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Research Article

Applications Of AI Topology On Renewable Energy Resources: A Review

Dr. Puneet Kumar[1], Mr. A. Padmanabhan[2*], Dr. Gaurav Agarwal[3]

[1]Anand Engineering College, AKTU, Keetham, Agra-Mathura Road, Agra 282007, India
[2*]Anand Engineering College, AKTU, Keetham, Agra-Mathura Road, Agra 282007, India
[3]Anand Engineering College, AKTU, Keetham, Agra-Mathura Road, Agra 282007, India
*Emails:pkcaeceee@gmail.com

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ARTICLE INFO	ABSTRACT

Renewable energy (RE) plays a crucial role in promoting sustainability, environmental conservation, and cost-effective electricity generation. The gradual reduction in fossil fuel dependency for electricity production since 2019 underscores the rising prominence of RE in meeting global energy demands. Ongoing research activities aim to enhance the efficacy of RE technologies, with a particular focus on improving energy conversion efficiency. Concurrently, Artificial intelligence (AI) has emerged as a transformative tool in the energy sector, offering extraordinary capabilities in data analysis, operational optimization, and future development forecasting. The transition to new energy sources can be facilitated by the application of AI solutions. We can reduce greenhouse gas (GHG) emissions by identifying regions where there is potential for boosting the usage of solar energy through supply forecasting. AI can help achieve about 80% of the SDGs. This paper provides a comprehensive overview of commonly utilized AI techniques in various applications within the domain of sustainable energy. From optimizing efficiency to augmenting precision, AI holds immense potential to revolutionize energy systems and pave the path towards a more intelligent and sustainable future.

Keywords: Renewable energy (RE), artificial intelligence (AI), greenhouse gas GHG, Sustainable Development Goals (SDG)

1. INTRODUCTION

In today's world, the looming threats of global warming casts a shadow over both the environment and humanity's future. The energy sector, especially power generation sector, shoulders a considerable burden, responsible for about 75% of the world's total CO_2 emissions [1]. These emissions worsen the greenhouse gas (GHG) problem, intensifying global warming. Responding to this pressing issue, the United Nations urges nations worldwide to commit to Sustainable Development Goals (SDGs) [2]. The primary aim is to mitigate the adverse effects of climate change by promoting the widespread adoption of renewable energy sources. This move not only addresses energy needs but also aims to reduce per capita consumption [3].
Numerous countries have pledged their support to the SDGs by devising strategies for embracing renewable energy sources. These strategies involve setting targets and implementing policies to bolster renewable energy (RE) production. In India, the National Institution for Transforming India (NITI) Aayog, a non-statutory advisory body, has taken on the task of developing a comprehensive index. This index seeks to provide a unified view of the socio-economic and environmental landscape of the country, aiding in monitoring progress towards SDGs [4]. India's energy demand is on an upward trajectory, with projections indicating a doubling of total energy demand and nearly tripling of electricity demand by 2030 compared to present levels [5]. Moreover, reliance on conventional energy sources not only contributes to climate change but also faces limitations in capacity. Therefore, there is an urgent need to transition towards cleaner, sustainable alternatives with virtually limitless potential. India possesses a renewable energy (RE) potential of approximately 900 GW sourced from various outlets. This potential is distributed as follows: Wind- 10%, Solar- 17%, Thermal- 56%, Bioenergy- 3%, Nuclear- 2%, Hydro- 11%, and Small Hydro- 1%.

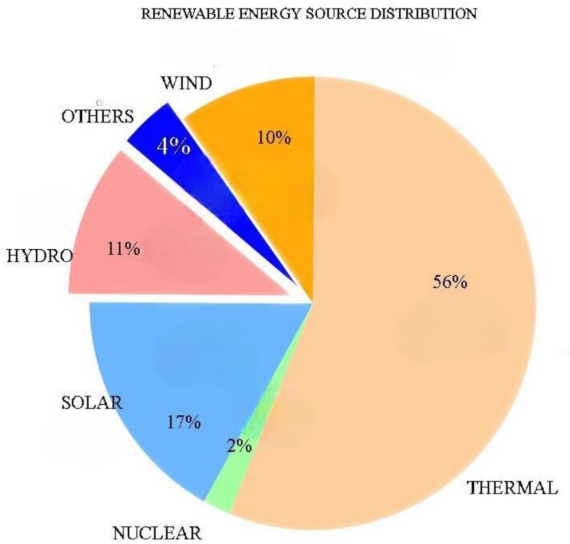

Figure 1 Renewable Energy Source Distribution in India

Committed to fostering a healthier planet, India has pledged its dedication to the objectives outlined in the Paris Accord on climate change [11], [12]. As part of its commitment, India aims to ensure that up to the end of 2030; at least Forty percent of its entire power generation will derive from renewable energy resources (RER) [15]. Additionally, to further advance its green energy initiatives, the Indian Government has given its approval to the National Green Hydrogen Mission.

