PATHFINDER OF RESEARCH

Review Research

AI-Driven Renewable Energy Transitions for Suitable Agriculture and Rural Development: Socio-Economic, Technical, and Policy Perspectives

Tufael
Eudoxia Research University, New Castle, United States

Abstract: The integration of artificial intelligence (AI) with renewable energy systems presents a robust strategy for enhancing agricultural output and fostering rural development. With the increasing worldwide need for food and the issues faced by agricultural systems, such as resource scarcity, labor shortages, and erratic climate conditions, AI-driven solutions provide unique tools for enhanced energy management, resource allocation, and decision-making processes. Principal uses encompass smart irrigation, which enhances water efficiency; predictive analytics that anticipate yields or market trends; and pest and nutrient management systems that assist farmers in sustaining healthy crops. Agrovoltaic systems that integrate energy generation with agriculture are gaining popularity. These technologies boost efficiency and sustainability while generating new income streams and improving rural livelihoods. Yet, the integration of AI in the sectors of renewable energy and agriculture presents certain hurdles. Substantial obstacles must be surmounted, including elevated initial investment expenses, disparities in internet accessibility, regulatory challenges, ethical dilemmas, and opposition to novel technology. To effectively address these concerns, it is imperative to establish adaptive policies, cultivate public-private partnerships, involve communities, and invest in capacity-building projects that promote equal access and inclusive growth. This study highlights the complex socio-economic, technological, and policy aspects of AI-driven transformations in renewable energy. It underscores the imperative for ethical governance, data openness, and the empowerment of local populations. Through the cultivation of an inclusive, sustainable, and resilient energy ecosystem, AI can profoundly alter agricultural landscapes, promote environmental stewardship, and empower rural people to adequately address the increasing global needs for food and energy.

Keywords: Artificial Intelligence (AI), Renewable Energy, Agrovoltaics, Rural Development, Sustainable Agriculture

Check for Updates

Article History:
Received: 02 July 2025
Accepted: 05 August 2025
Online: 07 August 2025

Corresponding author:
tofayelahmed083@gmail.com

Citations: Tufael. (2025). AI-Driven Renewable Energy Transitions for Suitable Agriculture and Rural Development: Socio-Economic, Technical, and Policy Perspectives. *Pathfinder of Research*, *3*(2), 68-85

1. Introduction

Artificial intelligence (AI) and renewable energy are generating exciting opportunities in agriculture, contributing to the enhancement of rural economies. Agriculture is essential for food security and rural lives, although it confronts significant problems. The escalating population, increased material prices, and erratic weather patterns due to climate change are intensifying the need for food production **(Agostinelli et al., 2021; Urbi et al., 2025).** With global food demand anticipated to escalate in the forthcoming years, it is evident that conventional agricultural techniques are insufficient. This is where the integration of AI with renewable energy becomes transformative. Utilizing innovative digital technologies, farmers may enhance efficiency, augment output, and reduce environmental impact. For instance, AI may enhance irrigation efficiency by delivering the precise quantity of water to crops, hence minimizing waste. It may also assess meteorological trends and soil vitality, enabling farmers to make educated decisions to save their crops. Advanced AI technologies enable farmers to control pests and illnesses more efficiently, therefore diminishing the need for chemical inputs, which is advantageous for both environmental sustainability and public health. Combining renewable energy sources like solar electricity can significantly enhance the impact. Numerous rural towns face challenges in obtaining dependable and cost-effective electricity, thus constraining their capacity to irrigate crops, preserve cold storage, and employ modern equipment **(Ifty et al., 2024)**. Farmers may utilize sustainable, decentralized energy sources by integrating solar panels and wind turbines. Agrovoltaics, which utilizes farmland for simultaneous crop production and solar energy generation, exemplifies how renewable energy may provide possibilities for farmers, bolster energy security, and promote agricultural resilience **(Al-Othman et al., 2022).** Artificial intelligence technologies can further augment these renewable energy uses. For example, intelligent AI systems can optimize solar panel positioning for peak energy production while also offering crucial shade to crops in high temperatures. Machine learning can forecast energy requirements in agricultural communities, synchronizing energy generation with essential farming operations, such as irrigation and climate regulation for greenhouses. This signifies a transition from conventional resource-intensive agricultural practices to more intelligent, sustainable systems.

The socio-economic advantages of incorporating AI and renewable energy into agriculture are significant. Rural communities employing these technologies can achieve more economic independence, diminishing their dependence on costly fossil fuels. Enhanced energy availability can augment production and generate new employment possibilities in agro-processing. Furthermore, AI solutions can address labor shortages by automating repetitive jobs, enabling individuals to concentrate on more significant work within the agricultural supply chain. These developments can facilitate entrepreneurship and enhance participation in local economies for women and underprivileged groups **(Awan et al., 2022; Hossain et al., 2024).** However, we must overcome significant obstacles. Significant initial investment expenses can be intimidating, particularly for smallholder farmers with constrained financial means. Although the long-term financial benefits of renewable energy are evident, the upfront costs associated with AI tools and other technology might render them unattainable for most individuals. The digital divide, which is defined by unequal access to the internet and digital education, may worsen the gap between those who can and cannot use these technologies. If we don't take intentional steps to bridge this gap, the existing disparities in rural development could deepen. Moreover, as we transition to a more technology-centric paradigm, we must take into account ethical and societal issues. Harmonizing innovation with inclusivity is essential for guaranteeing that the advantages of AI and renewable energy are widely distributed, rather than monopolized by a select few. As we traverse this changing environment, it is essential to concentrate on establishing sustainable and equitable institutions that benefit all individuals in rural areas.

2. AI Technologies in Renewable Energy

Artificial intelligence (AI) is profoundly transforming the renewable energy sector, enhancing system efficiency and intelligence. It transcends technology; it involves fostering a better, more sustainable environment for everybody. Through advanced data analysis, AI assists industries, such as agriculture, in optimizing the use of renewable energy, particularly in rural regions where energy access has posed challenges **(Babatunde et al., 2020).** AI significantly influences energy harvesting and management. It aggregates and examines data from sources such as solar panels and wind turbines, allowing more precise forecasts of energy generation. This not only guarantees more effective power utilization but also helps sustain a stable energy grid. The result signifies enhanced access to electricity for farmers and communities in energy-deficient areas, facilitating their prosperity. Furthermore, AI excels at predictive analytics. Utilizing diverse methodologies, it can forecast phenomena ranging from solar radiation to meteorological patterns, which is essential for strategizing energy requirements. Machine learning, a kind of artificial intelligence, is increasingly entering the energy trading sector. The technology assists producers in formulating more effective bidding tactics and predicting fluctuations in market demand, thus optimizing their profits. In the realm of energy storage, artificial intelligence excels. Utilizing sophisticated algorithms, it can assess battery health, enhance charging cycles, and improve overall efficiency **(Bashir et al., 2022; Chowdhury et al., 2025).** This aspect is especially crucial during periods of high energy demand or when generation varies due to changing weather conditions. The emergence of digital twin technology, which generates real-time virtual representations of battery activities, is transforming the maintenance and integration of these systems with smart grids. The integration of big data and the Internet of Things (IoT) significantly amplify AI's function in renewable energy management. Ongoing input from sensors and smart meters enables AI to identify inefficiencies and propose enhancements in real time. The result indicates that renewable energy systems enhance resilience and reliability, assuring communities of their dependability **(Deng et al., 2023; Sunny et al., 2025b).** AI is fundamentally transforming our perceptions and applications of renewable energy. Through enhancements in resource management and energy storage, AI serves as a pivotal catalyst in the shift to sustainable energy systems. Its function in agricultural and rural development highlights its capacity to foster cleaner, more intelligent, and resilient communities capable of flourishing in a sustainable future.

