Research Journal in Civil, Industrial and Mechanical Engineering
ISSN: 3079-2630
DOI: https://doi.org/10.61424/rjcime.v3i1.924
Journal Homepage: https://bluemarkpublishers.com/index.php/RJIEE

RJCIME
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| RESEARCH ARTICLE

Synergistic Frameworks in Renewable Energy and Industrial Systems: Integrating AI, Optimization, and Socioeconomic Dynamics for Sustainable Supply Chains

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| ABSTRACT

With the growing demand for sustainable energy across the globe, the shift from fossil fuel based systems to renewable energy technologies has gained momentum, necessitating the need for intelligent and resilient supply chains. This review examines synergy approaches in which artificial intelligence (AI), optimization methods and socio-economic aspects are combined to improve the performance of renewable energy or industrial systems. The study emphasizes that the integration of various energy sources and energy storage technologies in HRES can enhance energy efficiency, reliability, and sustainability. Advanced optimization techniques are explained, and the need for using them to achieve a balance of the technical, economic and environmental goals, as well as to reduce the operating costs and to increase the system performance, is emphasized. Predictive maintenance, energy forecasting, resource allocation, and intelligent grid management are explored, showcasing AI's promise of enhancing operational efficiency and aiding in data-driven decision-making. The study also highlights the role socioeconomic issues such as community involvement, job creation, engaging stakeholders and benefiting the parties in a fair manner play in the sustainability of renewable energy projects. Additionally, model transparency and sustainability are discussed. Future directions highlight the importance of supportive policy frameworks, financial incentives, circular economy approaches, and interdisciplinary collaboration. The use of AI, optimization methods, and socio-economic factors offers a comprehensive approach to creating energy systems that are sustainable and resilient. These synergistic approaches can help solve global energy problems and can also contribute to environmental protection, economic development and social development.

| KEYWORDS

Artificial Intelligence (AI), Renewable Energy Systems, Sustainable Supply Chains, Hybrid Renewable Energy Systems (HRES), Socioeconomic Sustainability

| ARTICLE INFORMATION

ACCEPTED: 21 April 2026 **PUBLISHED:** 26 June 2026 **DOI:** https://doi.org/10.61424/rjcime.v3i1.924

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1. Introduction

In an increasingly global world, where energy systems are shifting from a reliance on fossil fuel sources to cleaner and more sustainable energy sources such as solar and wind, this framework has become even more important. New technological developments have made renewable energy technologies much more affordable and efficient and are now able to compete with traditional energy sources [1]. The investments in renewable energy sources have increased significantly, with considerable support from governments and changing market conditions driving the continued rapid growth of use of sustainable energy systems. Meanwhile, experimental optimization of photovoltaic module significant efforts must be made in energy integration and infrastructure investment to make it possible to integrate renewables into current power grids [2]. AI is becoming a game-changer in the era of modern energy systems. AI technologies can analyze vast amounts of data in real time, helping stakeholders make informed decisions about optimizing energy production, distribution, and consumption. AI can be applied in various ways to improve the reliability and efficiency of renewable energy systems and facilitate a smoother energy transition, such as predictive maintenance, energy load management, and resource allocation [3]. Moreover, the optimization technique enhances the performance of hybrid renewable energy systems by harmonizing the economic, technical and environmental goals and integration of various energy sources. Nevertheless, the challenges for socioeconomic transition to renewables are enormous. The transition to a more sustainable energy landscape could result in economic volatility for heavy fossil fuel reliant industries and communities [4]. Thus, policies need to be formulated to facilitate the workforce transition, generate jobs and encourage inclusive economic growth while ensuring energy security. The broad adoption of AI also poses ethical considerations regarding data quality, fairness of algorithms, transparency, and accountability. However, overcoming this challenge demands stakeholders to be actively involved, effective governance and community engagement to make sure that new technologies are adopted equitably and responsibly [5]. Overall, synergistic frameworks offer a holistic approach for the implementation of advanced technologies, optimization methodologies and socioeconomic concepts in renewable energy and industrial systems. The multidisciplinary strategy helps to enhance sustainability, improve supply chain robustness and drive long term socioeconomic growth, ensuring the development of more resilient and sustainable energy systems in a changing world.

