

Advances in Renewable Energy Research and Applications

Sharul Sham Dol ^{1,*} , Anang Hudaya Muhamad Amin ²  and Hasan Hamdan ¹

¹ Department of Mechanical and Industrial Engineering, Abu Dhabi University, Abu Dhabi P.O. Box 59911, United Arab Emirates; 1065775@alumni.adu.ac.ae

² Faculty of Computer Information Science, Higher Colleges of Technology, Dubai P.O. Box 15825, United Arab Emirates; aamin@hct.ac.ae

* Correspondence: sharulshambin.dol@adu.ac.ae

1. Introduction

Renewable energy has emerged as a critical focus area for addressing the dual challenges of growing electricity demand and environmental sustainability. Traditional reliance on fossil fuels has been a significant contributor to greenhouse gas emissions, which in turn drive climate change and environmental degradation. In response, renewable energy sources, such as solar, wind, tidal, and hydrogen, are increasingly being developed as viable alternatives that can reduce carbon footprints, diversify energy supply, and contribute to a cleaner and more sustainable future.

The development of these renewable energy solutions involves a multi-faceted approach, encompassing economic, technological, and policy-related challenges [1]. Solar power remains one of the most widely adopted renewable technologies, while wind energy, despite facing some challenges, continues to be a competitive energy source [2]. Additionally, there is growing potential in offshore renewable energy, including tidal and wave energy, as well as emerging technologies like vortex-induced vibrations (VIV) that offer new methods of energy harvesting [3]. Artificial intelligence (AI) and machine learning (ML) have also begun to play a significant role in optimizing renewable energy systems by improving forecasting accuracy and operational efficiency, thus enhancing overall adaptability and reliability [4]. In recognition of the need for comprehensive solutions to these pressing energy challenges, this Special Issue (SI) of *Energies*—titled “Advances in Renewable Energy Research and Applications”—brings together diverse contributions from researchers addressing a wide range of topics. This SI aims to introduce the most recent advancements in renewable energy technologies, present economic evaluations, explore technological innovations, and discuss strategic management practices that facilitate renewable energy integration. By gathering a collection of 12 high-impact research papers, the SI aims to provide insights into how renewable energy systems can be advanced and optimized to meet the demands of a sustainable future.

2. Key Contributions from the Special Issue

The Special Issue offers a wide array of contributions, grouped under several main themes that reflect the diversity and innovation present within renewable energy research. Below, we provide an overview of some of the key contributions within these thematic areas.

2.1. Economic Considerations and Management of Renewable Systems

Economic analysis plays a fundamental role in evaluating the viability of renewable energy systems, particularly when considering large-scale adoption. Several papers in this SI focused on understanding the economic feasibility and strategic management of renewable energy production. One paper presented a multi-stage game model to assess investment and production strategies under renewable energy quotas and green certificate systems, revealing how market mechanisms can influence investment levels and profitability for energy suppliers. This approach offers insights into the delicate balance required to



Citation: Dol, S.S.; Muhamad Amin, A.H.; Hamdan, H. Advances in Renewable Energy Research and Applications. *Energies* **2024**, *17*, 6198. <https://doi.org/10.3390/en17236198>

Received: 21 November 2024

Accepted: 5 December 2024

Published: 9 December 2024



Copyright: © 2024 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

incentivize both traditional and new energy suppliers, thus fostering a smoother transition to renewable energy [5].

Another key study explored the transition to a hydrogen energy system in the UAE, assessing sectoral efficiency to determine which industries would benefit most from early adoption of hydrogen as an energy carrier. The findings suggest that hydrogen has immense potential for decarbonizing sectors like transportation and industry, provided that appropriate investments are made to scale production and infrastructure [6]. The importance of economic principles in renewable energy extends beyond initial investments; it also involves managing operational costs and ensuring long-term profitability. One of the studies highlighted in this SI provides an in-depth analysis of how renewable energy projects can balance profitability with sustainability by using strategic energy pricing and green certificates. This approach not only improves the market attractiveness of renewable energy but also fosters a competitive landscape where traditional and renewable energy suppliers can coexist [7].