2.1 Technical Perspectives

Artificial intelligence (AI) is transforming the operational and resource management practices of utilities inside energy systems. Historically, in the 1980s and 1990s, AI was predominantly employed in rudimentary forms such as expert systems and neural networks for functions such as energy demand forecasting and defect detection. Although these methods were beneficial in the past, they failed to adapt to the growing complexity of energy requirements over time. Today, due to substantial technological breakthroughs, AI has significantly enhanced the efficiency of energy infrastructures, particularly smart grids. Contemporary AI algorithms can swiftly assess data to forecast energy requirements, regulate consumption, and oversee systems in real time **(Di et al., 2020; Sunny et al., 2025a).** Such advancement enables utilities to use more sophisticated demand response systems that facilitate the equilibrium of energy supply and demand while incorporating additional renewable energy sources. AI significantly impacts the maintenance and dependability of energy infrastructure. Utilities are now employing predictive and proactive measures, driven by AI and machine learning, instead of depending on traditional approaches that handle issues post-occurrence. Through the analysis of extensive data sets obtained from sensors and operating records, AI can identify patterns indicative of potential equipment failure. This facilitates improved scheduling of maintenance and replacements.

Furthermore, AI is capable of analyzing photos and videos to swiftly detect flaws in infrastructure such as electricity lines, wind turbines, or solar panels **(Dogaru et al., 2020; Tiva et al., 2025b).** This progressive strategy reduces downtime and maintenance expenses while enhancing operational efficiency and dependability, facilitating a cleaner and more resilient energy future. Nonetheless, obstacles remain, particularly regarding the scalability and accessibility of AI solutions for everybody. To use AI effectively on a bigger scale, robust infrastructure, open platforms, and multinational collaboration are essential to guarantee universal access to these technological advancements. Numerous underserved areas are deficient in essential resources, including computing capacity and technical expertise, rendering the use of AI in energy management difficult. Furthermore, obsolete legislation and economic impediments frequently hinder advancement. To address these challenges, we want policies that evolve with innovation while guaranteeing equity in the energy transition. Investing in local skills development, establishing cross-industry relationships, and promoting inclusive research efforts are essential for enhancing the benefits of AI in global energy systems. Artificial intelligence transcends mere energy efficiency; it is radically transforming the forecasting, distribution, and maintenance of our energy supplies **(Sunny et al., 2023; Ghadami et al., 2021)**. As we adopt technologies like predictive maintenance and smart grids, we must also emphasize their accessibility for everybody. Overcoming these hurdles through collaboration, infrastructure enhancement, and supporting legislation will be essential for realizing the full promise of AI in creating sustainable and resilient energy systems for the future.

2.2 Future Opportunities and Policy Perspectives

The future of artificial intelligence (AI) in renewable energy transcends mere technological advancement; it necessitates interdisciplinary collaboration and the establishment of appropriate regulations. Artificial intelligence has demonstrated its capacity to enhance the efficiency of energy production, storage, and distribution; nevertheless, its full potential requires collaboration among technical specialists, social scientists, and economic strategists. By comprehending community requirements through social sciences and behavioral investigations, we can guarantee that AI equitably advantages all individuals. Policymakers are essential to this endeavor. They must establish adaptable regulations that promote innovation while safeguarding public welfare. This necessitates a meticulous navigation of the intricate interaction between the adoption of new technology, the provision of economic incentives, and the assurance of environmental safety. Through adaptability and foresight, governments may facilitate the advancement of AI-driven renewable energy solutions without impeding progress **(He et al., 2022; Islam et al., 2025).**

Public-private partnerships can further augment this ecosystem. Through collaboration, governments and private enterprises can distribute the financial risks and resources essential for advancing AI in agriculture and renewable energy. Involving conventional energy stakeholders from the outset helps alleviate apprehensions and foster confidence, transforming possible resistance into passionate collaboration. This form of collaboration demonstrates that AI can integrate with current systems instead of undermining them. Notwithstanding the tremendous potential, economic obstacles persist, especially for small-scale farmers and rural regions. Numerous governments are intervening with subsidies, tax incentives, and lending initiatives to mitigate these financial difficulties. In addition to financial assistance, it is essential to provide user-friendly technologies and algorithms that integrate seamlessly with existing systems to promote smoother adoption. Exhibiting enduring advantages such as enhanced efficiency, improved agricultural outputs, and fewer environmental repercussions would further substantiate the need for these expenditures. A crucial element for the effective use of AI in renewable energy is the availability of high-quality data. Accurate and current data is crucial for training AI models to function efficiently in various environments. Investments in technology, like sensors and the Internet of Things, coupled with robust data-sharing platforms, are essential. Policymakers should prioritize promoting openness in data collection and utilization while reconciling the necessity for innovation with security (**Islam et al., 2025; Inderwildi et al., 2020).** Ethical issues and data protection must remain paramount as AI increasingly integrates into agriculture and renewable energy. Governments and international organizations are instituting guidelines to promote responsible usage, protect farmers' rights, provide equitable access to technology, and avert the exploitation of sensitive information. Addressing these ethical problems earnestly can foster public confidence and facilitate sustainable innovation. The future of AI in renewable energy is promising, necessitating a comprehensive strategy that integrates technology advancement, favorable legislation, economic inclusivity, and ethical concerns. By promoting interdisciplinary cooperation, establishing flexible policies, and prioritizing data quality and privacy, we can realize AI's whole potential. This approach enables the transition to sustainable energy systems that foster resilience, equity, and growth in agricultural and rural communities.

