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Impact of Artificial Intelligence (AI) on Environmental Security (ES) of Post-Pandemic Covid-19: A Literature Review Study

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Abstract

The rapid advancement of Artificial Intelligence (AI) has brought innovative solutions to diverse industries. The global COVID-19 pandemic serves as a stark reminder of AI's critical role in environmental security (ES). The pandemic induced significant shifts in human activities and global dynamics, unveiling environmental challenges and opportunities. The movement restrictions and economic slowdowns temporarily improved air quality, reduced water pollution, and diminished carbon emissions in numerous cities. The pandemic simultaneously unveiled the inadequacies of existing ES systems in effectively addressing and mitigating environmental threats. AI emerges as a solution for reinforcing ES, particularly as the pandemic disrupted traditional environmental efforts and catalysed innovation in remote work and digital solutions, offering the potential for long-term reductions in carbon footprints. Therefore, this review aims to explore the post-pandemic impact of AI on ES. The study examines various vital areas where AI technologies are applied, encompassing climate modelling, disaster management, biodiversity conservation, and sustainable resource allocation. Additionally, it also delves into ethical considerations and potential risks associated with the expanded use of AI in environmental contexts. This study employs a comprehensive literature review which involves analysing existing research and scholarly articles on AI and ES. Moreover, thematic analysis was utilised to identify recurring themes and patterns in the literature, helping to gain deeper insights into the subject matter. This analytical approach elucidates the multifaceted relationship between ES in the post-COVID-19 era and AI, emphasising the potential of AI-driven solutions to construct a more sustainable and resilient post-pandemic world while highlighting the importance of ethical considerations in AI deployment. The synthesis of information through thematic analysis enriches our understanding of how AI can stimulate innovation and sustainability, promising a more secure environment in the post-COVID-19 world. In conclusion, this literature review underscores the profound impact of COVID-19 on ES and highlights AI's role in addressing the challenges and opportunities that have emerged in the post-pandemic era.

1. Introduction

The World Health Organization (WHO) revealed the coronavirus (COVID-19) as an infectious disease caused by the novel severe acute respiratory syndrome coronavirus 2, SARS-CoV-2, in late 2019 (Lai *et al.*, 2020). A global pandemic has resulted from the virus's rapid spread from Wuhan, China, to various countries since the latter part of December. The disease has resulted in remarkable shortages in healthcare, care equipment, and other sectors. The COVID-19 pandemic limited the availability of raw resources in traditional industries. However, only a small number of these shortcomings have been identified in digital industries operating within the framework of Industry 4.0. Several industries, such as nanotechnologies, the Internet of Things (IoT), blockchain technologies, and artificial intelligence (AI), have achieved remarkable operational success. Researchers have shown a growing interest in AI technologies in recent years. Therefore, numerous attempts have been made to define AI precisely.

According to several scholars, AI refers to the ability of a machine to interpret and comprehend input in an intelligent framework. According to Lüdeke-Freund (2010), some claim that AI represents a new and innovative approach to information management within a business framework. Schilirò (2020) categorises AI into five major domains: computer vision, natural language, virtual assistants, robotic process automation, and advanced machine learning. Additionally, digital data and information are novel concepts. The more research on this subject, the better the world's issues will be solved. Moreover, the data, concepts, technologies, and best practices in this field influence global investors' decisions, resulting in opportunities for data monetisation. Over the past few decades, such information has significantly contributed to the global Gross Domestic Product (GDP). Artificial intelligence and digital technologies have impacted economic growth more than global trade in goods (Schilirò, 2020).

The concept of environmental security (ES) highlights the link between human well-being and ecological integrity. It implies that factors such as the environment are crucial for maintaining ecological stability. This paradigm recognises resource shortages, climate change, biodiversity loss, pollution, and global and local impacts of transboundary environmental issues. These issues must be addressed to prevent the destruction of ecosystems, conflicts, displacement, and public health disasters. Hence, ES must integrate environmental considerations into security policies, international relations, and multidisciplinary methods to promote peace between nature and society (Allenby, 2000). ES has two origins: establishing concepts related to environmental risks in critical zones and sustainable development. The likelihood that environmental degradation would result in violent conflict is a major issue.