2. Key Concepts and Framework Components

In renewable energy and industrial systems, synergistic frameworks combine artificial intelligence (AI), optimization methods, and socioeconomic considerations to develop effective, sustainable, and resilient supply chains [6]. The multidisciplinary approach underscores the shift from industrialized systems to more human-centered systems connected with Industry 4.0 and the new Industry 5.0 that promote human-robot interaction to increase operational efficiency, flexibility and sustainability over time. Optimization techniques are part of the basic part of hybrid renewable energy system (HRES) [7]. Different optimization techniques, such as classical, contemporary, and combined optimization techniques have been used to overcome the problem of optimizing the integration of multiple renewable energy sources. The techniques are designed to achieve a balance between technical performance, economic viability and environmental sustainability, while maintaining system reliability (Table 1). Optimization frameworks aim to maximize energy output, simplify operation, reduce operating costs and enhance the performance of the overall system. Socio-economic conditions are also crucial in enabling the effective implementation and commercialisation of RE technologies [8]. Renewable energy systems have economic and social effects that aid stakeholders in creating strategies for sustainable growth. Effective cooperation between industry, governments, communities and policy makers is crucial to encourage innovation, to ensure adherence to regulatory requirements and to develop policies that reconcile innovation with public benefits. However, with environmental laws becoming more stringent and the rest of the world increasingly more concerned about the environmental impact, the economic situation of renewable energy has been changing quickly [9]. These developments are transforming the supply chain, and are prompting investment in renewable energy infrastructure. Blended finance tools are helping to scale clean energy projects, including in markets that are remote and underserved, and to bolster low carbon economies. Artificial intelligence (AI) and machine learning have emerged as game changers in renewable energy by enhancing the effectiveness of hybrid GIS and Multi Criteria Decision Making (MCDM) frameworks for regional renewable energy prioritization [10]. These technologies improve data analysis, energy demand forecasting, resource allocation, and decision making, enabling efficient renewable energy planning while strengthening energy security and promoting sustainable energy development. These technologies allow for analysing vast amounts of data, and making more accurate predictions of energy use, optimizing resource use, facilitating better energy distribution, and predicting demand more effectively. Predictive analytics powered by AI also help in predictive maintenance, minimizing downtime for equipment and maximizing the lifespan of renewable energy assets [11]. As more autonomous systems are being used in solar and wind power plants, AI's impact on improving productivity, reliability, and operational efficiency continues to be a promising avenue for exploration. The combination of all these factors enhances sustainable supply chains, boosts the performance of renewable energy systems, and allows for long-term economic and environmental sustainability.

Table 1. Key Technologies and Their Roles in Sustainable Renewable Energy Systems

Component	Major Functions	Applications	Expected Outcomes	References
Artificial Intelligence (AI)	Real time data analysis, predictive maintenance, demand forecasting, intelligent decision making	Smart grids, energy forecasting, predictive maintenance, resource allocation	Improved operational efficiency, reduced downtime, enhanced energy reliability	[3], [10], [11], [17], [18]
Hybrid Renewable Energy Systems (HRES)	Integration of multiple energy sources with energy storage systems	Solar, wind, conventional energy and battery storage systems	Increased energy security, reliability, and sustainability	[7], [12], [13]
Optimization Techniques	Multi objective optimization, adaptive energy management, resource utilization	Fuzzy logic, Particle Swarm Optimization (PSO), probabilistic modelling	Reduced operational costs and improved system performance	[7], [16]
Industry 5.0 Integration	Human AI collaboration and intelligent decision support	Human supervised autonomous systems	Improved transparency, adaptability, and ethical decision making	[6], [19]
Sustainable Supply Chain Management	Resource optimization and environmental impact reduction	Circular economy practices, smart logistics	Enhanced sustainability and reduced carbon footprint	[8], [32]

3. Integration Approaches

Coordinating renewable energy, optimization methods, and artificial intelligence are essential in designing efficient, reliable, and sustainable energy systems [12]. To enhance the overall performance of the energy system and energy security, hybrid renewable energy systems (HRES) be an effective solution by integrating various energy sources, such as solar, wind, and conventional energy sources, along with energy storage solutions. There are two types of HRES integration, which can be broadly classified as series integration and parallel integration [13]. In series integration, the outputs of the energy sources are integrated in succession with the output of one energy source as the input to the next. This facilitates synergic interactions between the system components and improves the efficiency of the energy conversion as a whole. The technical, economic, environmental, and social sustainability indicators should be evaluated in the design and optimization of systems that are integrated in series to ensure their reliable and efficient operation (Figure 1) [14]. Parallel integration, on the other hand, enables several energy sources to function separately in the system. Each source operates independently, offering more flexibility of operation and reliability to the system, especially in settings where energy usage varies. An effective implementation of parallel integration will need a solid knowledge of the interactions and characteristics of the various energy sources [15]. Optimization methods are important for the management of hybrid RE systems. As fuzzy logic and Particle Swarm Optimization (PSO), they allow adaptive energy management, efficient resource allocation and multi objective decision making. These methods enable maximizing energy utilization, reliability, cost-effectiveness, and system performance in RE systems [16]. To deal with long time uncertainties (like uncertainty in weather conditions and non-linearity in the systems), it is necessary to use probabilistic and advanced modelling methods. The coupled dynamics of ecological footprints, energy transition, land use change, and urbanization can be further addressed through advanced optimization techniques and Artificial Intelligence (AI). These approaches enhance the sizing, performance prediction, and operational scheduling of hybrid solar and wind energy systems while enabling intelligent design, operation, and management of energy infrastructures, thereby improving energy system integration and supporting sustainable urban and environmental development [17]. AI technologies can process vast amounts of data in real-time, ensuring optimal energy utilization, distribution, and production, while also reducing environmental footprint and keeping costs in check. AI also aids in the area of predictive maintenance, energy forecasting, and efficient supply chain management [18]. In addition to automation, AI also fosters a human-centric approach, focusing on the interaction and cooperation between intelligent systems and human operators. This is aligned with the concepts of Industry 5.0, where technology is not meant to take over human decision making, but to support it [19]. Incorporating AI, advanced optimization techniques, and renewable energy technologies, businesses can construct energy systems that are robust, sustainable, and adaptable to future energy needs, thereby promoting environmental and socioeconomic objectives.