2.3 Navigating Challenges Toward Sustainable AI Integration

Employing AI in renewable energy systems for agricultural and rural development presents a combination of significant difficulties and promising potential for the future. Artificial intelligence possesses the capacity to enhance energy management by making it more sustainable, efficient, and equitable; however, to fully realize these advantages, it is imperative to address several economic, social, and regulatory obstacles while guaranteeing universal access to the technology. The primary obstacle is the substantial expense associated with implementing AI and renewable energy technology. These charges encompass not only the acquisition of new hardware or software but also the recruitment of proficient personnel, the continuous collection of data, and the upkeep of the systems **(Leal et al., 2023; Tiva et al., 2025a).** For small-scale farmers and rural energy suppliers, these expenses can be burdensome. The digital divide exacerbates financial concerns, since several rural regions continue to contend with inconsistent energy and internet connectivity, hindering community engagement with sophisticated AI systems. In the absence of investment in digital infrastructure and education, the advantages of AI will likely be disproportionately allocated to those who are already affluent. Social considerations complicate the adoption of AI. In several rural towns, the aspiration to establish "green jobs" may result in a talent exodus, as qualified persons relocate for superior chances, therefore depleting local resources and diminishing capacity. Furthermore, the imposition of new technology from a hierarchical perspective can alienate local populations and cultivate reliance on uncontrollable systems. We must also address ethical concerns like privacy, data security, and biases in artificial intelligence systems. Given that AI depends on extensive datasets, there exists a danger of sensitive information being misappropriated or that the models may perpetuate current disparities in energy access. To address these difficulties, we require ethical norms that safeguard community rights and foster inclusion. Regulatory regimes present a substantial problem. Numerous existing policies favor conventional energy systems, generating ambiguity for AI-driven solutions. Utility firms and authorities may be reluctant to use AI owing to concerns around compliance, liability, and the possible disruption of existing business models **(Li et al., 2024; Sunny et al., 2021).** To address these difficulties, it is essential to establish adaptable policies that foster innovation while preserving dependability, thus guaranteeing that AI enhances rather than detracts from energy systems. There exists a cultural aversion to technology, particularly in agriculture, where sophisticated technologies may be perceived as too disruptive. Establishing trust and involving local populations through efficient training and participatory methods is essential. Despite these challenges, there exists significant potential for AI to transform renewable energy systems in agricultural and rural development (Figure 1). A possible approach is developing AI-driven policy frameworks that utilize predictive analytics to anticipate long-term energy trends. This proactive strategy would empower policymakers to make educated decisions while accounting for socioeconomic effects and guaranteeing equitable energy access.

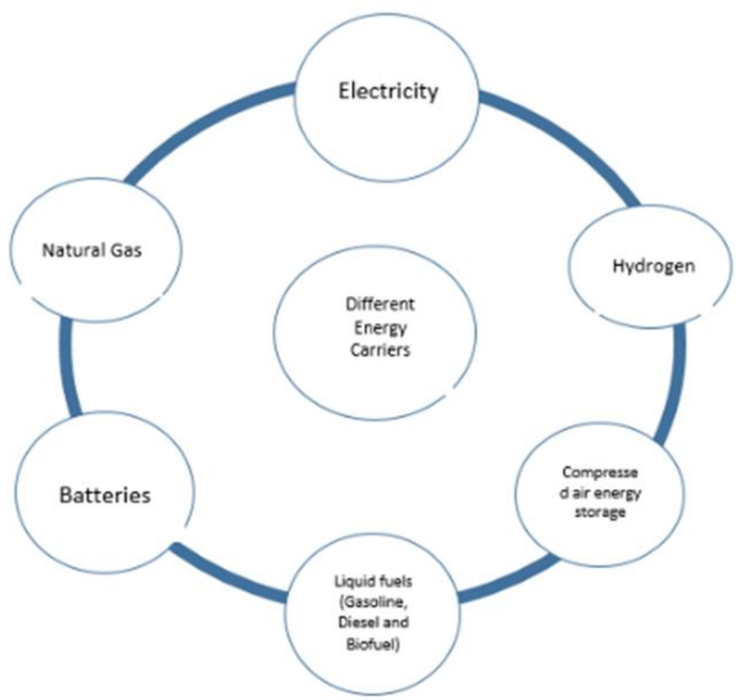

Figure 1. Different energy carriers in renewable energy (Adopted from **Yildizbasi et al.,2021**)

Technological advancements will be pivotal to this progression. Tailoring AI solutions to accommodate diverse economic and infrastructural contexts is essential for ensuring their global accessibility. As investments in renewable energy, especially solar, expand, artificial intelligence may assist in improving forecasts, optimizing grid integration, and bolstering resilience against climatic concerns such as fluctuating weather patterns. Rural development will be a primary emphasis in the forthcoming years. Artificial intelligence can mitigate the digital gap by revolutionizing agricultural methodologies, educational systems, and healthcare services in marginalized areas. By demonstrating real, localized uses of AI, we may empower rural people and illustrate their ability to enhance livelihoods and strengthen resilience **(Liu et al., 2024; Sunny et al., 2020)**. Subsequent study ought to examine the ecological ramifications of artificial intelligence. Although AI can enhance the integration of renewable energy, its energy consumption poses a threat to sustainability initiatives. Optimizing AI models, minimizing the energy consumption of data centers, and incorporating AI into national energy policies will be essential for achieving a beneficial long-term effect (Figure 2). Let us concentrate on dismantling current obstacles and implementing novel techniques. In this context, we can assist in guaranteeing that AI contributes significantly to the development of a more inclusive, robust, and efficient energy environment (Table 1). The future of AI in energy relies on the synchronization of technology progress with ethical governance, flexible policies, and community empowerment. By adhering to principles of equality and sustainability, AI can play a significant role in transitioning to renewable energy systems that meet global needs while also promoting agricultural and rural development initiatives.

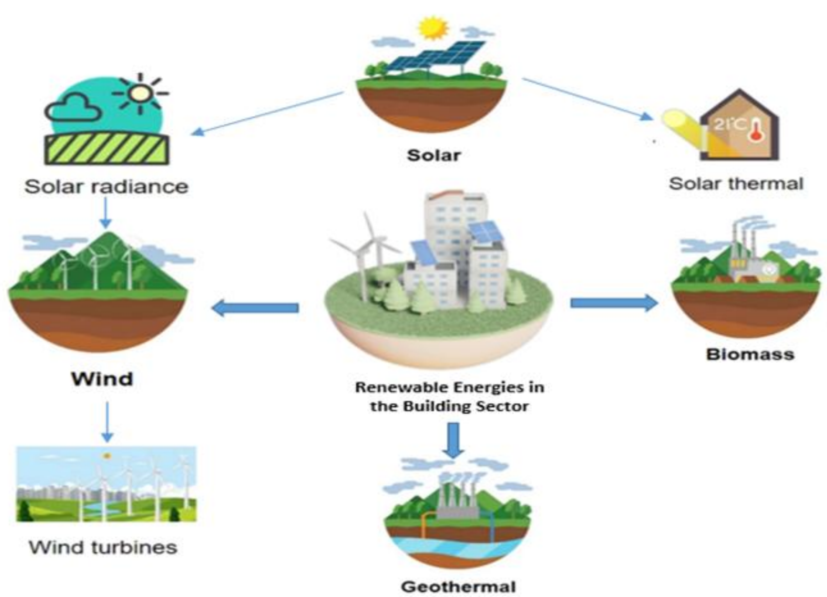

Figure 2. Green building practices to integrate renewable energy in construction site (Adopted from **Zhong et al.,2020).**

