

Toward 2035: Renewable Energy Innovations Transforming Our Future

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Abstract

This paper explores the transformative role of renewable energy innovations in addressing global challenges such as climate change and energy security. By 2035, significant milestones are expected to be achieved through targeted policies and technological advancements. Key innovations in solar technology, wind energy, bioenergy, and energy storage are discussed, along with the role of digitalization and AI in optimizing renewable energy systems. The paper also highlights global and regional efforts, including Malaysia's National Energy Transition Roadmap (NETR), and addresses challenges such as intermittency, high costs, and material safety. The conclusion emphasizes the importance of strategic investments and collaboration to ensure a sustainable energy future.

Keywords: renewable energy, solar technology, wind energy, bioenergy, energy storage, AI, Malaysia, NETR

1. Introduction

Renewable energy has become a cornerstone in the global effort to combat climate change and ensure energy security. As the world faces increasing environmental challenges, the transition to renewable energy sources is no longer optional but imperative. By 2035, significant milestones are expected to be achieved through targeted policies and technological innovations. This paper aims to provide a comprehensive overview of the key innovations in renewable energy, the role of digitalization and artificial intelligence (AI), and the global and regional efforts driving this transformation. Additionally, the paper will address the challenges that need to be overcome to ensure a seamless transition to renewable energy.

The urgency of this transition is underscored by global agreements such as the Paris Agreement (2016), which aims to limit global warming to below 1.5°C. Countries around the world are setting ambitious targets to increase the share of renewable energy in their energy mix. For example, the United States aims to achieve a carbon-free power sector by 2035, while China plans to expand renewable energy to account for 50% of its total power generation by the same year. In Southeast Asia, Malaysia has developed the National Energy Transition Roadmap (NETR) to decarbonize its electricity sector and promote renewable energy adoption.. Fig. 1 illustrates the Global Average Temperature from 1850 to 2023.

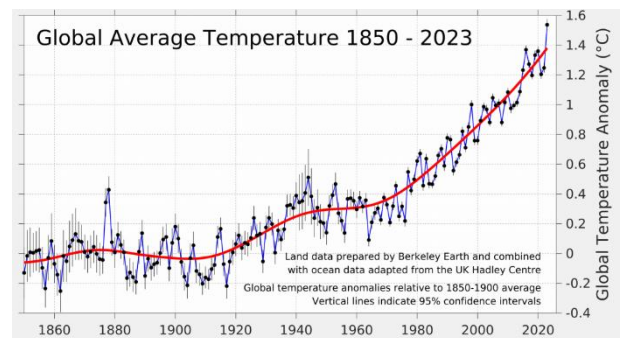


Fig.1 Global Average Temperature.

2. Key Innovations in Renewable Energy

2.1. Solar Technology

Solar energy continues to be one of the most promising renewable energy sources, with significant advancements in technology driving its adoption. One of the most notable innovations in recent years is the development of perovskite solar cells. These cells have shown higher efficiency (+8%) compared to conventional silicon-based solar cells, making them a game-changer in the solar industry. The world's first perovskite solar cell factory was established in Wroclaw, Poland, in 2021, marking a significant milestone in the commercialization of this technology. However, challenges remain in terms of stability, cost, and scalability, which need to be addressed before perovskite solar cells can be widely adopted [1]. Perovskite solar cells – higher efficiency (+8%) is shown in Fig. 2.

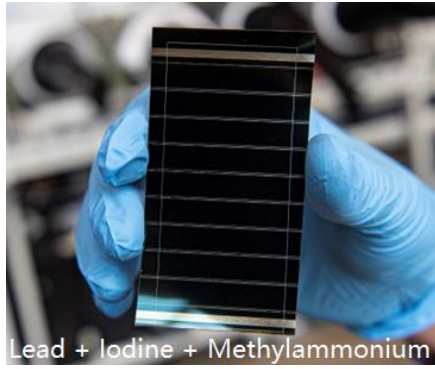


Fig.2 Perovskite solar cells.

Another promising innovation in solar technology is spectral splitting concentrated solar power (CSP) as shown in Fig.3. This hybrid technology combines CSP and photovoltaic (PV) systems to optimize electricity generation by splitting the solar spectrum. By doing so, it achieves a 10% increase in power output compared to conventional CSP systems. While still in the experimental stages, ongoing research is focused on improving the economic viability of this technology [2].