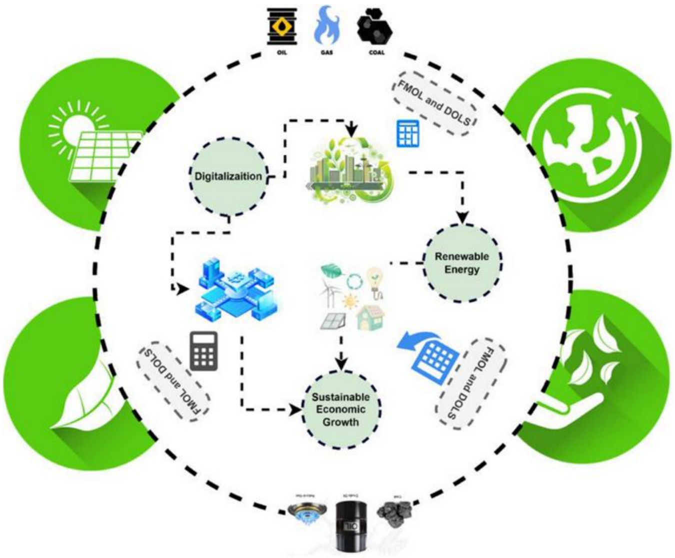

Figure 1: Conceptual framework mapping the impacts of digitalization and renewable energy on sustainable economic growth, analyzed via FMOLS and DOLS estimations amidst a transition away from fossil fuels [50].

4. Socioeconomic Impacts

Socioeconomic factors are important indicators of the success and long-term sustainability of renewable energy projects [20]. Demographic factors such as age, gender, education, and household income have a profound impact on the community's participation, acceptance, and engagement in renewable energy projects. An integrated assessment of all these factors enables better understanding of the relationships between energy systems and socioeconomic development on the part of the stakeholders [21]. Effective community involvement is essential for the successful deployment of renewable energy. Community-owned and locally-supported projects can have significant social, political, environmental, economic and technological benefits [22]. Local people's participation brings the sense of belonging, enhances social responsibility, and ensures sustainability of the project over a longer period. Engaging local organizations and communities in collaborative projects can also help to strengthen food security, boost livelihoods, and promote sustainable practices. Renewable energy initiatives provide substantial economic benefits, including jobs, business expansion and workforce skills development [23]. Reliable and affordable energy services can help to diminish reliance on fluctuating fossil fuel markets and contribute to the economic stability. Renewable energy projects can also bring benefits to local communities in the areas of public utilities, transportation, and quality of life. Community benefit frameworks are crucial in order to provide tangible benefits to the communities that will be impacted by renewable energy projects [24]. These are transparent, accountable and involve the community in decision making and implementation. These approaches help build confidence and trust between project developers and local communities and help smooth out the implementation of a project and the distribution of benefits. Long term socioeconomic transformation can also be stimulated through renewable energy projects (Table 2). These projects can have a positive impact on the overall social development of the region by providing employment opportunities, fostering economic growth, and promoting sustainable development [25]. Effective collaboration between governments, industry, policy makers and local communities is crucial for achieving successful results, and for ensuring that renewable energy investments are in accordance with their regional development priorities. The synergy between renewable energy systems and socioeconomic strategies can drive inclusive economic growth, social well-being, and the creation and empowerment of resilient communities, while simultaneously achieving environmental goals.

Table 2. Socioeconomic Impacts, Challenges, and Future Strategies for Renewable Energy Systems

Category	Key Issues	Potential Benefits	Recommended Strategies	References
Socioeconomic Impacts	Community participation, demographic influences, stakeholder engagement	Job creation, economic growth, improved quality of life	Community benefit frameworks and stakeholder collaboration	[20], [21], [22], [23], [24], [25]
Technical Challenges	Complex optimization models and system integration	Improved energy efficiency and resilience	Advanced modelling and interdisciplinary collaboration	[26], [27]
Data and AI Challenges	Poor data quality, legacy infrastructure compatibility, algorithm transparency	Better AI performance and stakeholder trust	Data standardization, explainable AI, and ethical governance	[28], [29]
Environmental Considerations	Waste generation from solar panels, batteries, and electronic components	Reduced greenhouse gas emissions	Lifecycle management and recycling technologies	[30], [46]
Future Directions	AI expansion, digital twins, advanced analytics, policy support	Climate resilient and adaptive energy systems	Green financing, public private partnerships, and community engagement	[31], [33], [34], [35], [47], [48], [49]

5. Challenges and Limitations

The potential for incorporating artificial intelligence (AI) and hybrid renewable energy systems (HRES) into sustainable supply chains is great, but there are also numerous technical, operational, and organizational considerations and challenges that could obstruct the successful integration of AI and HRES [26]. The difficulty with system optimization is one of the main issues. Hybrid renewable energy systems (HRS) combine various energy sources, storage technologies, and operating parameters which need to be coordinated at the same time. To create efficient optimization models, highly advanced algorithms are needed that can address multiple objectives, such as energy efficiency, economic feasibility, reliability and sustainability. Such complexity may require significant technical expertise, computational resources, and specialized knowledge. Energy storage system management is another important problem. Smoothly balancing energy storage systems to meet varying energy demands and energy generation from variable renewable sources is challenging [27]. To achieve long-term sustainability and energy security, ongoing developments in storage technologies and smart management solutions are needed. Issues with data also play a crucial role in the effective implementation of AI-dependent systems. Completeness, accuracy, consistency, and timeliness of data gathered from multiple data sources is often a challenge for organizations. Creating meaningful insights from AI applications starts with providing high-quality data, which involves a lot of data cleaning, standardisation, validation and integration [28]. There are extra challenges related to the integration of AI into existing information technology infrastructures. There are lots of organizations that still use old systems, which might not be completely compatible with contemporary AI technologies. Seamless communication between newly developed intelligent systems and legacy systems necessitates careful planning, considerable investment, and technical adaptation. Another critical issue is fairness and transparency of AI models. Complex AI algorithms can be thought of as "black box" algorithms, meaning the decisions made by the algorithm cannot be easily understood [29]. Its transparency can be a source of disillusionment of stakeholders and issues of accountability, ethics and decision making. Fairness, explainability, and responsible implementation of AI are therefore essential for their acceptance. The solution is an interdisciplinary approach, ongoing technological advancement, sound data management, and policy support. These are key challenges that will need to be addressed to achieve resilient, efficient and sustainable energy systems and supply chains in the future.