3. Discussion

Artificial intelligence (AI) has emerged as a disruptive force in the global energy sector, with significant potential to improve the adoption of renewable energy, maximize resource utilization, and facilitate sustainable agriculture practices. Integrating AI with renewable energy sources can address critical difficulties in agriculture and rural development. As global food consumption is projected to increase substantially in the forthcoming decades, conventional agricultural systems face considerable pressure to enhance productivity, reduce resource waste, and maintain environmental sustainability **(Marzban et al., 2022; Sunny et al., 2020).** AI-driven renewable energy technologies, such as intelligent irrigation systems, predictive analytics, and energy-efficient solar installations, offer a comprehensive framework for tackling these challenges, facilitating data-informed decision-making, enhancing operational efficiency, and fostering more resilient agricultural ecosystems. The integration of AI in renewable energy management allows meticulous oversight of the whole energy generation, storage, and consumption process. Advanced algorithms, particularly those rooted in machine learning and deep learning, enable predictive forecasting of solar and wind energy production. This functionality facilitates enhanced scheduling and load control, as AI systems evaluate real-time data from sensors, IoT devices, and historical trends to predict intervals of elevated or diminished energy generation (Chowdhury et al., 2025). This foresight is essential in rural agricultural settings, where energy supplies may be irregular, and resource efficiency is directly correlated with crop yields and the sustainability of livelihoods. Moreover, AI improves energy storage optimization by assessing battery quality and forecasting charge-discharge cycles, therefore guaranteeing a stable power supply even during periods of diminished renewable energy generation. The use of digital twin technologies enhances operational efficiency by generating virtual models of energy systems that allow real-time simulations and predictive maintenance, hence minimizing downtime and extending equipment longevity. In the agricultural industry, AI-driven renewable energy applications extend beyond energy management; they substantially improve production and sustainability.

Intelligent irrigation systems employ AI algorithms to ascertain ideal watering schedules by evaluating soil moisture levels, meteorological predictions, and crop needs **(López et al., 2022; Mithun et al., 2024).** This method not only minimizes water waste but also guarantees uniform crop development and alleviates the impacts of unpredictable climate conditions. Likewise, AI-driven technologies for pest and nutrient management use environmental and agricultural data to forecast insect outbreaks or nutrient shortages. This allows tailored treatments that reduce chemical consumption while preserving yield quality. The integration of AI applications with renewable energy sources, especially solar power, allows agrovoltaics, a novel approach that simultaneously employs farmland for solar energy generation and agricultural output. This dual-use strategy diversifies farmers' income while supplying clean, stable energy for agricultural activities, hence diminishing reliance on fossil fuels and improving overall sustainability **(Rana et al., 2023; Mahin et al., 2021).** Notwithstanding these myriad advantages, the deployment of AI-driven renewable energy systems presents considerable hurdles, both technological and socio-economic. The significant initial investment required for AI infrastructure, renewable energy technology, and the necessity for specialized labor might pose a considerable obstacle for small-scale farmers and rural communities. The prevailing digital gap intensifies inequality, as several rural regions lack dependable internet access and digital literacy, obstructing the efficient use of AI technologies. Moreover, social and cultural elements, including opposition to new technologies, distrust of automation, and the exodus of skilled individuals to urban areas for improved prospects, can hinder local capacity development and undermine the enduring sustainability of AI integration **(Miskat et al., 2023**). Ethical considerations, encompassing data privacy, algorithmic bias, and the judicious use of sensitive information, provide further problems, particularly in systems that collect and analyze substantial amounts of community and operational data **(Ashok et al., 2025; Sazzad et al., 2024).** In the absence of appropriate ethical frameworks and regulatory monitoring, the deployment of AI may unintentionally exacerbate existing inequalities in energy access and agricultural output. Regulatory and legislative frameworks are crucial in influencing the acceptance and efficacy of AI-driven renewable energy solutions. Numerous prevailing energy policies preferentially support traditional energy sources, generating uncertainty for entrepreneurs keen to deploy AI-driven green technology.

Policymakers must consequently create adaptive policies that promote innovation while safeguarding grid stability and consumer safety. Public-private partnerships are essential in this setting, since they enable cost-sharing, risk reduction, and resource mobilization. Collaborations may propel essential developments in AI and renewable energy, fostering a more sustainable future for agricultural and rural communities. Progress in quantum machine learning, decentralized energy networks, and edge computing offers promising prospects for improving the efficiency and robustness of our systems **(Sazzad et al., 2025; Chowdhury et al., 2024).** By incorporating insights from social sciences, behavioral studies, and community-based research, we can tailor AI applications to local requirements, thereby promoting equal access and sustainable outcomes. It is crucial to consider the environmental impact of AI, especially with the energy consumption linked to data centers and computational operations. The emphasis on improving AI-driven energy systems is essential for ensuring their long-term sustainability and enhancing the advantages of renewable energy transitions **(Islam et al., 2025; Sunny et al., 2019)**. Through the ongoing refinement of algorithms, the optimization of infrastructure efficiency, and the incorporation of real-time data analytics, AI may markedly enhance the dependability and performance of renewable energy systems. This guarantees a reliable energy supply for agricultural activities while minimizing waste and environmental effect, thus fostering a more robust and efficient energy ecosystem. AI's capacity to analyze extensive datasets and forecast trends enables communities to anticipate energy requirements, prepare for seasonal fluctuations, and react proactively to unforeseen interruptions, rendering the systems far more resilient than conventional energy models **(Mohammadi et al., 2022; Ifty et al., 2024).**