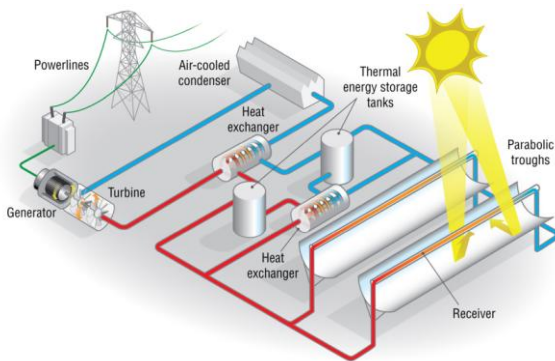


Fig. 3 Spectral splitting CSP.

2.2. Wind Energy

Wind energy has also seen significant advancements, particularly in turbine technology. The development of larger and more efficient wind turbines has dramatically increased energy generation capacity. For instance, the MySE 22 MW turbine, developed by MingYang Wind Power in China, features a rotor diameter of 310 meters, making it one of the largest and most powerful wind turbines in the world. This breakthrough in turbine technology has the potential to significantly reduce the cost of wind energy and increase its competitiveness with traditional energy sources [3].

2.3. Next-Generation Bioenergy

Bioenergy, particularly algae biofuels, is emerging as a promising alternative for sustainable energy production. Algae biofuels are derived from microalgae, which can be cultivated in large quantities and have a high lipid

content, making them an excellent source of biofuel. While still in the research and development phase, pilot projects have demonstrated the feasibility of small-scale production. However, challenges such as high production costs and the need for large-scale cultivation facilities remain barriers to widespread adoption [4].

2.4. Energy Storage

Energy storage is a critical component of renewable energy systems, addressing the intermittency issues associated with solar and wind energy. Smart grid technologies have emerged as a key innovation in this area, facilitating communication between energy suppliers and consumers. These technologies integrate renewable energy sources through automation, sensors, and predictive analytics, enabling more efficient energy management. For example, Malaysia has implemented smart grid systems that integrate solar farms, electric vehicle (EV) charging stations, and battery storage systems, creating a more resilient and flexible energy grid [5].

3. The Role of Digitalization and AI

3.1. Applications of AI in Renewable Energy

Artificial intelligence (AI) is playing an increasingly important role in optimizing renewable energy systems. AI enhances the efficiency, reliability, and economic viability of renewable energy by improving resource assessment, energy forecasting, and system monitoring. Machine learning algorithms, deep learning techniques, and optimization methodologies are being used to predict energy generation patterns, optimize grid operations, and reduce maintenance costs. For example, AI-powered predictive maintenance systems can identify potential failures in wind turbines or solar panels before they occur, reducing downtime and improving overall system performance [6].

3.2. Status of AI Initiatives

Several AI initiatives are already underway in the renewable energy sector. In Malaysia, Tenaga Nasional Berhad (TNB) has implemented AI-driven technologies such as Digital Twin and IoT sensors for predictive maintenance and real-time analytics. These technologies enable TNB to monitor the condition of transformers and transmission lines more effectively, reducing the risk of power outages and improving grid reliability. Additionally, hyperscale data centers, such as the AirTrunk JHB1 in Johor Bahru, are utilizing renewable energy and advanced AI systems to optimize their operations, further demonstrating the potential of AI in the renewable energy sector [7]. Asset Performance Management System is shown Fig.4.

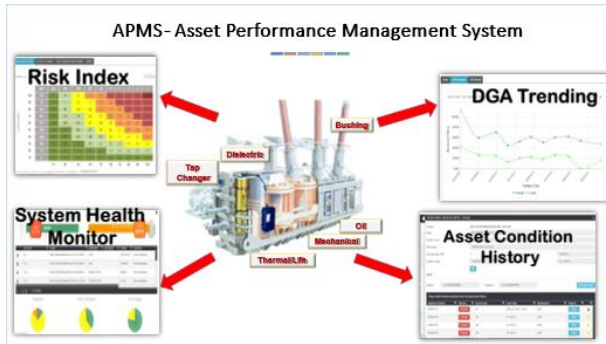


Fig. 4 Asset Performance Management System.