In recent decades, artificial intelligence has emerged as essential part of research due to its unlimited optimization capacity to automate systems, leading to enhanced product value and efficiency [6]. Throughout sophisticated training methodologies, ai systems can replicate human learning, reasoning, and decision-making processes. Furthermore, ai's play a vital role in the digital transformation of re systems is acknowledged for its potential to bolster stability of power grid network and also improve the dynamic sensitivity of power grid network, and other significant advancement [7]. Presently, artificial intelligence is increasingly deployed in the different area power grid network system, encompassing devise design [7], prophesy, control, upgrading, protection, and safety measures [8-10]

2. RENEWABLE ENERGY TYPES

This section provides a brief explanation of the methods and techniques used in the literature assessment, Give enough information to clear up any potential misunderstandings regarding the design, treatments, capacity, investigation and Modifications to established methods.

2.1. Solar Energy

Solar energy can be captured through two primary methods: Solar photovoltaic (SPV) and concentrated solar power systems (CSPS). SPV based system directly transform sunlight into electricity by harnessing the photovoltaic effect, wherein photons of light stimulate electrons to generate an electric current. Conversely, CSP systems concentrate solar radiation to produce, which then drives a turbine to generate electricity [17]. Initially employed for space missions, photovoltaic technology has diversified into various everyday applications. These include powering off-grid residences, operating water pumps for irrigation, supporting electric vehicle charging stations, supplying energy to emergency communication systems along roadsides, and enabling remote sensing operations [18].

2.2. Wind Energy

Wind stands as a sustainable, cost-effective, and easily accessible form of renewable energy. Worldwide, wind turbines capture atmospheric energy, converting it into electricity consistently [19]. The significance of wind power in delivering a clean, enduring answer to our energy demands continues to grow. Across centuries, wind has served as a pivotal energy resource, translating its kinetic energy into electricity via windmills and turbines [20].

2.3. Hydroelectric Energy

In Hydroelectric based electrical energy is generated by the flow of water through a dam. The dam's gates can be adjusted to control the flow of water and then regulate the speed of turbine to generate electricity production based on demand. These turbines, in turn, spin generators to produce electricity. The amount of electricity generated is based on the height of the water fall and the amount of water thrust produced through the system. This electricity can then be distributed to different sectors of industries, and businesses via extensive electrical grids. Hydroelectric based power generating system used as a base demand electricity production system, constituting nearly 16% of electricity generated from renewables [20].

2.4. Bio-energy

Bioenergy has emerged as an attractive RER, contributing to both heating and transportation sectors, along with the generation of eco-friendly electricity [21]. It primarily stems from biological materials called biomass, obtained through either traditional or modern means [22]. Traditional bioenergy is derived from agricultural materials like fuel wood, charcoal, crop residues, and animal waste, which are processed for urban use. Conversely, modern bioenergy is utilized in industries to generate heat and electricity, producing biogas, biodiesel, and bio char through various heat exchange methods as in case of carbonization, gasification, fuel ignition, and pyrolysis [23, 25]. Different heat treatments methods used in biomass for bioenergy production, affecting the properties_ of the resulting yield differently [26]. Employing biomass for bio char, bio fuel, and biogas production contributes to improved sanitation, reduced landfill areas, sound waste management practices, and various sustainable development goals [27]. Bioenergy holds significant recognition in international, national, and regional plans, particularly for urban growth, where it may be substantially contribute to progress in urban areas [28].