AI-driven renewable energy systems provide dramatic potential for rural development that surpasses mere agricultural output. These technologies facilitate local education, skills development, and sustainable employment, thereby mitigating rural-to-urban migration by maintaining skilled people within their communities. AI integration fosters local economic prospects and self-reliance; hence, it enhances socio-economic stability and enables rural communities to prosper in previously impossible ways. Exhibiting real, localized uses of AI enhances community empowerment by enabling the observation of visible advantages; hence, it fosters adoption and sustains long-term participation. Farmers, local technicians, and community leaders develop trust in these systems as they observe enhancements in efficiency, productivity, and energy accessibility, so confirming the significance of sustainable technology investments **(Chowdhury et al., 2025; Ifty et al., 2023b).** Equally crucial is the alignment of AI development with ethical ideals and inclusive policy frameworks. To ensure that technology advancement benefits all stakeholders, it is essential to address possible adverse effects, like unequal energy distribution, data privacy issues, and job displacement due to automation. Ethical governance, transparency, and participatory decision-making are crucial to avert these difficulties from eroding community confidence or exacerbating existing inequities. By incorporating these concepts into AI deployment methods, policymakers and developers may guarantee that the shift to renewable energy is socially responsible and economically advantageous **(Niazkar et al., 2023; Chowdhury et al., 2022).** The incorporation of AI-driven renewable energy signifies a crucial juncture in the advancement of agricultural and rural development. The potential advantages are considerable, including increased energy efficiency, greater agricultural output, socio-economic empowerment, and environmental sustainability; yet, the process of effective adoption is complex and diverse. Surmounting economic, social, regulatory, and technological obstacles necessitates a synchronized and cooperative strategy that engages politicians, private sector participants, researchers, and local communities. Investment in digital infrastructure, skills enhancement, and accessible technology is essential for closing disparities and enabling rural communities to fully utilize AI advancements. Future endeavors should emphasize adaptable and context-specific legislative frameworks, technological advances suited to local requirements, multidisciplinary cooperation, and ethical governance **(Chowdhury et al., 2025 Hossain et al., 2024).** Research and development must concentrate on enhancing AI algorithms for energy efficiency, incorporating renewable energy systems into local agriculture methods, and devising inclusive models that empower communities. By proactively tackling these difficulties, AI can transform agricultural and rural energy systems, fostering resilient, inclusive, and sustainable communities capable of meeting the needs of a fast-evolving world. The intentional incorporation of AI-driven renewable energy may enhance rural livelihoods, bolster local economies, and establish sustainable, climate-resilient agricultural environments while guaranteeing fair access to energy and technology **(Fahad et al., 2022; Ifty et al., 2023a).**

4. Challenges and Future Directions

Although the integration of artificial intelligence (AI) into renewable energy systems presents significant potential, it also entails distinct obstacles that require direct attention. From a technological perspective, a significant challenge is guaranteeing data quality and accessibility. Artificial intelligence relies on extensive, precise, and uniform information; nevertheless, several areas, particularly rural regions, have challenges with erratic data collecting and monitoring systems. The absence of dependable data can impede the efficacy of AI models. Furthermore, the intricate characteristics of advanced AI necessitate considerable processing power and specialized knowledge, which may be scarce in developing regions **(Nishant et al., 2020; Chowdhury et al., 2021**). The lack of definitive rules regarding AI utilization in the energy sector exacerbates this complexity, resulting in uncertainty for investors and practitioners and hindering the speed of adoption. To achieve significant advancement, it is essential to cultivate cooperation among governments, enterprises, and local communities. By adopting transparent data-sharing methods and inclusive regulations, we can guarantee that developing technologies benefit all individuals equitably. Future improvements in AI are crucial for overcoming these issues. Emerging domains such as quantum machine learning and blockchain technology have the capacity to enhance energy systems significantly. They provide expedited calculations, safe data transmission, and prospects for peer-to-peer energy trading. These advances might enhance our energy systems, provide access to inexpensive energy for rural people, and advance our transition to more sustainable energy sources **(Shahbaz et al., 2022; Chowdhury et al., 2020).** Nevertheless, inclusion and responsiveness to local requirements are essential for sustained success. The socio-economic ramifications of AI in renewable energy are significant. Integrating AI with renewable energy can significantly improve energy availability, agricultural output, and overall resilience for rural areas reliant on traditional energy sources. Access to dependable, clean energy facilitates critical operations like irrigation and agricultural processing, hence enhancing food security.

It is essential to confront the digital gap that deprives several smallholder farmers and rural inhabitants of sufficient internet access and the requisite digital competencies to effectively utilize AI technology. This exclusion can exacerbate disparities, resulting in certain groups lagging farther behind while others prosper. In agriculture, artificial intelligence may enhance sustainability and save expenses by optimizing the utilization of resources such as water, fertilizers, and pesticides. Through the assessment of soil health and the anticipation of pest infestations, farmers may mitigate environmental repercussions and adjust to the adversities presented by climate change. However, for these advantages to result in tangible transformation, it is imperative that rural people have access to these technologies, along with the requisite training for their efficient use **(Akhter et al., 2025; Tutak et al., 2020).** Education and community involvement are essential for leveraging the future capabilities of AI in renewable energy and agriculture. Successful transition necessitates active participation from communities in the construction and governance of local energy systems, such as microgrids. Equipping rural communities, particularly women and youth, with technical skills and decision-making capabilities may cultivate a feeling of ownership and empowerment. Investment in inclusive education and training initiatives, along with ethical frameworks that emphasize local need, will be imperative. Communities ought to be regarded as essential players, utilizing AI as an instrument for emancipation and autonomy rather than as an externally imposed force. The amalgamation of AI with renewable energy presents complex challenges technical, legislative, and socio-economic yet the potential for beneficial transformation is substantial. By tackling concerns related to data quality, inclusiveness, and capacity-building through strategic policies and educational programs, AI-driven renewable energy systems can emerge as a significant catalyst for sustainable development in rural regions. The next trip necessitates collaboration across many sectors and ethical governance focused on community needs, guaranteeing that the advantages of emerging technologies are accessible to all **(Alam et al., 2023; Chowdhury et al., 2020).**

Table 1. The role of AI in renewable energy and rural/agricultural development.