2.2. Technological Innovations in Renewable Systems

The Special Issue features significant contributions that explore the technological advancements in renewable energy systems, including photovoltaic–thermal desalination, vortex generators for wind turbines, and the use of leading-edge tubercles. One noteworthy paper presented an integrated photovoltaic–thermal (PV-T) membrane desalination system, which aims to address the energy–water nexus by utilizing solar energy for both power generation and water desalination. The results showed substantial energy savings and demonstrated the feasibility of such integrated systems in arid regions [8]. Moreover, a study investigated the use of advanced thermal transport systems in solar power tower plants. By modeling the dynamic thermal characteristics, researchers provided insights into how real-time adjustments could enhance the efficiency of solar power generation. This contribution is particularly relevant for improving the scalability of solar energy in regions with fluctuating solar irradiance levels [9].

A further notable contribution of this SI involves the integration of photothermal and photovoltaic systems to improve the thermal environment in Chinese solar greenhouses. This paper provides a comprehensive review of existing systems that utilize both photothermal and photovoltaic mechanisms to regulate internal temperatures while generating renewable electricity. The integration of these technologies not only enhances the microclimate for crop production but also contributes to the energy self-sufficiency of the greenhouses. Such hybrid applications represent a promising approach to agricultural sustainability, particularly in regions where energy-intensive greenhouse farming is prevalent [10]. Technological innovations in renewable systems are key drivers for improving efficiency and reliability. For instance, another paper in the SI examined the use of vortex generators on wind turbine blades to enhance aerodynamic performance. These vortex generators, inspired by natural phenomena, help delay flow separation, thereby improving the overall efficiency of the wind turbine. Such modifications are particularly important for small wind turbines, which are often used in decentralized and rural energy applications [11].

Another contribution examined the impact of leading-edge tubercles inspired by humpback whales on the performance of small-scale horizontal-axis wind turbines (HAWTs). The study found that small-amplitude tubercles could enhance power output and aerodynamic stability, especially under low wind speed conditions. This innovative passive flow control technique has the potential to improve the efficiency of small wind turbines, which are vital for decentralized energy production in rural areas [12]. One of the papers in this SI explores innovative approaches to biological hydrogen energy production using novel strains of *Bacillus paramycoides* and *Cereibacter azotoformans* through both dark and photo fermentation processes. This research aims to diversify the methods of hydrogen production beyond conventional electrolysis and steam methane reforming, focusing on biological methods as a more sustainable and potentially cost-effective alternative. The

findings demonstrate the feasibility of these microbial processes for producing hydrogen, which can play a critical role in reducing the carbon footprint associated with hydrogen production and integrating it as a mainstream renewable energy carrier [13]. The impact of this study is evident as it provides foundational insights into using biological organisms for scalable hydrogen production, particularly in regions with limited access to conventional energy infrastructure [14]. Another significant contribution to this SI is the evaluation of communication infrastructure for peer-to-peer (P2P) energy trading in community microgrids. The study evaluates the effectiveness of different communication strategies in enabling decentralized energy trading among prosumers. This P2P model has the potential to enhance the efficiency of local energy consumption, reduce transmission losses, and increase the adoption of renewable energy at the community level. By using simulation and real-world implementation, the study demonstrates that robust communication protocols are crucial to ensuring reliable energy exchange, which could make microgrids more self-sufficient and resilient [15].

3. Key Findings

3.1. Technological Advances and Efficiency Improvements

The Special Issue includes several notable contributions that have advanced the efficiency and reliability of renewable energy systems. Technological advancements are at the heart of renewable energy research, with efforts focusing on both enhancing the existing infrastructure and developing new, innovative solutions.