2.5 Hydrogen Energy

Hydrogen energy plays a pivotal role in energy generation and holds promise as a substitute for fossil fuels, garnering increasing attention as a future energy source. It stands out as a simple and environmentally clean energy option. Currently, hydrogen gas is primarily derived from oil, natural gas, coal, and biomass through processes like gasification and fast pyrolysis [23]. As the world transitions away from fossil fuels towards non-fossil-based energy sources, hydrogen, alongside electricity, is projected to become a dominant energy carrier for meeting end-use demands. In the future, the demand for hydrogen energy is expected to steadily rise, reflecting its growing importance in the global energy landscape

3. ARTIFICIAL INTELLIGENCE IN RENEWABLE ENERGY

Incorporating Artificial Intelligence (AI) into renewable energy systems marks a paradigm shift in energy management and optimization

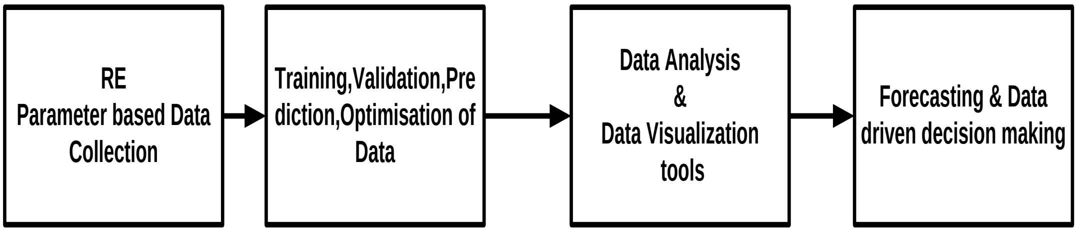

Figure 1. **Procedural Flow Chart for Predicting AI integration with RE's**

3.1. Role of AI to optimized Solar Energy System

In the realm of solar energy systems, the effectiveness of light absorption and conversion holds significant importance. Delve into the advancement of nano array structures for artificial photosynthesis, a concept further refined with the integration of AI. Utilizing machine learning algorithms, the configuration and layout of these nano arrays can be fine-tuned to achieve optimal levels of light absorption and conversion efficiency [29]. AI possesses the capability to scrutinize extensive datasets, identifying intricate patterns and correlations that may elude human researchers, thereby contributing to the enhancement of solar energy systems' efficiency. The incorporation of Artificial Intelligence (AI) into solar energy systems has transformed the methods of harnessing, managing, and utilizing solar power. AI applications in this sector span from optimizing sensor functionality to advancing energy collection and predicting solar energy output. During investigation sensors play a vital role within solar energy systems, underscoring their significance in measuring system parameters and guaranteeing operational success. AI assumes a crucial role in optimizing these sensors, enabling them to adapt to fluctuating environmental conditions and enhance the efficacy of solar power generation [30]. Through the analysis of sensor data, AI algorithms can enact real-time adjustments to the solar system, ensuring peak power output and system dependability. The following parameters are used to estimate by AI-based techniques: (a) tracking change in irradiation for MPP; (b) tracking accurateness for MPP; (c) steady-state fluctuation; (d) algorithm convolution that influences calculation time; and (e) total cost. The accepted AI-based MPP techniques are often classified as FLC, ANN, SI, hybrid, GA, ML, and other newly emerging algorithms [31].