Sl. No.	Data	Reference
1	AI improves agricultural efficiency through smart irrigation, yield prediction, and pest/nutrient management.	Agostinelli, S., Cumo, F., Guidi, G., & Tomazzoli, C. (2021). *Energies, 14*, 2338. https://doi.org/10.3390/en14082338
2	Agrovoltaics (dual-use of land for farming + solar energy) enhances resilience and income in rural areas.	Al-Othman, A., Tawalbeh, M., Martis, R., Dhou, S., Orhan, M., Qasim, M., & Ghani Olabi, A. (2022). *Energy Conversion and Management, 253*, 115154. https://doi.org/10.1016/j.enconman.2022.115154

3	AI boosts rural livelihoods by supporting energy access, productivity, and reducing reliance on fossil fuels.	Awan, A., Abbasi, K. R., Rej, S., Bandyopadhyay, A., & Lv, K. (2022). *Renewable Energy, 189*, 454–466. https://doi.org/10.1016/j.renene.2022.03.051
4	Neural networks and AI applications optimize renewable energy systems.	Babatunde, D. E., Anozie, A. N., & Omoleye, J. A. (2020). *Int. J. Energy Economics and Policy, 10*, 250–264. https://doi.org/10.32479/ijeep.10119
5	AI enhances battery health monitoring, charging cycles, and efficiency.	Bashir, M. F., Ma, B., Hussain, H. I., Shahbaz, M., Koca, K., & Shahzadi, I. (2022). *Renewable Energy, 184*, 541–550. https://doi.org/10.1016/j.renene.2021.12.087
6	Digital twins in energy management improve real-time operations and predictive maintenance.	Deng, Y., Jiang, W., & Wang, Z. (2023). *Resources Policy, 82*, 103522. https://doi.org/10.1016/j.resourpol.2023.103522
7	AI-driven smart grids enable predictive maintenance and energy demand balancing.	Di Vaio, A., Palladino, R., Hassan, R., & Escobar, O. (2020). *Journal of Business Research, 121*, 283–314. https://doi.org/10.1016/j.jbusres.2020.08.024
8	AI applications reduce downtime by detecting defects in solar/wind systems.	Dogaru, L. (2020). *Procedia Manufacturing, 46*, 397–401. https://doi.org/10.1016/j.promfg.2020.03.065
9	AI supports decarbonization through cyber-physical systems and smart cities.	Inderwildi, O., Zhang, C., Wang, X., & Kraft, M. (2020). *Energy & Environmental Science, 13*, 744–771. https://doi.org/10.1039/C9EE03087H
10	AI can bridge digital divide and empower rural communities with green jobs.	Leal Filho, W., Yang, P., Eustachio, J. H. P. P., Azul, A. M., Gellers, J. C., Gielczyk, A., Dinis, M. A. P., & Kozlova, V. (2023). *Environment, Development and Sustainability, 25*, 4957–4988. https://doi.org/10.1007/s10668-022-02929-6

5. Conclusions and Future Actions

AI-driven integration of renewable energy is transforming agriculture and rural development by enhancing efficiency, sustainability, and resilience in farming practices. AI enhances production for farmers by optimizing energy management, resource use, and decision-making, all while safeguarding the environment. However, we must meticulously handle issues such as elevated prices, restricted internet access, regulatory obstacles, and ethical dilemmas to ensure equitable benefits for all. The future resides in collaborative methodologies that integrate technical innovation with inclusive legislation, education, and community involvement. When utilized judiciously, AI may enhance rural communities, bolster local economies, and establish sustainable agriculture and energy systems that address increasing global demands.

Funding

This work had no outside funding.

Author Contribution

The authors were involved in the creation of the study design, data analysis, and execution stages. Every writer gave their consent after seeing the final work.

Acknowledgments

We would like to thank the authors of the reviewed articles

A statement of conflicting interests

The authors declare that none of the work reported in this study could have been impacted by any known competing financial interests or personal relationships.

5. References

Agostinelli, S., Cumo, F., Guidi, G., & Tomazzoli, C. (2021). Cyber-physical systems improving building energy management: Digital twin and artificial intelligence. Energies, 14, 2338.

Akhter, S., Ansari, M. A. S., Tiva, M. G., & Bhuyian, M. S. (2025). Improving Treatments for Oral Diseases, Head and Neck Cancers, as well as Developing New Technologies. Pathfinder of Research, 3(1), 1-25.

Alam, K., Chowdhury, M. Z. A., Jahan, N., Rahman, K., Chowdhury, R., Mia, M. T., & Mithun, M. H. (2023). Relationship between Brand Awareness and Customer Loyalty in Bangladesh: A Case Study of Fish Feed Company. Journal of Knowledge Learning and Science Technology ISSN: 2959-6386 (online), 2(3), 212-222.

Al-Othman, A., Tawalbeh, M., Martis, R., Dhou, S., Orhan, M., Qasim, M., & Ghani Olabi, A. (2022). Artificial intelligence and numerical models in hybrid renewable energy systems with fuel cells: Advances and prospects. Energy Conversion and Management, 253, 115154.

Ashok Kumar Chowdhury, Islam, &. R. (2025). "Economic Feasibility of Al-Based Distributed Energy Systems in Agricultural Enterprises", Business & Social Sciences, 3(1),1-6,10300.

Awan, A., Abbasi, K. R., Rej, S., Bandyopadhyay, A., & Lv, K. (2022). The impact of renewable energy, internet use, and foreign direct investment on carbon dioxide emissions: A method of moments quantile analysis. Renewable Energy, 189, 454–466.

Babatunde, D. E., Anozie, A. N., & Omoleye, J. A. (2020). Artificial neural network and its applications in the energy sector—An overview. International Journal of Energy Economics and Policy, 10, 250–264.

Bashir, M. F., Ma, B., Hussain, H. I., Shahbaz, M., Koca, K., & Shahzadi, I. (2022). Evaluating environmental commitments to COP21 and the role of economic complexity, renewable energy, financial development, urbanization, and energy innovation: Empirical evidence from the RCEP countries. Renewable Energy, 184, 541–550.

Chowdhury, A. K. (2025). "Smart Renewable Energy Integration for Precision Agriculture in Off-Grid Areas", Applied Agriculture Sciences, 3(1),1-6,10286.

Chowdhury, A. K., Aziz, M. S. M. (2025). "Al-Driven Microgrid Solutions for Enhancing Irrigation Efficiency in Rural Farming", Applied Agriculture Sciences, 3(1),1-6,10299.

Chowdhury, A. K., Hossain, M. M. (2025). "Exploring the Role of Renewable Energy in Enhancing Rural Livelihoods", Energy Environment and Economy, 3(1),1-7,10328.

Chowdhury, A. K., Islam, M. R. (2025). "Spatiotemporal Assessment of Socio-Technical Factors in Deploying AI-Based Renewable Energy Solutions in Agricultural Communities", 6(1),1-8,10313. Journal of Primeasia,

Chowdhury, A. K., Islam, M. R., & Hossain, M. M. (2024). Accelerating the Transition to Renewable Energy in Contemporary Power Systems: A Survey-Based Analysis from Bangladesh. Energy Environment & Economy. 2(1), 1-7.

Chowdhury, R., Fahad, M. A. H., Alam, S. S., Tusher, M. I., Rana, M. N. U., Ahmed, E., ... & Mahin, M. R. H. (2020). Database Management in the Era of Big Data: Trends, Challenges, and Breakthroughs. *Pathfinder of Research*, *1*(1), 15-15.