Therefore, in the current review, the researchers attempt to examine the effects of AI on ES, focusing on the post-COVID-19 pandemic period. For this purpose, the researchers first discuss how COVID-19 affects ES. Afterwards, the key area where AI was utilised in ES was discussed. The ethics and environmental risks of AI deployment were also mentioned.

This study aims to investigate the post-pandemic impact of AI on ES. With the outbreak of the COVID-19 pandemic, there has been a growing interest in understanding how AI technologies can contribute to addressing environmental challenges and enhancing security in this context. The study intends to explore various critical areas where AI has been applied within ES, including climate modelling, disaster management, biodiversity conservation, and sustainable resource allocation. Additionally, the study delves into the ethical considerations and potential risks associated with the expanded use of AI in environmental contexts.

In terms of methodology, this study employs a comprehensive literature review approach. It involves analysing existing research and scholarly articles on AI and ES, focusing on post-pandemic implications. Thematic analysis is utilised to identify recurring themes and patterns in the literature, helping to gain deeper insights into the subject matter.

The significance of this study lies in its contribution to understanding how AI can play a pivotal role in addressing ES challenges in a world reshaped by the COVID-19 pandemic. By examining the applications of AI, ethical considerations, and potential risks, the study provides valuable insights for ES researchers. Moreover, it underscores the importance of harnessing AI's capabilities responsibly and collaboratively to build a more sustainable and secure future in the post-pandemic era.

2. Literature Review

2.1 Post-Covid 19 Impacts on ES

The global COVID-19 pandemic has further highlighted the importance of AI for ES. With the COVID-19 pandemic, there has been a significant shift in human activities and global dynamics, leading to environmental challenges and opportunities. On the one hand, movement restrictions and a significant slowdown of social and economic activities have temporarily improved air quality, reduced water pollution, and reduced carbon emissions in many cities worldwide, showing rapid environmental change(Rume & Islam, 2020). On the other hand, the pandemic has revealed weaknesses in our ES systems. The disruptions caused by the pandemic have made it evident that our current systems are not equipped to respond to and mitigate environmental threats effectively. AI can be crucial in addressing these weaknesses and strengthening our ES. The pandemic disrupted traditional environmental efforts but spurred innovation in remote work and digital solutions, which could reduce carbon footprints over time. Resilient societies have highlighted the need to incorporate sustainable practices into recovery plans for a greener, more equitable future.

2.1.1 Opportunities Arising for Addressing ES

Industry and transport closures reduced air pollution and greenhouse gas (GHG) emissions during COVID-19. These reductions demonstrate pandemic-related environmental benefits (Central Pollution Control Board, 2020). For instance, China's industry shutdown cut N2O, a cause of acid rain and respiratory issues, and CO emissions by 50% (Caine, 2020), while shutdowns in the US, Canada, China, India, Italy, and Brazil reduced NO_2 emissions, mainly from vehicles (Biswal *et al.*, 2020; Ghosh, 2020; Saadat *et al.*, 2020; Somani *et al.*, 2020). Transport sector emissions include 72% from vehicles and 11% from aviation (Vinet & Zhedanov, 2011). Virus containment measures have significantly impacted aviation, with global flight cancellations and reduced capacity. Air travel plummeted by 96% compared to the previous year (Wallace, 2020), leading to notable environmental implications. Reduced fossil fuel consumption reduces GHG emissions, aiding in combating climate change. Comparing the first three months of 2020 to the same period of the previous year, global oil demand decreased by 435,000 barrels (OECD/IEA, 2011). The lockdown also decreased global coal consumption, leading to a reduction in coal-based power generation of 26% in India and 36% in China (Dahiya & Myllyvirta, 2020; Ghosh, 2020).