A standout contribution involved hybrid renewable energy systems (HRES), which are gaining popularity due to their ability to mitigate the intermittency challenges associated with renewable energy sources. By combining solar, wind, and other renewable sources, HRES can provide a more stable and reliable energy supply. In the paper featuring recurrent neural networks (RNNs) for weather forecasting, the authors explored how the application of advanced machine learning techniques could optimize the design of HRES by predicting solar irradiance and wind speed more accurately. This optimization reduced both the loss of load probability (LOLP) and the overall system costs, emphasizing the potential of AI to revolutionize renewable energy systems [16]. Another contribution presented a dynamic thermal transport model for a solar power tower plant. This model simulated the thermal dynamics of a molten salt receiver, offering insights into how real-time adjustments could optimize energy capture and reduce energy loss. The study emphasized that the ability to predict and manage thermal transport in real-time is crucial for improving the efficiency of solar power plants, especially in regions with fluctuating solar irradiance. This finding has implications for the broader deployment of solar power, particularly in developing regions where optimizing energy efficiency can be the key to economic viability [9]. In addition, the integration of energy storage supercapacitors (ESS) and braking resistors in wind turbine systems marked another significant technological advancement. One of the primary challenges with renewable energy is the ability to manage power fluctuations and ensure consistent energy output. The proposed integration of ESS and braking resistors aimed to enhance the fault ride-through (FRT) capabilities of wind turbine systems, thereby improving grid stability during fluctuations. This study not only addressed a key technical challenge but also offered a cost-effective solution by reducing the need for extensive energy storage infrastructure [17].

Technological advancements were also highlighted in small-scale horizontal-axis wind turbines (HAWTs), where researchers used leading-edge tubercles to mimic the adaptive flow control observed in humpback whale flippers. The implementation of this nature-inspired design resulted in enhanced power output, particularly at low wind speeds, making these small-scale turbines more efficient and suitable for rural or off-grid applications. Such improvements in HAWT efficiency are vital for extending renewable energy benefits to communities that do not have access to centralized power grids [12].

3.2. AI Integration for Optimization and Forecasting

The integration of artificial intelligence (AI) and machine learning (ML) techniques has been a game changer for the renewable energy sector, and this SI includes several papers that showcase how these advanced tools can optimize energy production, reduce operational costs, and improve system resilience. One of the key applications of AI in renewable energy lies in resource forecasting, which is critical for managing energy generation, especially given the intermittent nature of renewable energy sources like wind and solar.

In a notable study from the SI, the Prophet forecasting model was used to predict solar and wind energy availability in Far North Queensland, Australia. The accuracy of this model, compared to traditional methods such as Seasonal Auto-Regressive Integrated Moving Average (SARIMA), demonstrated the value of using advanced forecasting techniques for better energy management. Accurate resource forecasting is essential for ensuring that renewable energy systems can meet demand without excessive reliance on backup power sources. This work underscores the importance of incorporating machine learning models into renewable energy forecasting to enhance grid reliability and reduce costs [18]. Another paper delved into the use of long short-term memory (LSTM) networks—a type of RNN well-suited for time series prediction. The study applied LSTMs to forecast wind speeds, allowing for more precise scheduling of energy production and storage. The improved accuracy of these forecasts reduced the operational costs of hybrid systems by optimizing energy storage and reducing dependence on auxiliary diesel generators. This has significant implications for the scalability of hybrid renewable systems, particularly in regions where energy storage remains a costly and limiting factor [16]. Moreover, leveraging AI optimizes energy consumption patterns. By integrating ML algorithms into energy management systems, researchers were able to predict energy consumption more effectively and adjust renewable energy input accordingly. This predictive capability ensures that the generated energy is used efficiently, minimizing waste, and reducing the need for non-renewable energy supplements. The ability to dynamically manage energy consumption and generation through AI is a promising development for achieving a truly smart and sustainable energy grid [19].

3.3. Policy and Strategic Insights

The successful deployment of renewable energy systems relies not only on technological advancements but also on supportive policy frameworks and strategic initiatives. Several papers in the SI provide a comprehensive examination of the policy tools and strategic frameworks necessary to foster the growth of renewable energy adoption globally.

