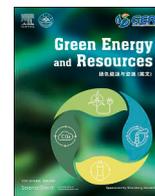




Contents lists available at ScienceDirect

Green Energy and Resources

journal homepage: www.journals.elsevier.com/green-energy-and-resources

Editorial: AI-driven green revolution

At the 2019 UN Climate Summit, global leaders pledged to achieve net-zero carbon dioxide (CO₂) emissions by 2050. This ambitious goal has catalyzed innovation in the energy and environmental sectors, pushing industries to adopt greener, more sustainable solutions (Soni et al., 2024; Dwivedi et al., 2021). As societies strive to mitigate the environmental impact of traditional energy sources, technologies like solar photovoltaics, biomass energy, geothermal systems, and wind power are increasingly gaining momentum. However, achieving sustainability targets at scale requires the adoption of transformative technologies, with Artificial Intelligence (AI) emerging as one of the most promising enablers.

Recent advancements in AI—spurred by improvements in computational power, data availability, and affordable sensor technologies—have positioned it as a pivotal tool for tackling some of the most pressing sustainability challenges. AI-driven approaches offer unprecedented capabilities for process optimization, real-time data analysis, and autonomous decision-making, allowing for smarter, more efficient systems across energy production, distribution, consumption, and environmental management.

AI's influence on sustainable energy and environmental management is multifaceted. Here are some examples that illustrate AI's broad and transformative impact (Duan et al., 2019; Boza and Evgeniou, 2021; Huang and Koroteev, 2021; Ghahramani et al., 2020; Saberikamarposhti et al., 2024; Priya et al., 2023; Abdalla et al., 2021).

- 1. Smart Grids and Renewable Integration:** AI-driven strategies predict energy demand, manage supply fluctuations, and optimize load balancing within smart grids. By incorporating renewable energy sources, such as solar and wind, AI ensures reliable power distribution, reducing energy loss and improving efficiency.
- 2. Smart Energy Storage system:** AI optimizes battery charging and discharging cycles, predicts storage degradation, detect faults and risks, and manages grid-scale storage integration. Through coordinating diverse energy storage resources, AI balance energy supply-demand, enhance battery lifespan, and provides reliable grid support services.
- 3. Precision Agriculture:** AI-enabled tools analyze data from sensors, drones, and satellites to optimize water use, fertilizer application, and crop yield. By offering actionable insights into soil health, pest control, and weather conditions, AI enhances agricultural productivity while minimizing resource wastage and environmental harm.

- 4. Sustainable Water Management:** AI technologies monitor and optimize water consumption in urban and industrial infrastructure. For example, AI-powered systems detect leaks, predict demand patterns, and automate irrigation processes, promoting water conservation and reducing operational costs.
- 5. Waste Management and Recycling:** AI-driven robotics and computer vision systems enhance recycling processes by accurately sorting materials, reducing contamination, and improving recycling rates. Additionally, AI algorithms optimize waste collection routes, minimizing emissions and fuel consumption.
- 6. Greenhouse Gas Monitoring:** Machine learning models analyze emissions data to identify patterns, forecast trends, and propose mitigation strategies. AI solutions support industrial optimization by detecting inefficiencies and automating emissions-reduction measures, reducing carbon footprints through energy-efficient processes.
- 7. Carbon Capture:** AI systems optimize carbon capture processes, monitor storage site integrity, analyze patent landscape, predict optimal capture conditions and real-time efficiency. Machine learning models help identify suitable geological storage locations and monitor leakage risks.
- 8. Energy-Efficient Buildings:** AI-based building management systems analyze occupancy patterns, energy consumption, and environmental conditions to optimize heating, ventilation, and lighting systems. These technologies significantly reduce energy demand while improving occupant comfort.
- 9. Sustainable Transportation:** AI facilitates intelligent traffic systems, electric vehicle (EV) management, and autonomous transportation networks. By optimizing routes, reducing congestion, and managing EV charging infrastructure, AI lowers greenhouse gas emissions and enhances transportation efficiency.
- 10. Smart Manufacturing:** In industrial settings, AI-driven predictive analytics identify inefficiencies, minimize energy use, predict equipment maintenance, and optimize production processes. Automation and resource-efficient AI solutions enable industries to move toward circular economy models.

Despite its transformative potential, the integration of AI in sustainable energy and environmental sectors is not without challenges. Key barriers include data availability, quality, and reliability—issues that are particularly prominent in engineering applications. Engineering datasets are often characterized by low volume, high noise, and incomplete or restricted data. This heterogeneous data nature,

This article is part of a special issue entitled: AI for Sustainability published in Green Energy and Resources.

<https://doi.org/10.1016/j.gerr.2025.100144>

2949-7205/© 2025 The Authors. Published by Elsevier B.V. on behalf of Shandong University. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

combined with security restrictions on critical infrastructure and inconsistent data collection methods, makes developing robust AI solutions particularly challenging.