4. Renewable Energy Policies and Roadmap

4.1. Global Efforts

Global efforts to promote renewable energy are being driven by international agreements and national policies. The Paris Agreement (2016), signed by over 194 countries, aims to limit global warming to below 1.5°C by reducing greenhouse gas emissions. In Europe, the EU's REPowerEU Plan (2022) seeks to phase out Russian fossil fuels and accelerate the adoption of renewable energy. Similarly, China's 14th Five-Year Plan targets a 50% increase in renewable energy generation by 2025, reflecting the country's commitment to transitioning to a low-carbon economy [8].

4.2 Malaysia's National Energy Transition Roadmap (NETR)

Malaysia has developed the National Energy Transition Roadmap (NETR) to decarbonize its electricity sector and promote renewable energy adoption. The roadmap includes several flagship projects, such as the Hybrid Hydro Floating Solar (HHFS) initiative, which combines hydropower with floating solar panels. Feasibility studies for the first phase of this project have been completed, with operations planned to begin between 2025 and 2040. Additionally, Malaysia is developing large-scale solar parks with a combined capacity of 500 MW, in collaboration with local SMEs. Another key initiative is the green hydrogen and ammonia co-firing project, which aims to decarbonize power plants by using hydrogen and ammonia as alternative fuels. Feasibility studies for this project have been completed for key facilities such as the Jimah East Power plant [9].

5. Challenges and Limitations

Despite the significant progress in renewable energy, several challenges remain. One of the most pressing issues is the intermittency of renewable energy sources such as solar and wind, which are dependent on weather conditions. This intermittency affects the reliability of renewable energy systems and necessitates the

development of advanced energy storage solutions. Additionally, geographic limitations restrict the feasibility of certain renewable technologies in regions with limited solar or wind resources.

High costs also pose a significant barrier to the widespread adoption of renewable energy. The initial investment required for renewable energy infrastructure, such as solar panels and wind turbines, remains substantial, particularly in developing countries. Furthermore, policy and collaboration gaps hinder the development of innovative solutions, as effective collaboration between policymakers, industries, and researchers is essential for driving progress in the renewable energy sector.

Finally, material safety concerns associated with certain renewable technologies, such as the use of toxic materials like lead in perovskite solar cells, pose environmental risks. Addressing these challenges will require continued research and development, as well as the implementation of robust safety regulations [10].

6. Success Stories

Several success stories highlight the potential of renewable energy to transform the global energy landscape. One notable example is the @DisCo Software, developed to enhance cybersecurity for energy utilities. Funded by the US Department of Energy (DOE) with a \$4.5 million grant, this software uses machine learning to identify vulnerabilities in devices such as solar inverters, reducing detection time from months to hours. The software won the 2023 R&D World Award, underscoring its potential to improve the security and reliability of renewable energy systems (US Department of Energy, 2023).

In Malaysia, the 2010 National Renewable Energy Policy set a target of achieving 20% renewable energy in the energy mix by 2025. By 2023, Malaysia had already surpassed this goal, achieving a 25% renewable energy mix. This success is attributed to the implementation of large-scale solar projects, the adoption of smart grid technologies, and the development of innovative solutions such as hybrid hydro floating solar systems (Malaysia Ministry of Energy and Natural Resources, 2023).

7. Conclusion

The global shift toward renewable energy is not just essential for sustainability but also vital for energy security. Innovations in technology, supported by proactive policies and collaboration, are paving the way for significant milestones by 2035. However, addressing challenges such as intermittency, high costs, and material safety is crucial to ensure a seamless transition. With strategic investments and advancements in AI, renewable energy systems can achieve optimal efficiency and reliability, securing a sustainable future for generations to come.

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Author Introduction

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He is an Associate Professor at Universiti Tenaga Nasional (UNITEN), Malaysia, specializing in renewable energy and sustainable technologies. With a strong academic background and extensive research experience, Dr. Ismail has contributed significantly to the field of renewable energy, particularly in solar technology, wind energy, and bioenergy. His work focuses on advancing innovative solutions to address global challenges such as climate change and energy security. Dr. Ismail has been actively involved in various national and international projects, including Malaysia's National Energy Transition Roadmap (NETR), where he has played a key role in promoting renewable energy adoption and decarbonization strategies. He is also a sought-after speaker at international conferences, sharing insights on the latest advancements in renewable energy technologies and policies. In addition to his research and teaching responsibilities, Dr. Ismail is committed to fostering collaboration between academia, industry, and policymakers to drive the global transition toward a sustainable energy future.