One of the key studies analyzed how renewable energy quotas and green certificates impact energy suppliers' strategies. This analysis showed that well-designed policy instruments could incentivize both traditional and renewable energy suppliers to increase their renewable energy investments. For example, renewable quotas obligate energy producers to ensure that a specific percentage of their energy comes from renewable sources, while green certificates create a financial incentive for exceeding these quotas. The study highlighted how such instruments can foster a competitive yet collaborative environment conducive to expanding renewable energy capacity while maintaining market stability [6].

4. Gaps and Future Directions

Despite the significant advancements highlighted in this Special Issue, several gaps remain unaddressed, presenting opportunities for future research. One notable area that requires further exploration is the scalability of hybrid renewable systems for diverse environmental contexts. While many studies focused on the technical and economic feasibility of renewable energy systems, there is still a need to investigate how these technologies can be scaled up efficiently to meet the demands of different regions, particularly in developing countries [20].

Another gap involves the integration of underrepresented energy sources, such as geothermal and tidal energy, which were mentioned as potential areas of interest but were not extensively covered by the contributions in this SI. Future research should delve into these energy sources and their integration into existing renewable systems, particularly considering their unique advantages and regional availability [21,22]. Furthermore, there is an evident need for more studies focusing on the social and economic impacts of renewable energy systems. Many of the contributions to this SI have concentrated on the technical aspects of renewable energy technologies; however, the socio-economic factors that drive or hinder adoption remain underexplored. Understanding the social acceptance of renewable technologies, the implications for job creation, and the overall economic impact will be crucial for the sustainable growth of renewable energy adoption. In addition, the role of comprehensive policy frameworks, such as feed-in tariffs, tax incentives, and PPPs, should be examined further to understand how these tools can be adapted to specific regional needs to maximize renewable energy adoption and integration [23]. Future research should also focus on developing standardized metrics for evaluating the performance of renewable energy projects across different regions. These metrics could facilitate better cross-comparisons and help identify the factors that contribute most significantly to successful renewable energy projects. In addition, the resilience of renewable energy systems to climate change-induced extreme weather events is another area that warrants deeper investigation. Strengthening the resilience of energy systems could be the key to ensuring an uninterrupted power supply in the face of climate uncertainties [24,25].

5. Conclusions

The Special Issue (SI) on “Advances in Renewable Energy Research and Applications” has successfully brought together a diverse range of research efforts aimed at addressing the pressing challenges facing renewable energy adoption and development. The 12 papers included in this SI span across various domains of renewable energy, including economic considerations, technological innovations, AI integration, and policy frameworks. By combining these several aspects, this SI provides a comprehensive understanding of the pathways available for advancing renewable energy technologies and optimizing their adoption.

One of the major achievements of this SI is the emphasis on technological advancements that drive the efficiency and reliability of renewable energy systems. From enhancements in wind turbine design to the integration of photovoltaic–thermal (PV-T) desalination systems, these studies highlight the practical improvements that can make renewable energy systems more viable for large-scale deployment. The use of AI and machine learning to improve forecasting accuracy and optimize energy systems further underscores the transformative potential of advanced technologies in this sector. The economic feasibility and management of renewable systems were another significant focus of this SI, with studies exploring strategic pricing, green certificates, and the transition to hydrogen energy. These insights are crucial for understanding how renewable energy can be made more attractive to investors while ensuring long-term sustainability and profitability. In addition to technical and economic aspects, policy frameworks play a pivotal role in driving renewable energy adoption. The papers in this SI provide valuable lessons on how different policy tools—such as quotas, incentives, and public–private partnerships—can be tailored to regional contexts to maximize their effectiveness. The strategic integration of these policy measures is essential for creating a supportive environment where renewable energy can thrive. While this SI has provided substantial advancements, several gaps remain that need further exploration. The scalability of hybrid renewable systems in diverse environments, the integration of underrepresented energy sources like geothermal and tidal energy, and the socio-economic impacts of renewable energy adoption are areas that warrant deeper investigation. Future research should aim to bridge these gaps by focusing on the development of standardized performance metrics, enhancing system resilience to climate change, and investigating the broader societal impacts of renewable energy projects.