Another significant hurdle lies in scaling AI solutions across diverse geographic regions. Developing nations, which often lack the technological and financial resources to deploy AI systems, require innovative strategies for capacity building and infrastructure development. Moreover, the computational intensity of advanced AI models remains a concern, particularly in resource-constrained environments. Advanced AI models, such as deep learning and large language models, require vast computational resources for training and inference, which can limit their scalability. Training these models often involves high-performance computing clusters, GPUs, or TPUs, which consume significant energy and incur substantial costs. To address these challenges, researchers are exploring several strategies (Salehi and Schmeink, 2023; Jarrahi et al., 2023; Murshed et al., 2021; Wahl et al., 2018; van and Wynsberghe, 2021).

1. **Data-Centric Solutions.** Transfer learning and few-shot learning enable models to learn from limited datasets by leveraging knowledge from related domains. Synthetic data generation using physics-informed AI models can augment real-world data. Federated learning allows users to collaboratively train models without sharing sensitive data. These approaches, combined with domain-specific data augmentation techniques, help overcome the data scarcity challenges common in environmental and energy applications.
2. **Resource-Efficient AI.** Lightweight models optimized for edge devices, combined with model compression and progressive learning approaches, reduce computational demands while maintaining performance. Edge computing brings AI processing closer to data sources, enabling real-time applications in resource-constrained environments while minimizing energy consumption and operational costs.
3. **Capacity Building.** Sustainable implementation of AI solutions requires robust capacity building initiatives that focus on long-term development. This includes creating open-source AI tools and frameworks specifically designed for energy and environmental applications, establishing knowledge transfer programs between developed and developing regions, and developing local training programs for AI system maintenance. Partnerships between regional universities, research centers, and industry stakeholders strengthen local AI ecosystems meanwhile ensuring solutions are adapted to local contexts and needs.
4. **Infrastructure Development.** Cloud-based solutions with pay-as-you-go models make advanced AI capabilities accessible to organizations and geographic regions with limited resources. Hybrid edge-cloud architectures balance computational loads between local and cloud resources. Satellite and Unmanned Aerial Vehicles (UAV) based connectivity and computing networks provide crucial infrastructure support for remote and underserved areas. Additionally, establishing local computing clusters powered by renewable energy sources addresses both computational needs and sustainability goals, making AI solutions more accessible to developing regions.

Looking ahead, the convergence of AI with emerging technologies such as the Internet of Things (IoT), digital twins, blockchain, intelligent robotics, edge computing, and quantum computing holds immense potential for driving sustainable transformations. For instance, AI-enabled digital twins of energy systems can simulate and optimize performance in real-time, while blockchain solutions ensure transparent and secure energy trading. Autonomous AI-driven carbon capture and environmental monitoring systems are poised to play a central role in achieving decarbonization targets.

This special issue, *Innovative AI Applications for Sustainable Energy & Environment*, highlights pioneering AI solutions that address critical challenges in energy and environmental sectors. Through a collection of

research articles, case studies, and reviews, this special issue explores the breadth of AI's transformative impact, from renewable energy integration, smart infrastructure to sustainable waste management. Below, we highlight the key contributions organized around the issue's core themes:

1. **Renewable Energy Optimization**
 - o *Exploring the Landscape of Machine Learning-Aided Research in Biofuels and Biodiesel: A Bibliometric Analysis:* This work provides an insightful bibliometric analysis of machine learning applications in biofuels and biodiesel research, emphasizing the interdisciplinary and collaborative nature of this field. This work highlights the research trends, key funding agencies, and the geographic distribution of the research contributions, offering an insightful roadmap for future research directions.
 - o *Using Machine Learning Methods for Long-term Technical and Economic Evaluation of Wind Power Plants:* This study employs a hybrid CNN-LSTM model to predict wind speeds over 25 years for a power plant in Calgary, Canada. The research demonstrates the model's superior accuracy, providing valuable insights into energy production forecasts and economic viability.
 - o *Optimal Control Strategy Based on Artificial Intelligence Applied to a Continuous Dark Fermentation Reactor for Energy Recovery from Organic Wastes:* This work explores innovative AI-driven control strategies for optimizing hydrogen production in bioreactors, showcasing significant improvements in energy efficiency and scalability for industrial applications.
2. **Waste-to-Energy and Resource Efficiency**
 - o *Review of Machine Learning Applications for Predicting the Quality of Biomass Briquettes for Sustainable and Low-Carbon Energy Solutions:* This review highlights the application of AI to predict and optimize the quality of biomass briquettes, paving the way for sustainable and low-carbon energy systems.
 - o *A Review on AI-driven Thermal Treatment of Solid Waste: Emission Control and Process Optimization:* This review investigates AI applications in optimizing thermal treatment processes like pyrolysis and gasification, emphasizing energy recovery and emission reduction.
3. **Cross-Sectoral AI Innovations**
 - o *Time-series Signal Analysis of Sustainable Process Intensification: Characterization Method Development of Gas-Solid Fluidized Bed Hydrodynamics towards AI-Enhanced Algorithms:* This review evaluates time-series signal processing methods for gas-solid fluidized beds, emphasizing the limits of traditional approaches in capturing heterogeneous flow dynamics. It highlights the potential of AI-driven approaches to overcome these challenges, enabling improved hydrodynamic understanding and supporting sustainable manufacturing technologies.
 - o *Parametric Study of the Decomposition of Methane for CO_x-free H₂ and High-Valued Carbon Using Ni-based Catalyst via Machine-Learning Simulation:* This study leverages machine learning to optimize methane decomposition processes, providing actionable insights for catalyst design and clean hydrogen production.
 - o *Exploring the Application of Artificial Intelligence for Bioelectrochemical Systems: A Review of Recent Research:* This review explores how AI techniques, including machine learning and metaheuristic optimization, enhance bioelectrochemical systems (BES) by improving performance prediction, system design, and adaptive control, while addressing challenges in data standardization and biological complexity.