6. Environmental Considerations and Future Directions

Issues of environmental sustainability are important when developing and implementing the technologies of renewable energy and intelligent industrial systems. The use of technologies like solar panels, batteries, and advanced electronics significantly cut down on the amount of greenhouse gases emitted, but they can pose environmental issues in their production, use, and disposal [30]. Hence, the implementation of effective life cycle management, sustainable development of materials, and efficient recycling schemes are critical to reduce environmental impacts and ultimately achieve long-term sustainability. Artificial Intelligence (AI) is poised to transform the future of renewable energy systems, further enhancing their efficiency, reliability, and overall performance (Figure 2) [31]. With the development of AI technologies, predictive maintenance, energy forecasting, and grid management will benefit. Energy operations will be automated, renewable energy projects integrated into existing power systems rapidly and efficiently, and equipment failure detection, minimising downtime and maximising resource utilisation, through intelligent systems. AI-powered solutions will be increasingly on the table to help create sustainable supply chains that minimize environmental impact and maximize operational efficiency. Machine learning algorithms can be used to optimize energy use, reduce waste production, and reduce greenhouse gas emissions across industrial processes [32]. These innovations will also contribute to the shift towards circular economy models by encouraging the re-use of resources, optimizing logistics, and designing sustainable supply chains. Policy frameworks and financial incentives will play a key role in supporting technologies to be adopted. Tax incentives, energy efficiency regulations, financing programmes and strategic public private partnerships are important tools for governments and financial institutions to facilitate the investment in renewables and sustainable technologies [33]. These initiatives can speed up the technology uptake and enable large-scale deployment. Engagement of the community and environmental protection will gain greater significance as well. Artificial intelligence enabled manufacturing optimization strategies can enhance the resilience and scalability of domestic photovoltaic supply chains by integrating community consultation into project planning and decision making, increasing social acceptability, reducing potential conflicts, and ensuring that projects deliver economic, social, and environmental benefits while promoting long term sustainability through the incorporation of environmental protection measures [34]. The need for ongoing research and technological development will persist in the field of clean energy and will be crucial to meet new challenges. The use of technologies like three-dimensional (3D) modeling and visualization, advanced data analytics and AI-supported decision support systems will help to optimize low carbon resource utilization, improve energy management and boost the effectiveness of renewable energy projects [35]. Future advancements in renewable energy and industrial systems will rely on the integration of cutting-edge technologies, sustainable practices, favorable policies, and interdisciplinary cooperation. This will be crucial for developing climate-resilient energy systems that can meet global energy demand, resource limitations, and climate change.

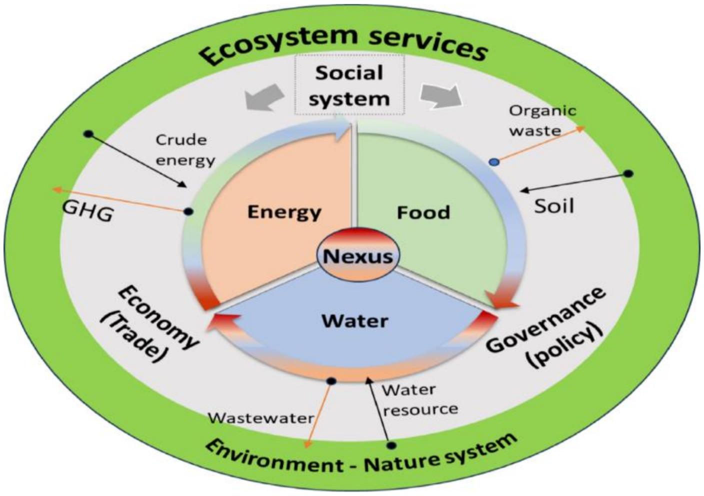

Figure 2: Conceptual model of the Energy-Food-Water Nexus, illustrating its socio-economic drivers (middle ring), inputs/outputs (arrows), and foundational ecological boundaries (outer ring) [51].