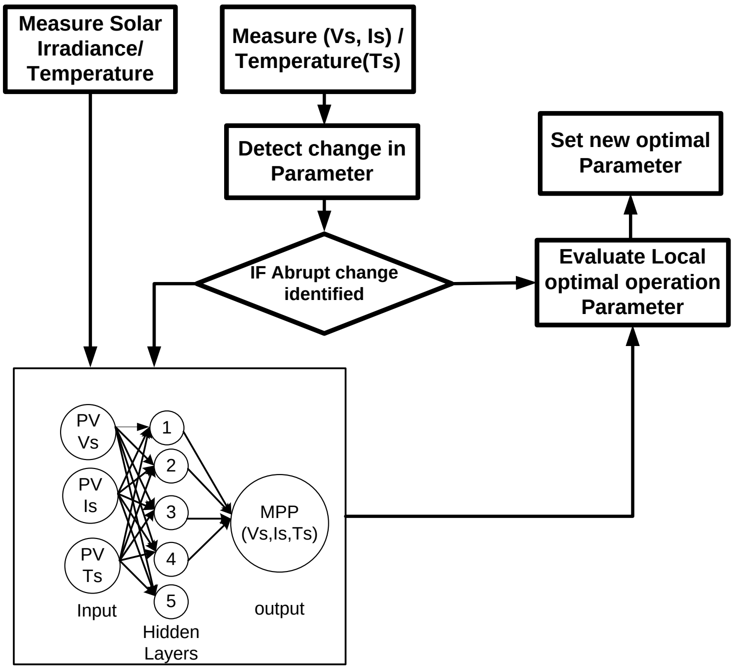

Figure 2. ANN based MPP controlled scheme

3.2Role of AI to optimized Wind Energy System

The incorporation of Artificial Intelligence (AI) in wind energy optimization has ushered in notable progressions, providing inventive solutions to amplify efficiency and performance introduce a pioneering method to optimize the layout design of cables in offshore win farms [31]. Their research unveils an algorithm that merges the Firefly Algorithm with the Minimum Spanning Tree technique, with a particular emphasis on minimizing the overall cable length during the design stage of offshore wind farms. The substantial decrease in mass observed in wind turbine components highlights the promise of AI-driven design methodologies in bolstering the effectiveness and functionality of wind energy systems offer valuable perspectives on the utilization of AI in crafting more efficient and sustainable wind energy technologies [32]. The benefits of AI technology in managing challenging nonlinear WSP/WPP situations are becoming more widely recognized due to its quick development [33]. A diversity of Machine Learning techniques(MLT), such as Support- Vector- Machines (SVM), are included in AIbased data-driven [34], AI-based Extreme Learning Machines (AI-ELM), and other traditional artificial neural networks (ANNs), represented by Back-Propagation-Neural Networks (BPNN) [35], The majority of system frequently used ANN before being entered into the Radial Basis Function (RBF), the data from all levels must first be processed using a data pre-processing model. Next, the outdated wind power forecasting data at that level are produced, together with the comparative forecasting data needed by the improved wind power forecasting model. The tutor-guided learning model, or RBF, will be trained for the parameters such as The direction of wind, wind-speed are the input values of each primitive forecasting data set, while the wind power's generating capacity at is the output value [36]. The propagation function and hidden layer neuron are the two key parameters that determine the RBF.

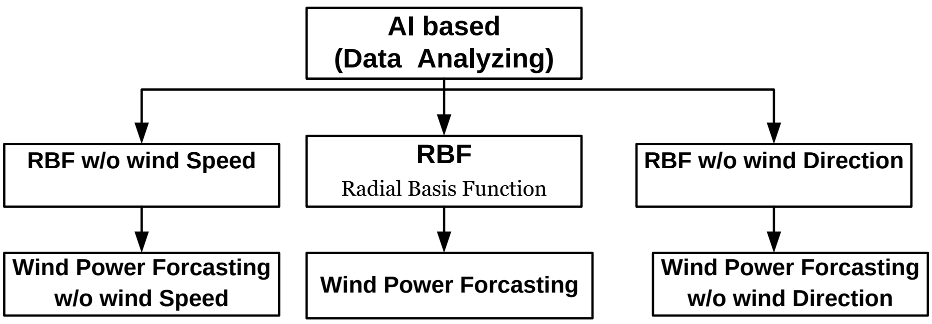

Figure 3. AI (RBF) based wind power forcasting model

3.3 Role of AI to optimized Hydropower System

The integration of AI into hydropower systems marks ground breaking advancement. AI algorithms utilize real-time data analysis, taking into account variables such as weather conditions, water flow rates, and electricity demand to make dynamic decisions aimed at optimizing energy production. To determine the plant capacity, precise discharge and head estimations are crucial. The main obstacles in the production of hydropower energy are erosion, cavitation, and operation & maintenance. Artificial Intelligence (AI) has gained popularity as a tool for optimizing operations and maintenance, evaluating parameters, and choosing sites. This paper presents a survey of the literature on artificial intelligence applications in hydropower and attempts to pinpoint future prospective locations for hydropower facilities [37]. This review article offers a detailed summary of artificial intelligence and machine learning applications for scheduling, optimization, and prediction in the hydroelectric power sector [38].

3.4 Role of AI to optimized Hydrogen System

Recent research has found an AI technique that accelerates the identification of materials possessing desired attributes. Leveraging this breakthrough, the team successfully unearthed water electrolyzer electrode materials boasting exceptional performance without relying on platinum-group elements, previously deemed essential for such applications. These novel materials hold the potential to slash costs associated with the widespread manufacture of green hydrogen, heralding a promising era for next-generation energy sources. Energy conversion efficiency of above 60% and the hydrogen fuel cell can produce zero greenhouse gas emissions. The only waste that is released is water. It assists in understanding and resolving issues related to global warming, the general energy crises across many countries, and environmental. The globe is very concerned about pollution and how it is created and used [39].