In conclusion, the contributions made by the authors of this SI are significant steps forward in the journey toward a sustainable energy future. By combining technological innovation, economic insight, and strategic policy recommendations, this SI serves as a critical resource for researchers, policymakers, and industry stakeholders. The findings presented in these papers lay a robust foundation for continued research and development in renewable energy, ultimately contributing to a cleaner and more sustainable global energy landscape.

Author Contributions: Conceptualization, S.S.D.; formal analysis, A.H.M.A.; writing—original draft preparation, H.H.; writing—review and editing, S.S.D. and H.H.; supervision, S.S.D. and A.H.M.A.; project administration, S.S.D. and A.H.M.A. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Uzundu, N.C.; Lele, D.D. Multifaceted impact of renewable energy on achieving global climate targets: Technological innovations, policy frameworks, and international collaborations. *Int. J. Appl. Res. Soc. Sci.* **2024**, *6*, 1520–1537. [\[CrossRef\]](#)
2. Tiwari, A. Renewable Energy and Physics: Harnessing Solar and Wind Power. *Int. J. Multidiscip. Res.* **2024**, *6*. [\[CrossRef\]](#)
3. Alias, F.; Mohd, M.H.; Rahman, M.A.A. The Influence of Different Mass Ratios on Vortex-Induced Vibration Energy Extraction of Four Cylinder Arrays. *J. Adv. Res. Fluid Mech. Therm. Sci.* **2024**, *117*, 1–14. [\[CrossRef\]](#)
4. Somasundaram, D.; Muthukumar, R.; Rajavinu, N.; Ramaiyan, K.; Kavitha, P. Machine learning applications for predicting system production in renewable energy. *Int. J. Power Electron. Drive Syst.* **2024**, *15*, 1925–1933. [\[CrossRef\]](#)
5. Ibrahim, M.D.; Binofai, F.A.S.; Mohamad, M.O.A. Transition to Low-Carbon Hydrogen Energy System in the UAE: Sector Efficiency and Hydrogen Energy Production Efficiency Analysis. *Energies* **2022**, *15*, 6663. [\[CrossRef\]](#)
6. Song, M.; Wang, Y.; Long, Y. Investment and Production Strategies of Renewable Energy Power under the Quota and Green Power Certificate System. *Energies* **2022**, *15*, 4110. [\[CrossRef\]](#)
7. Prokopenko, O.; Kurbatova, T.; Khalilova, M.; Zerkal, A.; Prause, G.; Binda, J.; Berdiyrov, T.; Klapkiv, Y.; Sanetra-Pólgrabi, S.; Komarnitskyi, I. Impact of Investments and R&D Costs in Renewable Energy Technologies on Companies' Profitability Indicators: Assessment and Forecast. *Energies* **2023**, *16*, 1021. [\[CrossRef\]](#)
8. Ali, S.; Al-Amri, F.; Saeed, F. Numerical and Experimental Performance Evaluation of a Photovoltaic Thermal Integrated Membrane Desalination System. *Energies* **2022**, *15*, 7417. [\[CrossRef\]](#)
9. Huang, H.; Xu, E.; Si, L.; Zhang, Q.; Huang, Q. Dynamic Thermal Transport Characteristics of a Real-Time Simulation Model for a 50 MW Solar Power Tower Plant. *Energies* **2023**, *16*, 1946. [\[CrossRef\]](#)
10. Wu, G.; Fang, H.; Zhang, Y.; Li, K.; Xu, D. Photothermal and Photovoltaic Utilization for Improving the Thermal Environment of Chinese Solar Greenhouses: A Review. *Energies* **2023**, *16*, 6816. [\[CrossRef\]](#)
11. Özden, M.; Genç, M.S.; Koca, K. Passive Flow Control Application Using Single and Double Vortex Generator on S809 Wind Turbine Airfoil. *Energies* **2023**, *16*, 5339. [\[CrossRef\]](#)
12. Morina, R.; Akansu, Y.E. The Effect of Leading-Edge Wavy Shape on the Performance of Small-Scale HAWT Rotors. *Energies* **2023**, *16*, 6405. [\[CrossRef\]](#)
13. Chua, E.C.H.; Wee, S.K.; Kansedo, J.; Lau, S.Y.; Lim, K.H.; Dol, S.S.; Lipton, A.N. Biological Hydrogen Energy Production by Novel Strains *Bacillus paramycoides* and *Cereibacter azotoformans* through Dark and Photo Fermentation. *Energies* **2023**, *16*, 3807. [\[CrossRef\]](#)
14. Chua, E.C.H.; Wee, S.K.; Kansedo, J.; Lau, S.Y.; Lim, K.H.; Doi, S.S.; Lipton, A.N. Growth Study and Biological Hydrogen Production by novel strain *Bacillus paramycoides*. *MATEC Web Conf.* **2023**, *377*, 1004. [\[CrossRef\]](#)
15. Eltamaly, A.M.; Ahmed, M.A. Performance Evaluation of Communication Infrastructure for Peer-to-Peer Energy Trading in Community Microgrids. *Energies* **2023**, *16*, 5116. [\[CrossRef\]](#)
16. Medina-Santana, A.A.; Cárdenas-Barrón, L.E. Optimal Design of Hybrid Renewable Energy Systems Considering Weather Forecasting Using Recurrent Neural Networks. *Energies* **2022**, *15*, 9045. [\[CrossRef\]](#)
17. Nguyen, T.H.; Nawaz, A.; Sreekumar, P.; Natsheh, A.; Akre, V.; Van, T.L. Implementation and Validation for Multitasks of a Cost-Effective Scheme Based on ESS and Braking Resistors in PMSG Wind Turbine Systems. *Energies* **2022**, *15*, 8282. [\[CrossRef\]](#)
18. Islam, M.K.; Hassan, N.M.S.; Rasul, M.G.; Emami, K.; Chowdhury, A.A. Forecasting of Solar and Wind Resources for Power Generation. *Energies* **2023**, *16*, 6247. [\[CrossRef\]](#)
19. Muhammad, A.; Ishaq, A.A.; B, I.O.; Idris, M.B. Artificial Intelligence and Machine Learning for Real-time Energy Demand Response and Load Management. *J. Technol. Innov. Energy* **2023**, *2*, 20–29. [\[CrossRef\]](#)
20. Adanma, U.M.; Ogunbiyi, E.O. Assessing the economic and environmental impacts of renewable energy adoption across different global regions. *Eng. Sci. Technol. J.* **2024**, *5*, 1767–1793. [\[CrossRef\]](#)