Moreover, lockdown-induced reductions in major pollution sources decreased water pollution in countries like India. India's Ganga and Yamuna rivers met water quality standards during the lockdown (Singhal & Matto, 2020). Water quality parameters and pollutant concentrations improved in different monitoring stations, driven by lockdown measures (Arif *et al.*, 2020). Public gathering restrictions and reduced tourism decreased water pollution (Cripps K, 2020). Industrial water consumption, especially from textiles, and solid waste from construction and manufacturing decreased, contributing to lower water and soil pollution (Cooper, 2020). Furthermore, tourism accounts for 8% of the contribution to global GHG emissions (Lenzen *et al.*, 2018). Visitors generate harmful waste, affecting ecosystems. The pandemic and restrictions have curbed global tourism, impacting popular destinations.

2.1.2 Challenges Arising for Addressing ES

The COVID-19 pandemic has created ES challenges. Reallocating financial and human resources to immediate healthcare needs and economic stabilisation has reduced environmental protection efforts. This shift in focus may hinder long-term sustainability strategies. Hospitals' generation of infectious waste has surged, posing risks to public health and ES (Saadat *et al.*, 2020). For instance, Wuhan produced 240 metric tonnes daily, almost 190 metric tonnes above average (Zambrano-Monserrate *et al.*, 2020). Manila, Kuala Lumpur, Hanoi, and Bangkok's daily medical waste rose by 154–280 metric tonnes (Amalia *et al.*, 2020). SARS-CoV-2's viability on surfaces highlights the need to properly handle hospital waste to combat infection and global environmental pollution. Due to the increasing number of people using protective equipment such as masks and gloves to prevent infections, the waste generated by healthcare establishments has increased (Vinet & Zhedanov, 2011). Global plastic PPE production and usage have risen (Singh *et al.,* 2020), with China producing 14.8 million daily medical masks (Fadare & Okoffo, 2020). Improper disposal of face masks and gloves, often due to inadequate awareness of infectious waste management, clogs waterways and worsens pollution. Moreover, plastic protective gear might have microplastic fibres (Fadare & Okoffo, 2020), and materials like polypropylene and Tyvek used in masks and suits can persist in the environment (Singh *et al.*, 2020). Experts advocate proper disposal and separation of organic waste and plastic-based protective equipment, as mixing these wastes increases disease transmission risk and exposes waste workers to the virus (Singh *et al.*, 2020; Vinet & Zhedanov, 2011).

Furthermore, recycling reduction has worsened waste control and pollution, undermining environmental integrity. The quarantine measures imposed during the pandemic have driven increased online shopping and household waste from shipped packages, contributing to pollution. Recycling lessens pollution, energy consumption, and resource depletion. However, to curb virus transmission, many countries temporarily postponed waste recycling. In the USA, about 46% of cities restricted recycling programmes over concerns of COVID-19 spread in facilities (Somani *et al.*, 2020). Infected residents were prohibited from sorting waste in the UK, Italy, and other European countries (Zambrano-Monserrate *et al.*, 2020). These disruptions to waste management have heightened landfilling and environmental pollution on a global scale. Besides, the widespread application of disinfectants to eliminate SARS-CoV-2 has raised ecological concerns, as these measures might unintentionally harm non-targeted beneficial species and disrupt ecological balance (Didar-Ul Islam & Bhuiyan, 2016). Several countries have found the virus in patients' faeces and municipal wastewater. Bangladesh, which throws untreated wastewater into nearby waterways, needs better wastewater treatment. China has increased chlorine use to combat virus transmission via wastewater, which can produce harmful byproducts (Zambrano-Monserrate *et al.*, 2020). Due to health concerns, critical climate conferences and policy dialogues have been delayed or cancelled, which could hinder global environmental goals. Pandemic-driven urgencies dominate policy agendas, making comprehensive ES efforts difficult.

Thus, the COVID-19 pandemic created ES opportunities and challenges. The complex relationship between human health and ecological balance has raised awareness of the need to protect natural systems to prevent health hazards. Lowering commuting and office energy consumption can reduce carbon emissions, as shown by mandatory remote work and digital communication. Economic stimulus packages with sustainable practices signal a shift towards green initiatives and a low-carbon economy. Limiting industrial activity during lockdown has temporarily improved air quality in some areas, showing the benefits of pollution reduction. Travel and consumption may decrease sustainably due to pandemic restrictions. The pandemic requires environmental strategies to be more resilient and adaptable. The pandemic's unexpected effects offer a rare chance to refocus global ES priorities.