Table1. Review of different AI based topology applied to different renewable energy system

References	Topology	Description	Realization
Lalot [34]	ANN/RBF	An Artificial Neural Network (ANN) employing a Radial_Basis Function (RBF) utilized to discern the sequential attributes of solar power collectors.	For a single parameter, the recommended network detected a variance of 2%.
Veerachary and Yadaiah [35]	ANN	An Artificial Neural Network was employed to resolve the optimal working instant for a Solar PV system.	Regarding impulse/ Sump pump loads, the ANN prediction yielded errors of under 2% and 7%, respectively.
Senjyu et al, [36]	GA (Genetic Algorithm)	Utilization of GA was a best possible arrangement for Power production in isolated islands with renewable energy resource (RER) was developed (GA).	Compared to relying solely on diesel generators, this proposed method can reduce operational expenses by approximately 10%.
Dufo-Lopez et al.[37]	Hybrid optimization Genetic Algorithms	Hybrid Optimization GA was developed as a tool for designing a SPV+DG system, encompassing sizing and Automotive operational control through a genetic algorithm (GA).	The economic advantages of the PV-hybrid system are substantiated by computational results.
Mabel and Fernandez [38]	Feed-forward-Back-Propagation Neural-Network (BPNN)	A B.P.N.N is employed to assess wind power across several wind farms over a 3year time.	The BPNN demonstrates commendable prediction accuracy, with RMSE values of 0.0070 for the instruction-set and 0.0065 for the test-set.
Kariniotakis et al.[39]	Advanced version of ANN	To estimate wind power, an enhanced version of ANN was deployed.	When compared to N.B, the ANN exhibits the lowest R.M.S.E.
Damousis and Dokopoulos [40]	Fuzzy-logic topology along with two GA algorithms	To estimate wind-speed and power, fuzzy-logic approaches were developed along with two GA algorithms, which include Real-coded GA and Binary-coded GA.	The fuzzy-logic topology surpasses the resolution by 29.7% and 39.8% for next-hour and also provides long-term predictions, respectively.
Mashohor et al.[41]	Genetic-Algorithm (GA)	The use of (GA) in solar PV tracking system is used to enhance the performance and output power of Solar PV systems.	The system's effectiveness is further illustrated with least standard deviation about (1.55) in power generation system.
Atia et al.[43]	Genetic-Algorithm (GA)	Genetic Algorithm (GA) is employed to design a Solar concentrator based water heating system and optimized for maximum efficiency.	By setting the GA to 63 m, enhancements have been increase the plate solar capture region, achieving more solar fraction value of 98 %.

O'Sullivan et al.[42]	Particle swarm optimization (PSO)	Particle Swarm Optimization (PSO) is utilizing to make fine-tune the dimensions of a Hybrid Renewable Energy system (HRES).	It was expected to enhance its cost-effectiveness of HRES.

Table 2. Initialization and integration of AI into different renewable energy system

Renewable Energy Source	**Application of AI**
Solar Energy	- Optimization of solar panel orientation and tracking systems. - Predictive maintenance to enhance the lifespan of solar panels. - Forecasting solar irradiance for better energy production estimation. - Intelligent energy management systems for grid integration.
Wind Energy	- Optimization of turbine placement and design to maximize energy production. - Predictive maintenance to minimize downtime and repair costs. - Advanced control systems for optimal turbine operation. - Machine learning algorithms for wind speed forecasting.
Hydroelectric Energy	- Optimization of water flow management for increased efficiency. - Predictive maintenance of turbines and generators. - Intelligent scheduling of power generation to match demand fluctuations. - Analysis of environmental factors for sustainable water resource management.
Biomass Energy	- Optimization of biomass feedstock selection and processing. - Predictive maintenance of biomass conversion equipment. - Intelligent control systems for biomass combustion and gasification. - Analysis of feedstock availability and market trends for efficient resource utilization.
Hydrogen Energy	- Optimization of Hydrogen reservoir management for enhanced energy extraction. - Predictive maintenance of Hydrogen power plants. - Intelligent control systems for Hydrogen extraction and power generation. - Machine learning algorithms for reservoir characterization and performance prediction.