Chowdhury, T. E. C. T. E., Chowdhury, R. C. R., Alam, S. S. A. S. S., & Sazzad, S. A. S. S. A. (2020). Empowering Change: The Impact of Microcredit on Social Business Development. *Pathfinder of Research*, *1*(1), 13-13.

Chowdhury, T. E. C. T. E., Chowdhury, R. C. R., Chaity, N. S. C. N. S., & Sazzad, S. A. S. S. A. (2021). From Shadows to Sunrise: The Impact of Solar Power Plants on Enhancing Bangladesh's Economy. *Pathfinder of Research*, *2*(1), 16-16.

Chowdhury, T. E. C. T. E., Chowdhury, R. C. R., Rahman, M. M. R. M. M., & Sunny, A. R. S. A. R. (2022). From Crisis to Opportunity: How Covid-19 Accelerated the Global Shift to Online Business. *Pathfinder of Research*, *3*(1), 18-18.

Chowdhury, T. E., Chowdhury, R., & Urbi, S. R. C. (2025). Integrating Artificial Intelligence into Business Analytics: Sectoral Adoption Patterns and Strategic Implications in the United States. *Pathfinder of Research*, *3*(1), 72-97.

Deng, Y., Jiang, W., & Wang, Z. (2023). Economic resilience assessment and policy interaction of coal resource-oriented cities for the low-carbon economy based on AI. Resources Policy, 82, 103522.

Di Vaio, A., Palladino, R., Hassan, R., & Escobar, O. (2020). Artificial intelligence and business models in the sustainable development goals perspective: A systematic literature review. Journal of Business Research, 121, 283–314.

Dogaru, L. (2020). The main goals of the fourth industrial revolution. Renewable energy perspectives. Procedia Manufacturing, 46, 397–401.

Fahad, M. A. H., & Chowdhury, R. (2022). Evolution and Future Trends in Web Development: A Comprehensive Review. *Pathfinder of Research*, *3*(1), 13-13.

Ghadami, N., Gheibi, M., Kian, Z., Faramarz, M. G., Naghedi, R., Eftekhari, M., Fathollahi-Fard, A. M., Dulebenets, M. A., & Tian, G. (2021). Implementation of solar energy in smart cities using an integration of an artificial neural network, a photovoltaic system, and classical Delphi methods. Sustainable Cities and Society, 74, 103149. https://doi.org/10.1016/j.scs.2021.103149

He, Z., Guo, W., & Zhang, P. (2022). Performance prediction, optimal design, and operational control of thermal energy storage using artificial intelligence methods. Renewable and Sustainable Energy Reviews, 156, 111977. https://doi.org/10.1016/j.rser.2021.111977

Hossain, B., Chowdhury, T. E., Fahad, M. A. H., Hossen, M. E., Ahmed, R., Nesa, A., ... & Sunny, A. R. (2024). Machine Learning for Cardiovascular Healthcare: Opportunities, Challenges, and the Path Forward. *Integrative Biomedical Research*, *8*(12), 1-11.

Hossain, B., Sunny, A. R., Gazi, M. M. R. N., Das, A. R., Mohajon, R., Miah, T. H., & Rana, M. N. U. (2024). Advancing fish farming through deep learning: Applications, opportunities, challenges, and future directions. Pathfinder of Research, 2(3), 58–80.

Ifty, S.M.H, Bayazid, H., Ashakin, M.R., Tusher, M.I., Shadhin, R. H., Hoque, J., Chowdhury, R. & Sunny, A.R. et al. (2023b). Adoption of IoT in Agriculture - Systematic Review, Applied Agriculture Sciences, 1(1), 1-10, 9676

Ifty, S.M.H., Irin, F., Shovon, M.S.S., Amjad, M.H.H., Bhowmik, P.K., Ahmed, R., Ashakin, M.R., Hossain, B., Mushfiq, M., Sattar, A., Chowdhury, R. & Sunny, A.R. (2024). Advancements, Applications, and Future Directions of Artificial Intelligence in Healthcare, Journal of Angiotherapy, 8(8), 1-18, 9843, 10.25163/angiotherapy.889843

Ifty, S.M.H., S.M., Ashakin, M.R., Hossain, B., Afrin, S., Sattar, A., Chowdhury, R., Tusher, M.I., Bhowmik, P.K., Mia, M.T., Islam, T., Tufael, M. & Sunny, A.R. (2023a). IOT-Based Smart Agriculture in Bangladesh: An Overview. Applied Agriculture Sciences, 1(1), 1-6. 9563, 10.25163/agriculture.119563

Inderwildi, O., Zhang, C., Wang, X., & Kraft, M. (2020). The impact of intelligent cyber-physical systems on the decarbonization of energy. Energy & Environmental Science, 13, 744–771.

Islam, M. R., Chowdhury, A. K. (2025). "The Socio-economic Effects of Transitioning from Conventional Energy Sources to Renewable Energy Systems", Energy Environment and Economy, 3(1),1-8,10320.

Islam, M.M., Sunny, A.R., Hossain, M.M., Friess, D. A., 2018. Drivers of mangrove ecosystem service change in the Sundarbans of Bangladesh. Singapore Journal of Tropical Geography, 2018; 39(2).

Leal Filho, W., Yang, P., Eustachio, J. H. P. P., Azul, A. M., Gellers, J. C., Gielczyk, A., Dinis, M. A. P., & Kozlova, V. (2023). Deploying digitalisation and artificial intelligence in sustainable development research. Environment, Development and Sustainability, 25, 4957–4988.

Li, C., Tang, W., Liang, F., & Wang, Z. (2024). The impact of climate change on corporate ESG performance: The role of resource misallocation in enterprises. Journal of Cleaner Production, 445, 141263.

Liu, T., Guan, X., Wang, Z., Qin, T., Sun, R., & Wang, Y. (2024). Optimizing green supply chain circular economy in smart cities with integrated machine learning technology. Heliyon, 10, e29825.

López González, D. M., & Garcia Rendon, J. (2022). Opportunities and challenges of mainstreaming distributed energy resources towards the transition to more efficient and resilient energy markets. Renewable and Sustainable Energy Reviews, 157, 112018. https://doi.org/10.1016/j.rser.2021.112018

Mahin, M. R. H., Ahmed, E., Akhi, S. S., Fahad, M. A. H., Tusher, M. I., Chowdhury, R., & Rana, M. N. U. (2021). Advancements and Challenges in Software Engineering and Project Management: A 2021 Perspective. *Pathfinder of Research*, *2*(1), 15-15.

