be traded for their ability to deal with complicated energy "behavior". For large-scale energy use applications, it seems that hybrid artificial intelligence methods are the best option considering both performance and computational economy. However, the issues of performance-seamless scalability, security poses problems, and even model interpretability still have their shortcomings even after making a bold move by combining artificial intelligence technology and smart grids with IoT. The future research priorities must be the evolving light-weight artificial intelligence models and adapted learning approaches to guarantee higher acceptance into the network for distributed renewable energy.

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