7. Discussion

The shift to sustainable energy systems has gained momentum across the world as a result of rising climate change, energy security and environmental degradation concerns. In such a context, synergic frameworks combining Artificial Intelligence (AI), optimization techniques and socio-economic factors have proven to be a good solution for the development of sustainable supply chains in renewable energy and industrial systems [36]. These frameworks offer a multi-disciplinary view to not only enhance energy efficiency and operational performance, but also economic, social and environmental sustainability goals. The development of renewable energy technologies has resulted in substantial opportunities to lower reliance on fossil fuels and improve the production of cleaner energy, such as solar and wind power. Renewable energy sources are, however, not continuous in nature and hence pose challenges for maintaining the stability and reliability of energy supply. With this, hybrid renewable energy systems (HRES) have gained considerable significance as they integrate various energy sources and energy storage technologies to enhance the reliability and efficiency of the energy system [37]. These systems can be integrated into a wider energy system, making energy generation more flexible and resilient to changes in environmental conditions and demand. Optimization methods are important techniques in improving the performance of hybrid renewable energy systems. Optimization techniques have to address technical, economic and environmental goals, and reliability of energy supply. Fuzzy Logic, Particle Swarm Optimization and machine learning algorithms have shown considerable promise with respect to their application in enhancing energy management and operational costs [38]. These optimization techniques enable intelligent decision making, optimizing resources and adjusting energy requirements as they evolve. However, the complexity and sophistication of these systems demand advanced computation skills and multiple fields of expertise. AI has emerged as a game-changer in the field of renewable energy management and sustainable supply chains. AI technologies can analyse enormous amounts of real-time data, making it possible to forecast, predict maintenance and intelligent usage of energy. An integrated Artificial Intelligence and stochastic optimization framework can enhance the resilience and sustainability of low carbon renewable energy manufacturing systems by using predictive analytics to anticipate equipment failures, thereby reducing maintenance costs, minimizing system downtime, and improving overall operational efficiency and reliability [39]. Additionally, AI-powered energy prediction can boost grid stability by optimizing the match of electricity supply and demand. The introduction of Industry 5.0 further reinforces the importance of AI, by advocating a human-centric approach to technological development. In contrast to the previous industrial paradigm, which was mainly based on automation, Industry 5.0 is about the cooperation and interaction between intelligent technologies and human knowledge and skills [40]. Human operators are still crucial in overseeing, understanding, and guiding AI systems with ethical considerations. This collaborative approach improves system adaptability, keeps things accountable, and is transparent. None of these benefits come without its some technical difficulties. The complexity of the integration of various energy sources, energy storage devices, and optimization systems into one operating system is one of the main challenges. Extensive modeling and computational resources are needed for designing systems that can react to the varying requirements of energy flows and changing environmental conditions [41]. Furthermore, energy storage systems are a major constraint as their efficiency, durability, and cost affect the sustainability of renewable energy systems over time. Ongoing research and innovation are thus needed to develop better battery technology and other energy storage options. Data related challenges also pose significant challenges for the implementation of AI. AI systems rely heavily on the availability of accurate, reliable, and standardized data to be effective. Organizations often face data quality issues as their data are not comprehensive, consistent, or up-to-date and come from various sources [42]. To ensure that AI systems can produce consistent results, there are significant data cleaning, integration, and validation efforts that need to be done. Further, the use of AI technologies within legacy infrastructure can involve significant investments in both funds and technology. The ethical implications of using AI technology should also be discussed. Some complex AI models are shrouded in the black box effect, meaning that it can be hard to see how they are determining the reasoning behind some decisions [43]. This opacity may diminish the trust of stakeholders and raise questions of accountability, fairness and biases. To enable general acceptance of AI systems and ensure fair results, the creation of explainable and responsible AI systems will be crucial. However, the socioeconomic factors are important to the success of renewable energy projects beyond the technical aspects. The involvement of the community and engagement with stakeholders are essential to sustainable energy projects [44]. The acceptance and support of RE projects in the communities depends on the demographic factors like education, income level, etc. which has an impact on the social awareness. However, community owned projects can have wider benefits as local people feel they own and manage the project for long term success.

There is also significant economic opportunity for investments in renewable energy. New projects generate jobs, stimulate local businesses, and the skills of the work force. Stable and cost-effective energy supplies facilitate economic development and mitigate risk of fossil fuel market volatility. Furthermore, investments in renewable energy infrastructure can often enhance the quality of public services, transportation systems, and quality of life [45]. Creation of community benefit systems can continue to improve these benefits by creating a balance of economic and social benefits. One of the key issues in growing renewable energy technologies is environmental sustainability. While renewables will lower emissions while they're running, their manufacturing and recycling can be problematic. Modern solar panels, batteries and electronic parts depend on raw materials which could lead to the depletion of resources and pollution of the environment if not handled properly [46]. Thus, applying lifecycle management methods, sustainable materials and good recycling systems is critical for reducing adverse environmental effects. Looking ahead, further enhancements to AI integration, advanced analytics, and renewable energy technologies are expected to be a key priority for future developments [47]. Intelligent energy systems will be able to increasingly automate the operation of the energy grid, forecast energy needs and optimize energy resources. Machine learning algorithms also will help in sustainable supply chains, reducing energy use, waste generation and promoting the ideas of circular economy. Socioeconomic and institutional determinants of public acceptance play a crucial role in supporting sustainable energy transitions, while advanced data analytics, digital twins, 3D modelling, and other emerging technologies can further enhance decision making, improve operational efficiency, and strengthen the planning and implementation of waste to energy policies and renewable energy systems [48]. This transition will need to be accelerated through supporting government policies and financial incentives. Renewable energy investments can be promoted via tax incentives, green finance initiatives, energy efficiency measures, and PPs. Equally important is early community engagement that can enhance social acceptance and minimise conflicts around infrastructure development. Integrating environmental protection and stakeholders engagement into project planning will guarantee that renewable energy projects are sustainable, inclusive and environmentally friendly [49]. Synergistic approaches combining AI, optimization methods, and socioeconomic factors offer a holistic solution for achieving sustainable energy development. Interdisciplinary cooperation, ongoing technological progress, ethical management and broad stakeholder engagement are essential for successfully implementing such frameworks. These "whole-of-society" models offer a means to develop resilient and adaptive energy systems that can help meet future global energy demands while providing for long-term sustainable development, needs, and wellbeing.