The contributions in this special issue highlight AI's transformative potential to drive sustainable innovations across sectors, offering actionable strategies to advance global sustainability goals. By fostering interdisciplinary collaboration and democratizing access to AI tools, this research inspires advancements in AI-driven solutions. It is our hope that

this issue serves as a catalyst for innovative solutions that empower industries, governments, and societies to achieve a greener, more resilient, and sustainable future. Together, we can leverage the power of AI to accelerate the transition toward net-zero emissions and safeguard our planet for generations to come.

References

- Abdalla, A.N., Nazir, M.S., Tao, H., Cao, S., Ji, R., Jiang, M., Yao, L., 2021. Integration of energy storage system and renewable energy sources based on artificial intelligence: an overview. *J. Energy Storage* 40, 102811.
- Boza, P., Evgeniou, T., 2021. Artificial intelligence to support the integration of variable renewable energy sources to the power system. *Appl. Energy* 290, 116754.
- Duan, Y., Edwards, J.S., Dwivedi, Y.K., 2019. Artificial intelligence for decision making in the era of Big Data – evolution, challenges and research agenda. *Int. J. Inf. Manag.* 48, 63–71.
- Dwivedi, Y.K., Hughes, L., Ismagilova, E., et al., 2021. Artificial Intelligence (AI): multidisciplinary perspectives on emerging challenges, opportunities, and agenda for research, practice and policy. *Int. J. Inf. Manag.* 57, 101994.
- Ghahramani, M., Qiao, Y., Zhou, M.C., O'Hagan, A., Sweeney, J., 2020. AI-based modeling and data-driven evaluation for smart manufacturing processes. *IEEE/CAA J. Automatica Sinica* 7 (4), 1026–1037.
- Huang, J., Koroteev, D.D., 2021. Artificial intelligence for planning of energy and waste management. *Sustain. Energy Technol. Assessments* 47, 101426.
- Jarrahi, H.M., Memariani, A., Guha, S., 2023. The principles of data-centric AI. *Commun. ACM* 66 (8), 84–92.
- Murshed, M.G.S., Murphy, C., Hou, D., Khan, N., Ananthanarayanan, G., Hussain, F., 2021. Machine learning at the network edge: a survey. *ACM Comput. Surv.* 54 (8), 1–37.
- Priya, A.K., Devarajan, B., Alagumalai, A., Song, H., 2023. Artificial intelligence enabled carbon capture: a review. *Sci. Total Environ.* 886, 163913.
- SaberiKamarposhti, M., Ng, K-W., Yadollahi, M., Kamyab, H., Cheng, J., Khorami, M., 2024. Cultivating a sustainable future in the artificial intelligence era: a comprehensive assessment of greenhouse gas emissions and removals in agriculture. *Environ. Res.* 250, 118528.
- Salehi, S., Schmeink, A., 2023. Data-centric green artificial intelligence: a survey. *IEEE Transact. Artif. Intellig.* 5 (5), 1973–1989.
- Soni, N., Singh, P.K., Mallick, S., Pandey, Y., Tiwari, S., Mishra, A., Tiwari, A., 2024. Advancing sustainable energy: exploring new frontiers and opportunities in the green transition. *Advan. Sustain. Syst.* 8 (10), 2400160.
- van Wynsberghe, A., 2021. Sustainable AI: AI for sustainability and the sustainability of AI. *AI Ethics* 1, 213–218. <https://doi.org/10.1007/s43681-021-00043-6>.
- Wahl, B., Cossy-Gantner, A., Germann, S., Schwalbe, N.R., 2018. Artificial intelligence (AI) and global health: how can AI contribute to health in resource-poor settings? *BMJ Glob. Health* 3 (4), e000798.

Tianlong Liu, Ying Zheng^{*1}

Department of Chemical and Biochemical Engineering, Western University, London, Ontario, N6A 3K7, Canada

^{*} Corresponding author.

E-mail address: ying.zheng@uwo.ca (Y. Zheng).

¹ Prof. Ying Zheng had no involvement in the peer-review of this article and has no access to information regarding its peer-review.