2.2 The Intersection of AI and ES

The post-COVID-19 era has highlighted the need to address environmental challenges for long-term security, with AI poised to drive this transformation. AI has already proven its potential in various sectors, and its application to ES holds great promise. AI's potential impact is significant, enhancing risk assessment, early warnings, and adaptive strategies. Data analysis, machine learning, and predictive modelling accelerate response and preparedness to complex environmental issues like pollution, climate change, and natural disasters. AI helps with disaster management, conservation, real-time environmental monitoring, and trend identification. AI also improves renewable energy. However, ethical considerations are paramount for equitable AI deployment. Hence, AI and ES synergy is crucial for a sustainable future, offering innovative solutions for long-term security and resilience.

2.3 AI Applications in ES Post-COVID-19

2.3.1 Solutions for Climate Modelling and Prediction

Emissions contribute to climate change, which can cause extreme weather events. The rising carbon emissions can be attributed to the heavy utilisation of fossil fuels. This emphasises the need for more energy-efficient practices and developing environmentally friendly technologies (YUE & GAO, 2018). This crucial shift to electricity-driven frameworks can strengthen ecological preservation, constituting a crucial step in climate change mitigation. AI and climate change discourse emphasises technical aspects and ignores practical applications across affected domains. The effects of climate change on human life and production can be subdivided into sections that look at the role of AI in resource management, green energy efficiency, and sustainable development.

2.3.1.1 Energy Efficiency and Lower-Emission Operations

Economy and population growth have increased energy demand, requiring energy efficiency and waste reduction strategies for sustainable development. AI in energy offers opportunities and challenges to improve efficiency and sustainability. AI adoption will increase due to AI's expanding role in reducing energy use, environmental impact, and sustainable development. Despite expertise and financial barriers, AI's potential to improve energy efficiency and sustainability is promising. Companies are increasingly adopting green energy strategies to reduce emissions and enhance energy efficiency, with AI playing a pivotal role in this transformation (Lei *et al.*, 2023). AI closely monitors industrial processes, employing data analysis and feedback mechanisms to optimise energy consumption and reduce emissions. It also improves product design and layouts, reducing emissions and waste during preconstruction (Leo Kumar, 2017). AI aids in detecting equipment issues during construction, enhancing monitoring and control, and reducing emissions across various sectors (Perera *et al.*, 2023). AI-driven optimisation transforms industries, reduces environmental impact, and enhances efficiency (Dwivedi *et al.*, 2021).

2.3.1.2 Carbon Sequestration and Storage

AI improves carbon sequestration and storage, reducing climate change and protecting the environment post-COVID-19. AI can reduce GHG emissions and climate damage for carbon neutrality. AI identifies storage sites (Jin *et al.*, 2022), predicts CO2 behaviour (Chinh Nguyen *et al.*, 2022), optimises injection (Elsheikh *et al.*, 2022), monitors (Kishor & Chakraborty, 2022), innovates methods (Gupta & Li, 2022), curbs emissions (Jahanger *et al.*, 2023), and uses data for site selection and injection to reduce emissions. According to Liu *et al.* (2022), AI's role in carbon sequestration is evolving with technology and requires responsible implementation to overcome challenges and achieve sustainability and carbon neutrality. AI optimisation and conscious barrier-breaking improve carbon sequestration, climate, and sustainability. The synergy highlights carbon sequestration's sustainability, especially post-pandemic ES.