21. Forsythe, H.; Maheri, A. Integration of Wave Energy into Distributed Hybrid Renewable Energy Systems: Power and Cost Modelling Requirements. In Proceedings of the 2022 7th International Conference on Environment Friendly Energies and Applications (EFEA), Moka, Mauritius, 14–16 December 2022; pp. 1–6. [\[CrossRef\]](#)
22. Dokmak, H.; Faraj, K.; Faraj, J.; Castelain, C.; Khaled, M. Geothermal systems classification, coupling, and hybridization: A recent comprehensive review. *Energy Built Environ.* **2024**, *in press*. [\[CrossRef\]](#)
23. Uzundu, N.C.; Lele, D.D. Socioeconomic challenges and opportunities in renewable energy transition. *Int. J. Appl. Res. Soc. Sci.* **2024**, *6*, 1503–1519. [\[CrossRef\]](#)
24. Ekechukwu, D.E.; Simpa, P. A comprehensive review of renewable energy integration for climate resilience. *Eng. Sci. Technol. J.* **2024**, *5*, 1884–1908. [\[CrossRef\]](#)
25. Erenoglu, A.K.; Sengor, I.; Erdinc, O. Power System Resiliency: A Comprehensive Overview from Implementation Aspects and Innovative Concepts. *Energy Nexus* **2024**, *15*, 100311. [\[CrossRef\]](#)

Disclaimer/Publisher’s Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.