8. Conclusion

The integration of artificial intelligence, optimization techniques, and socioeconomic considerations within renewable energy and industrial systems offers a comprehensive pathway toward sustainable development. These synergistic frameworks improve energy efficiency, strengthen supply chain resilience, and support environmental protection while promoting economic growth and social well-being. Despite challenges related to technical complexity, data management, energy storage, and ethical concerns, continuous innovation and interdisciplinary collaboration can overcome these limitations. Future progress will depend on supportive policies, community engagement, and responsible technological implementation to create adaptive, resilient, and sustainable energy systems capable of meeting growing global energy demands.

Author Contributions: F.A. conceptualization, methodology, data curation, formal analysis, writing—original draft preparation, supervision, and correspondence. M.S.S. investigation, validation, visualization, writing—review and editing, and resource management.

References

[1] K. Liao, Z. Yang, D. Tao, et al., "Exploring the intersection of brain–computer interfaces and quantum sensing: a review of research progress and future trends," *Adv. Quantum Technol.*, vol. 7, p. 2300185, 2024.https://doi.org/10.1002/qute.202300185

[2] A. K. Chowdhury and S. C. Barman, "Experimental Optimization of Photovoltaic Module Lamination Parameters Using Design of Experiments and Statistical Process Control," *Energy Environment and Economy*, vol. 3, no. 1, pp. 1–9, 2025, Art. no. 10690. Available: https://doi.org/10.25163/energy.3110690

[3] M. A. A. Aziz, A. A. Jalil, S. Triwahyono, et al., "CO2 Methanation over heterogeneous catalysts: recent progress and future prospects," *Green Chem.*, vol. 17, pp. 2647–2663, 2015.https://doi.org/10.1039/C5GC00119F

[4] K. K. Szpunar, R. N. Spreng, and D. L. Schacter, "A taxonomy of prospection: introducing an organizational framework for future-oriented cognition," *Proc. Natl. Acad. Sci. USA*, vol. 111, pp. 18414–18421, 2014.https://doi.org/10.1073/pnas.1417144111

[5] M. F. Mridha, S. C. Das, M. M. Kabir, et al., "Brain-computer interface: advancement and challenges," *Sensors (Basel)*, vol. 21, no. 5746, pp. 1–46, 2021.https://doi.org/10.3390/s21175746

[6] Newaz, A. A. H., Al Imon, K. A., Jahan, R., & Tanvir, I. K. (2022). Advanced Motor Design and Optimization for High-Efficiency Industrial Applications. Metallurgical and Materials Engineering, 28(4), 697-713.

[7] A. G. Underwood, M. J. Guynn, and A. L. Cohen, "The future orientation of past memory: The role of BA 10 in prospective and retrospective retrieval modes," *Front. Hum. Neurosci.*, vol. 9, pp. 1–12, 2015, doi: 10.3389/FNHUM.2015.00668.

[8] R. Li, L. Li, and Q. Wang, "The impact of energy efficiency on carbon emissions: evidence from the transportation sector in Chinese 30 provinces," *Sustain. Cities Soc.*, vol. 82, p. 103880, 2022.https://doi.org/10.1016/j.scs.2022.103880

[9] Q. Wang, F. Zhang, and R. Li, "Revisiting the environmental Kuznets curve hypothesis in 208 counties: the roles of trade openness, human capital, renewable energy and natural resource rent," *Environ. Res.*, vol. 216, p. 114637, 2023.https://doi.org/10.1016/j.envres.2022.114637

[10] I. K. Egbuna, F. B. Salihu, C. C. Okara, and D. Olayiwola, "Advances in AI-powered energy management systems for renewable-integrated smart grids," *World Journal of Advanced Engineering Technology and Sciences*, vol. 15, no. 2, pp. 2300–2325, 2025. doi: 10.30574/wjaets.2025.15.2.0685.

[11] Q. Wang, F. Zhang, R. Li, et al., "Does artificial intelligence promote energy transition and curb carbon emissions? The role of trade openness," *J. Clean. Prod.*, vol. 447, p. 141298, 2024.https://doi.org/10.1016/j.jclepro.2024.141298

[12] R. Li, Q. Wang, and J. Guo, "Revisiting the Environmental Kuznets Curve (EKC) hypothesis of carbon emissions: exploring the impact of geopolitical risks, natural resource rents, corrupt governance, and energy intensity," *J. Environ. Manage.*, vol. 351, p. 119663, Feb. 1, 2024, Epub ahead of print.https://doi.org/10.1016/j.jenvman.2023.119663

[13] Akteruzzaman, M., Al Imon, K. A., Khan, R., Islam, M. H., Ahamed, T., Uddin, M. S., & Al Mashud, M. A. (2026). Unlocking the Potential of Cd-based Perovskite Solar Cells: An In-depth Study on Performance Optimization. Computational Condensed Matter, e01222. https://doi.org/10.1016/j.cocom.2026.e01222