2.3.1.3 Weather Forecasting

Severe weather events threaten infrastructure and public safety, causing significant financial losses. Complex earth system models and uncertainties make climate change predictions difficult despite advances in observational and calculation methods. After the COVID-19 pandemic, ES has become more critical, prompting a closer look at AI's weather forecasting and climate impact mitigation roles. AI is a vital weather forecasting tool because it can process large datasets and bridge digital model predictions and real-world outcomes (McGovern *et al.*, 2017). AI can predict climate more accurately and precisely because of data-rich satellite observations and complex climate models (Jones, 2017). With the integration of AI and numerical climate simulation, AI addresses data gaps, diminishes uncertainty, and reduces bias in climate forecasts (Kadow *et al.*, 2020). Machine learning analyses past and present weather data to improve meteorological models. This improves temperature, precipitation, and wind speed predictions (Z. Chen *et al.*, 2020; Zhang *et al.*, 2019). Furthermore, AI aids in the early detection and prediction of climate change's impact on solar activity, contributing to a comprehensive understanding of environmental changes (Jiang *et al.*, 2023). These applications help to optimise resource allocation, mitigate climate-related risks, and enhance land use efficiency. AI-driven weather forecasting can reduce disasters and enhance climate adaptation.

2.3.1.4 Renewable Energy Forecasting and Grid Management

Global population and economic growth have escalated energy consumption despite advancements in energy efficiency. Conventional energy sources contribute to acid rain, greenhouse effects, and ozone depletion (Chatterjee & Dethlefs, 2022). However, renewable sources like wind and solar power are mitigating carbon emissions. Notably, solar and wind power witness more than 8% growth in 2021. Experts predict a record 30% share of renewable energy in electricity generation (Hannan *et al.*, 2021). Nevertheless, the intermittent nature of renewable energy poses challenges to grid stability. The variability in solar radiation and wind speed makes green energy production unpredictable. Excessive green energy output can lead to power outages or waste (Alassery *et al.*, 2022). AI is revolutionising renewable energy integration and grid stability, offering solutions for sustainability, carbon reduction, and resilient grids amid energy challenges and post-COVID-19 recovery. AI can also optimise solar farm locations, panel orientation for sunlight capture, and solar energy generation (An *et al.*, 2023).

Besides, AI optimises site selection based on topography, climate, and land use, eliminating site visits and simplifying early renewable energy planning. Moreover, AI-driven predictive maintenance methods are gaining traction, addressing operational failures in the renewable energy sector. These methods employ neural networks to detect historical and real-time data anomalies, allowing timely interventions. This collaborative approach combines human expertise with AI suggestions for more accurate diagnostic decisions (Heo *et al.*, 2022). Such synergy is crucial for improving predictive maintenance in the renewable energy field. The collaborative use of AI and meteorological models improves sustainable energy forecasts. Historical data enhances solar energy prediction accuracy by over 30% compared to single-parameter models (Boza & Evgeniou, 2021). Similarly, AI aids in wind power predictions and reduces storm-related risks (Bendaoud *et al.*, 2022).

2.3.1.5 Optimising Transportation Systems for Reducing Greenhouse Gas Emissions

The transport sector contributes significantly to global GHG emissions, necessitating carbon footprint reduction. AI offers solutions by optimising routes, managing fleets, developing self-driving vehicles, and enhancing public transit. AI aids fleet management through predictive analytics, minimises fuel use, and improves fuel efficiency (Alexandru *et al.*, 2021). AI-driven self-driving vehicles enhance fuel efficiency and tackle traffic congestion, while AI-controlled public transit systems optimise routes according to demand and traffic patterns, enhancing efficiency and emissions (Nikitas *et al.*, 2020; Tyagi & Aswathy, 2021). Moreover, AI encourages sustainable modes of transport, leveraging user behaviour data to promote eco-friendly choices (Olayode *et al.*, 2020).

2.3.1.6 Precision Agriculture to Reduce Chemical Emissions

Chemical use in agriculture has increased due to food demand and harming pollinators. Precision farming uses AI-driven sensors to collect real-time data on soil, crops, weather, and more to improve yields and decision-making (Raj *et al.*, 2021). Robotics and AI boost productivity, while computer vision and machine learning quickly and accurately identify crop diseases (Barile et al., 2019). AI-driven precision spraying reduces herbicide use and residues (Balafoutis *et al.*, 2017). Deep learning and neural networks improve agricultural remote sensing and weed control (Kussul *et al.*, 2017). AI-guided weed-management robots could reduce chemical use and costs (Swaminathan *et al.*, 2023). Algorithms and unmanned aerial vehicles improve pest and disease recognition and reduce pesticide use. Finally, accurate real-time data and improved practices from AI-powered precision agriculture improve resource utilisation, food productivity, and environmental impact.

