

The Role of Artificial Intelligence in Driving Renewable Energy Transition from the Current Landscape to Future Pathways

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Introduction

The transition to renewable energy is critical for addressing climate change and achieving sustainable development, and artificial intelligence (AI) is increasingly recognized as a transformative enabler in this process. AI enhances renewable energy deployment by improving forecasting, optimizing grid management, and enabling intelligent control of energy systems, which helps integrate intermittent sources like solar and wind more effectively. It also supports innovations in energy storage, demand-side management, and cybersecurity, contributing to more resilient and efficient energy infrastructures. Despite its potential, challenges such as data quality, system interoperability, scalability, and ethical concerns remain significant barriers to fully leveraging AI in the renewable energy transition. Moreover, the impact of AI varies over time and regions; while it can accelerate renewable adoption in the long term, short-term integration difficulties and economic factors may limit immediate benefits. Future pathways involve advancing AI techniques like explainable AI and lightweight models to reduce computational footprints while fostering policy support that aligns AI development with renewable energy goals for a sustainable, low-carbon future.



Energy Storage

- State-of-health estimation
- Charge–discharge optimization
- Degradation modeling
- Safety monitoring



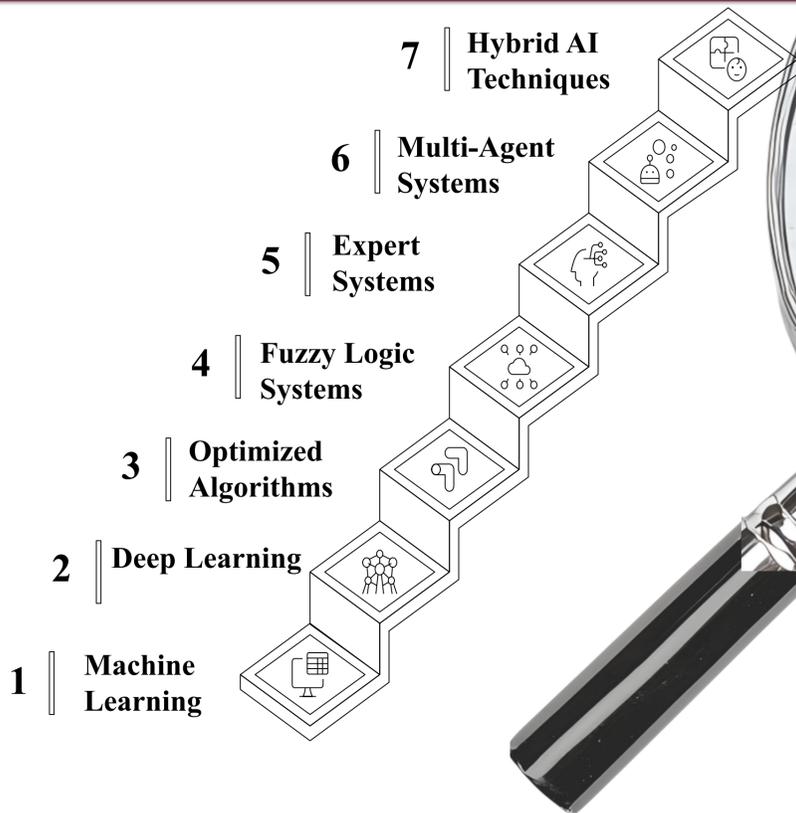
Hydropower Energy

- Inflow and runoff forecasting
- Reservoir operation optimization
- Turbine anomaly detection
- Multi-objective water management

Smart Grids

- Load forecasting
- Real-time balancing and dispatch
- Fault detection and isolation
- Market participation optimization

AI techniques in Energy Systems



AI in Operation and Integration

AI plays a crucial role in enhancing power system operation, stability, and grid integration, especially as renewable energy sources become more prevalent. AI technologies improve real-time monitoring, fault detection, and control, strategies, enabling more resilient and optimized grid management that can handle the variability and decentralization of the responsibility. ML and DL techniques enhance load forecasting, voltage stability assessment, and predictive maintenance, which are essential for maintaining grid reliability and preventing blackouts.

Climate and Sustainability Impact

AI-Enabled Support	Sustainability Dimensions	Long-Term Sustainability Outcomes
Data-driven decision support	Energy efficiency	Reduced environmental footprint
Adaptive learning and control	Resource efficiency	Lower greenhouse gas emissions
Early risk and anomaly detection	Emissions reduction	Emissions reduction
Early risk and anomaly detection	Emissions reduction	Extended infrastructure lifetime

Climate prediction,
 Optimizes renewable energy,
 Reduces energy consumption and emissions,
 Enables smart grids,
 Detects deforestation and land changes,
 Tracks carbon emissions, and
 Enhances disaster early warnings.

AI Applications Across Renewable Energy



Solar Energy

- Power output forecasting
- Fault detection via computer vision
- Tracker angle optimization
- Predictive maintenance

Wind Energy

- Wind and power forecasting
- Turbine condition monitoring
- Wake interaction optimization
- Load management



CONCLUSION

AI is a transformative catalyst in accelerating the renewable energy transition by enhancing system efficiency, stability, and integration across the energy sector. AI improves forecasting, optimizes grid operations, and supports large-scale renewable integration, which are essential for managing the variability of renewable sources like solar, wind, geothermal and others.

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