[14] B. K. Sovacool, D. J. Hess, S. Amir, et al., "Sociotechnical agendas: reviewing future directions for energy and climate research," *Energy Res. Soc. Sci.*, vol. 70, p. 101617, 2020.https://doi.org/10.1016/j.erss.2020.101617

[15] P. A. Owusu and S. Asumadu-Sarkodie, "A review of renewable energy sources, sustainability issues and climate change mitigation," *Cogent Eng.*, vol. 3, p. 1167990, Dec. 31, 2016, Epub ahead of print.https://doi.org/10.1080/23311916.2016.1167990

[16] K. O. Ukoba, A. C. Eloka-Eboka, and F. L. Inambao, "Review of nanostructured NiO thin film deposition using the spray pyrolysis technique," *Renewable Sustainable Energy Rev.*, vol. 82, pp. 2900–2915, 2018.https://doi.org/10.1016/j.rser.2017.10.041

[17] G. Giuggioli and M. Pellegrini, "Artificial intelligence as an enabler for entrepreneurs: A systematic literature review and agenda for future research," *International Journal of Entrepreneurial Behavior & Research*, vol. 29, no. 4, pp. 816–837, 2023. doi: 10.1108/IJEBR-05-2021-0426.

[18] K. O. Olatunji and D. M. Madyira, "Optimization of biomethane yield of Xyris capensis grass using oxidative pretreatment," *Energies*, vol. 16, p. 3977, 2023.https://doi.org/10.3390/en16103977

[19] K. Rohrig, V. Berkhout, D. Callies, et al., "Powering the 21st century by wind energy - Options, facts, figures," *Appl. Phys. Rev.*, vol. 6, p. 031303, 2019, doi: 10.1063/1.5089877/997348.https://doi.org/10.1063/1.5089877

[20] K. O. Olatunji, D. M. Madyira, N. A. Ahmed, et al., "Biomethane production from Arachis hypogea shells: effect of thermal pretreatment on substrate structure and yield," *Biomass Convers. Biorefin.*, vol. 14, pp. 6925–6938, 2024, Epub ahead of print 2022.https://doi.org/10.1007/s13399-022-02731-7

[21] T. Z. Ang, M. Salem, M. Kamarol, et al., "A comprehensive study of renewable energy sources: classifications, challenges and suggestions," *Energy Strategy Rev.*, vol. 43, p. 100939, 2022.https://doi.org/10.1016/j.esr.2022.100939

[22] Howlader, M.N., Chowdhury, S., Al Imon, K.A. et al. Design and implementation of a low-cost IoT-enabled dual-axis photovoltaic tracking system with experimental and simulation-based validation. Journal of Electrical Systems and Inf Technol 13, 44 (2026). https://doi.org/10.1186/s43067-026-00351-z

[23] E. T. Sayed, T. Wilberforce, K. Elsaid, et al., "A critical review on environmental impacts of renewable energy systems and mitigation strategies: wind, hydro, biomass and geothermal," *Sci. Total Environ.*, vol. 766, p. 144505, 2021.https://doi.org/10.1016/j.scitotenv.2020.144505

[24] M. A. Basit, S. Dilshad, R. Badar, et al., "Limitations, challenges, and solution approaches in grid-connected renewable energy systems," *Int. J. Energy Res.*, vol. 44, pp. 4132–4162, 2020.https://doi.org/10.1002/er.5033

[25] H. Lund, "Renewable energy strategies for sustainable development," *Energy*, vol. 32, pp. 912–919, 2007.https://doi.org/10.1016/j.energy.2006.10.017

[26] H. Lund and B. V. Mathiesen, "Energy system analysis of 100% renewable energy systems—the case of Denmark in years 2030 and 2050," *Energy*, vol. 34, pp. 524–531, 2009.https://doi.org/10.1016/j.energy.2008.04.003

[27] A. Evans, V. Strezov, and T. J. Evans, "Assessment of sustainability indicators for renewable energy technologies," *Renewable Sustainable Energy Rev.*, vol. 13, pp. 1082–1088, 2009.https://doi.org/10.1016/j.rser.2008.03.008

[28] F. Petrakopoulou, "The social perspective on the renewable energy autonomy of geographically isolated communities: evidence from a Mediterranean Island," *Sustainability*, vol. 9, p. 327, 2017.https://doi.org/10.3390/su9030327

[29] W. Liu, H. Lund, B. V. Mathiesen, et al., "Potential of renewable energy systems in China," *Appl. Energy*, vol. 88, pp. 518–525, 2011.https://doi.org/10.1016/j.apenergy.2010.07.014

[30] Anwar Hossain, Dorcas Oyebode, Kazi Abdullah Al Imon, Shah Md. Wasif Faisal, Rajesh Vayyala, and Mohammed Alaa H. Altemimi, “ANALYZING HOW MIS CAN OPTIMIZE THE DISTRIBUTION OF ENERGY IN SMART GRIDS, FOCUSING ON DATA-DRIVEN DECISION-MAKING PROCESSES”, SES, vol. 3, no. 7, pp. 321–338, Jul. 2025.