Hence, the evolving directions in AI for renewable energy denote substantial progressions in forecasting, application development, and risk management. These trends highlight the escalating significance of AI in augmenting the efficiency, dependability, and sustainability of renewable energy systems. As the sector progresses, AI is anticipated to assume an increasingly pivotal role in confronting challenges and unlocking the complete potential of renewable energy sources

4. CHALLENGES

Notwithstanding these progressions, the incorporation of AI in renewable energy encounters hurdles such as data quality and accessibility, algorithmic intricacy, and the necessity for interdisciplinary proficiency. Future investigations ought to concentrate on crafting more resilient AI models capable of managing incomplete or noisy data, along with algorithms adaptable to the swiftly evolving realm of renewable energy technologies.
Although the application of AI in energy systems has led to significant advancements in identifying problems and defects, it still struggles to meet the demands of the application. Presently, AI is primarily employed to augment existing operational practices. There is a need for infrastructure enhancement to fully leverage AI capabilities. Utilizing AI necessitates abundant data samples, robust computing resources, and interconnected global networks. Big data, in particular, plays a critical role in infrastructure; hence its magnitude and supporting capacity must be carefully considered.

5. CONCLUSIONS

Artificial Intelligence (AI) has materialized as a critical mechanism in the renewable energy sector. AI plays a pivotal role in advancing predictive maintenance, optimizing energy production, and seamlessly integrating renewable sources into the power grid. Utilizing advanced machine learning and deep learning techniques, AI effectively manages vast datasets and intricate parameters, resulting in enhanced efficiency and reliability of renewable energy systems. The integration of AI has not only bolstered operational efficiency but also paved the way for innovative strategies in energy management and distribution.

Integrating AI with renewable energy sources presents a complex endeavor, given the diverse range of applications and variables at play. Nonetheless, its integration promises substantial efficiency enhancements across various domains. Below is a summary of potential efficiency improvements resulting from AI integration in renewable energy, accompanied by estimated percentage increases where possible?

Table3. Estimated impact of integration of AI in RE's in key area

Area	**Methods**	**Impact**
Energy Forecasting	AI-driven forecasting algorithms can improve accuracy by up to 10-20%	better resource allocation and grid management
Energy Production Optimization	Predictive maintenance and optimization algorithms can increase energy production efficiency by up to 5-15%	Improved asset management and performance optimization.
Grid Stability and Management	AI-based grid management systems can enhance stability and efficiency, leading to up to 5-10% reduction in energy losses	Improved grid reliability.
Cost Reduction	Predictive maintenance and optimization can reduce maintenance costs by up to 10-30% and decrease downtime by up to 20-40%	Overall cost reductions.
Energy Storage Optimization	AI-driven optimization of energy storage systems can increase efficiency by up to 5-15% through improved charge-discharge management	Better utilization of storage assets.
Integration with Smart Grids	Integration with AI-enabled smart grids can lead to up to 5-10% improvement in overall grid efficiency.	Dem and response optimization and real-time energy management.
Remote Monitoring and Control	Remote monitoring and control systems powered by AI through remote diagnostics, predictive maintenance, and reduced travel requirements.	Reduce operational costs by up to 10-20%
Environmental Assessment	AI-based assessments can optimize site selection and reduce ecological impact.	Up to 5-10% improvement in environmental sustainability.
Technological Innovation	AI-driven technological innovation can lead to advancements in renewable energy technologies, materials, and processes,	Long-term efficiency gains that are difficult to quantify but significant over time.

Future research endeavors in AI-driven renewable energy solutions should prioritize tackling the challenges associated with AI integration, including economic limitations, complexities in grid integration, and the demand for advanced IOT infrastructure. Explorations into pioneering AI algorithms aimed at enhancing energy efficiency and facilitating the integration of AI within renewable energy grids will be pivotal areas of concentration. Additionally, research efforts should seek to comprehend the socio-economic ramifications of AI integration in renewable energy and formulate strategies to mitigate any adverse effects. The continual progression of AI technologies presents an opportunity for groundbreaking research that can further revolutionize the renewable energy sector. AI's transformative role in renewable energy offers abundant opportunities for optimization, innovation, and fostering sustainable development. The future trajectory of renewable energy hinges on advancements in AI, underscoring the necessity for a collaborative and forward-thinking approach from all stakeholders involved.

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