Marzban, N., Libra, J. A., Hosseini, S. H., Fischer, M. G., & Rotter, V. S. (2022). Experimental evaluation and application of genetic programming to develop predictive correlations for hydrochar higher heating value and yield to optimize the energy content. Journal of Environmental Chemical Engineering, 10, 108880. https://doi.org/10.1016/j.jece.2022.108880

Miskat, M. I., Sarker, P., Chowdhury, H., Chowdhury, T., Rahman, M. S., Hossain, N., Chowdhury, P., & Sait, S. M. (2023). Current scenario of solar energy applications in Bangladesh: Techno-economic perspective, policy implementation, and possibility of the integration of artificial intelligence. Energies, 16, 1494.

Mithun, M. H., Shaikat, M. F. B., Sazzad, S. A., Billah, M., Al Salehin, S., Foysal, M., ... & Sunny, A. R. (2024). Microplastics in Aquatic Ecosystems: Sources, Impacts, and Challenges for Biodiversity, Food Security, and Human Health-A Meta Analysis. Journal of Angiotherapy, 8(11), 1-12.

Mohammadi, E., Alizadeh, M., Asgarimoghaddam, M., Wang, X., & Simões, M. G. (2022). A review on application of artificial intelligence techniques in microgrids. IEEE Journal of Emerging and Selected Topics in Industrial Electronics, 3, 878–890.

Niazkar, M., Goodarzi, M. R., Fatehifar, A., & Abedi, M. J. (2023). Machine learning-based downscaling: Application of multi-gene genetic programming for downscaling daily temperature at Dogonbadan, Iran, under CMIP6 scenarios. Theoretical and Applied Climatology, 151, 153–168.

Nishant, R., Kennedy, M., & Corbett, J. (2020). Artificial intelligence for sustainability: Challenges, opportunities, and a research agenda. International Journal of Information Management, 53, 102104.

Rana, M. N. U., Akhi, S. S., Tusher, M. I., Bashir, M., Mahin, M. R. H., Ahmed, E., Chowdhury, T. E., & Chowdhury, R. (2023). The Role of AI and Generative AI in US Business Innovations, Applications, Challenges, and Future Trends. Pathfinder of Research, 1(3), 17-33.

Sazzad, S. A. S. S. A., Ana, R. A. R. S. R., Shawon, R., Moniruzzaman, M., Hussain, M. H. M., & Zaman, F. Z. F. (2024). Climate Change and Socioeconomic Challenges of Fishing Communities in the Coastal District of Shariatpur in Bangladesh. *Pathfinder of Research*, *2*(1).

Sazzad, S. A., Chowdhury, R., Hasan, M. R., Tiva, M. G., Rahman, K., Ansari, M. A. S., & Sunny, A. R. (2025). Public Health, Risk Perception, and Governance Challenges in the 2025 Los Angeles Wildfires: Evidence from a Community-Based Survey. *Pathfinder of Research*, *3*(1), 26-41.

Shahbaz, M., Wang, J., Dong, K., & Zhao, J. (2022). The impact of digital economy on energy transition across the globe: The mediating role of government governance. Renewable and Sustainable Energy Reviews, 166, 112620.

Sunny, A. R., Ahamed, G. S., Mithun, M. H., Islam, M. A., Das, B., Rahman, A., ... & Chowdhury, M. A. (2019). Livelihood status of the hilsa (Tenualosa ilisha) Fishers: The case of coastal fishing community of the Padma River. *Bangladesh. J Coast Zone Manag*, *22*(2), 469.

Sunny, A. R., Alam, R., Sadia, A. K., Miah, Y., Hossain, S., & Mofiz, S. B. (2020). Factors affecting the biodiversity and human well-being of an ecologically sensitive wetland of North Eastern Bangladesh. *Journal of Coastal Zone Management*, *23*(1), 471.

Sunny, A. R., Prodhan, S. H., Ashrafuzzaman, M., Sazzad, S. A., Aminur Rahman, S. M., Billah, M. M., ... & Alam, M. T. (2021). Livelihoods and Vulnerabilities of Small-Scale Fishers to the Impacts of Climate Variability and Change: Insights from the Coastal Areas of Bangladesh. *Egyptian Journal of Aquatic Biology & Fisheries*, *25*(4).

Sunny, A. R., Rahman, M. A., Hasan, M. N., Bhuyian, M. S., Miah, M. F., Ashrafuzzaman, M., Pervin, A., Rahman, J. F., & Prodhan, S. H. (2025a). *Hilsa (Tenualosa ilisha) genetic diversity and conservation strategies for sustainable wetland management in northeastern Bangladesh*. Egyptian Journal of Aquatic Biology & Fisheries, 29(1), 1089–1105. https://doi.org/10.21608/ejabf.2025.259581

Sunny, A. R., Sazzad, S. A., Bhuyian, M. S., Hasan, M. N., Miah, M. F., Ashrafuzzaman, M., & Prodhan, S. H. (2025b). Fish Genetic Resources and Wetland Conservation in Bangladesh: Comparative Insights on Biodiversity, Sustainable Management, and Sustainable Development Goals. *Limnological Review*, *25*(2), 20. https://doi.org/10.3390/limnolrev25020020

Sunny, A.R., Sazzad, S.A. & Mithun, M. H. (2023). Fishing Bans and Compensation Schemes for Fisheries Conservation and Livelihood Development: Challenges and Opportunities. In book: Small is Scale, Big In Contributions: Advancing Knowledge of Small-Scale Fisheries in Bangladesh, Chapter: 30 , Publisher: TBTI Global Book Series

Tiva, M. G., Tarin, N. N., Hasan, M. R. K., Urbi, S. R. C., & Sazzad, S. A. (2025a). Post-COVID-19 Work force Management in US Healthcare: Burnout, Retention, and Strategies for Enhancing Cultural Competency. Pathfinder of Research, 3(1), 98-119.

Tiva, M. G., Urbi, S. R. C. & Hasan, M. R. K. (2025b). Preventable Readmissions and Financial Management in Healthcare: A Comparative Study of Cost Containment in Non-Profit and For-Profit Hospitals. Pathfinder of Research,3(2), 1-21

Tutak, M., Brodny, J., Siwiec, D., Ulewicz, R., & Bindzár, P. (2020). Studying the level of sustainable energy development of the European Union countries and their similarity based on the economic and demographic potential. Energies, 13, 6643. https://doi.org/10.3390/en13246643

Urbi, S. R. C., & Tiva, M. G. (2025). Technology and Innovation in Healthcare: Adoption of AI and Predictive Analytics in Hospital Management. *Pathfinder of Research*, *3*(2), 22-45.

Yildizbasi, A. (2021). Blockchain and renewable energy: Integration challenges in circular economy era. Renewable Energy, 176**,** 183–197.

Zhong, Z., Peng, B., Xu, L., Andrews, A., & Elahi, E. (2020). Analysis of regional energy economic efficiency and its influencing factors: A case study of Yangtze River urban agglomeration. Sustainable Energy Technologies and Assessments, 41, 100784.