[31] A. H. Ghorashi and A. Rahimi, "Renewable and non-renewable energy status in Iran: art of know-how and technology-gaps," *Renewable Sustainable Energy Rev.*, vol. 15, pp. 729–736, 2011.https://doi.org/10.1016/j.rser.2010.09.037

[32] N. Tsolakis, R. Schumacher, M. Dora, et al., "Artificial intelligence and blockchain implementation in supply chains: a pathway to sustainability and data monetisation?," *Ann. Oper. Res.*, vol. 327, pp. 157–210, 2022.https://doi.org/10.1007/s10479-022-04785-2

[33] E. Cuevas and M. González, "An optimization algorithm for multimodal functions inspired by collective animal behavior," *Computing*, vol. 17, pp. 489–502, 2013.https://doi.org/10.1007/s00500-012-0921-6

[34] S. C. Barman and M. R. Haque, "Artificial Intelligence Enabled Manufacturing Optimization Strategies for Enhancing Resilience and Scalability of Domestic Photovoltaic Supply Chains- A Systemic Review," *Business and Social Sciences*, vol. 2, no. 1, pp. 1–7, 2024, Art. no. 10686. Available: https://doi.org/10.25163/business.2110686

[35] Y. Kitagawa, T. Tsuchiya, D. Etoh, et al., "A graphene oxide-based ionic decision-maker for simple fabrication and stable operation," *Jpn. J. Appl. Phys.*, vol. 59, p. SIIG03, 2020.https://doi.org/10.35848/1347-4065/ab740e

[36] S. Akgun and C. Greenhow, "Artificial intelligence in education: addressing ethical challenges in K-12 settings," *AI Ethics*, vol. 2, pp. 431–440, 2021.https://doi.org/10.1007/s43681-021-00096-7

[37] M. Hickok, "Lessons learned from AI ethics principles for future actions," *AI Ethics*, vol. 1, pp. 41–47, 2020.https://doi.org/10.1007/s43681-020-00008-1

[38] I. Gan and S. Moussawi, "A value sensitive design perspective on AI biases," *Proc. Annu. Hawaii Int. Conf. Syst. Sci.*, vol. 2022-January, pp. 5548–5557, 2022.https://doi.org/10.24251/HICSS.2022.676

[39] T. R. Razak, M. H. Ismail, M. Y. Darus, H. Jarimi, and Y. Su, "Artificial intelligence in renewable energy: A systematic review of trends in solar, wind, and smart grid applications," *Research and Reviews in Sustainability*, vol. 1, pp. 1–22, 2025. doi: 10.5334/rss.6.

[40] T. Davenport, A. Guha, D. Grewal, et al., "How artificial intelligence will change the future of marketing," *J. Acad. Mark. Sci.*, vol. 48, pp. 24–42, 2020.https://doi.org/10.1007/s11747-019-00696-0

[41] S. Umbrello, "Beneficial artificial intelligence coordination by means of a value sensitive design approach," *Big Data Cognit. Comput.*, vol. 3, p. 5, 2019.https://doi.org/10.3390/bdcc3010005

[42] A. Sivaram and V. Venkatasubramanian, "XAI-MEG: combining symbolic AI and machine learning to generate first-principles models and causal explanations," *AIChE J.*, vol. 68, p. e17687, 2022.https://doi.org/10.1002/aic.17687

[43] Imon, Kazi Abdullah Al & Ashik, Sk & Hamdache, Amine. (2024). Adaptive Fuzzy Logic Control for Shunt Active Power Filters in Improving Power Quality. Nanotechnology Perceptions. 2947-2961. 10.62441/nano-ntp.vi.5180.

[44] A. C. Serban and M. Lytras, "Artificial intelligence for smart renewable energy sector in Europe - Smart energy infrastructures for next generation smart cities," *IEEE Access*, vol. 8, pp. 77364–77377, 2020.https://doi.org/10.1109/ACCESS.2020.2990123

[45] R. Alsaigh, R. Mehmood, and I. Katib, "AI Explainability and governance in smart energy systems: a review," *Front. Energy Res.*, vol. 11, p. 1071291, 2023.https://doi.org/10.3389/fenrg.2023.1071291

[46] V. Puri, S. Jha, R. Kumar, et al., "A hybrid artificial intelligence and internet of things model for generation of renewable resource of energy," *IEEE Access*, vol. 7, pp. 111181–111191, 2019.https://doi.org/10.1109/ACCESS.2019.2934228

[47] S. Q. H. AZ and H. M. S. et al., "The role of renewable energy and artificial intelligence towards environmental sustainability and net zero," *Preprints Research Square*, pp. 1–25, 2023, doi: 10.21203/RS.3.RS-2970234/V1.https://doi.org/10.21203/rs.3.rs-2970234/v1

[48] S. C. Barman, S. Raval, and M. A. Hossian, "Socioeconomic and Institutional Determinants of Public Acceptance of Waste-to-Energy Policies: Evidence for Sustainable Energy Transitions," *IMJAT*, vol. 1, no. 2, pp. 65–75, Aug. 2023. Available: https://doi.org/10.51699/rhs7k850

[49] J. Chatterjee and N. Dethlefs, "Facilitating a smoother transition to renewable energy with AI," *Patterns*, vol. 3, p. 100528, 2022.https://doi.org/10.1016/j.patter.2022.100528

[50] J. Zhang, "Application of artificial intelligence in renewable energy and decarbonization," *ES Energy Environ.*, vol. 14, pp. 1–2, 2021, doi: 10.30919/esee8c550.https://doi.org/10.30919/esee8c550

[51] E. R. Joy, R. C. Bansal, C. Ghenai, et al., "Artificial intelligence and its applications in renewable integrated power systems," *Energy Proceedings*, vol. 27, pp. 1–8, 2022.https://doi.org/10.46855/energy-proceedings-10186