2.3.2 Solutions for Biodiversity Conservation Post-COVID-19

Hence, Smart technologies in the AI economy can help preserve biodiversity by improving ecological behaviour post-COVID-19. AI can aid biodiversity conservation decision-making. This will enable sustainable urban and rural development while minimising biodiversity loss. AI models can reduce natural resource loss. Neural networks helped Dominguez *et al*. (2022) predict Amazon deforestation and act early. Neural networks and drones improve deforestation monitoring (Torres *et al.*, 2020). Particle swarm optimisation neuro-fuzzy and random forest help predict and manage forest fires (Tien Bui *et al.*, 2017). Environmental restoration and land pollution management are aided by AI-assisted planning frameworks (Yin *et al.*, 2021). As enhanced water quality evaluation models show, urban water resource management requires adaptive, intelligent, dynamic planning (Xiang *et al*., 2021). AI predicts water shortages and manages reference evapotranspiration (Afzaal *et al.*, 2020). AI optimises resource allocation and reduces waste in natural resource management.

2.3.3 Solutions for Sustainable Resources Management Post-COVID-19

AI and digital technologies have benefitted renewable energy sources. The role of AI in optimising energy consumption, promoting renewable energy integration, and enhancing energy efficiency has become even more vital in the post-COVID-19 era. Renewable energy, such as solar and wind power, is crucial for sustainability. AI helps integrate them smoothly by forecasting energy production using weather data and historical records. This aids grid operators in balancing supply and demand, optimising storage, and ensuring stable energy supply alongside conventional sources despite renewables' intermittency. COVID-19 affects the solar energy sector, with Malaysia investing $2.9 billion in rooftop solar grids. AI also predicts power generation, enhancing system stability and security by anticipating changes in renewable plant output and improving overall performance (*Commission for Environmental Cooperation*, 1999). In the post-COVID-19 energy era, digitisation emerges as a key direction. Recommendations include bolstering electricity infrastructure in stricken nations and prioritising adaptable renewable electricity sources, well-suited for crises like COVID-19, offering reliability and resilience amidst challenging conditions where conventional methods falter (Norouzi *et al.,* 2020). Table 1 previews forthcoming articles exploring post-outbreak renewable energy opportunities via thematic analysis method for literature review.

3. Research Methodology

Thematic analysis is a qualitative method of data analysis that entails a comprehensive examination of a dataset, intending to identify frequent trends in meaning throughout the data. Using a flexible methodology in qualitative analysis allows researchers to generate new ideas and concepts based on the data at hand. This approach relates to the systematic examination and interpretation of qualitative data. It is a method of analysing qualitative data. It analyses any study that seeks to discover using interpretations (Alhojailan & Ibrahim, 2012). It can be a constructionist method that examines how events, realities, meanings, and experiences affect a range of discourses operating within society. The researchers are provided with lexemes as qualitative data, which are utilised alongside codes to generate themes within a given text (Alhojailan & Ibrahim, 2012).

Table 1 *Major opportunities after the COVID-19 outbreak in renewable energy and energy efficiency & thematic analysis method for literature review*

Research Project Description/ Approach	Country	Application Area	Current Status	Effectiveness	Critical Findings	Ref
Construction of energy infrastructure in nations at risk of social and economic damage. The significance of paying attention to the generation of renewable electricity	China	Renewable energy integration	used	effective	The dependability of this kind of energy in urgent scenarios like COVID-19.	(Norouzi *et al.*, 2020)
Consideration, support, and commercialisation of the electric vehicle sector.	Not specified	Renewable energy integration	Widely used	Highly effective	They are lowering air pollution and fuel energy sector demand.	(Wang *et al.*, 2020)
Solar technology and long-term investments should be considered for the sector's growth in solar, wind, and other industries.	Not specified	Renewable energy integration	Widely used	Highly effective	Lowering air pollution and not causing any environmental harm.	(Vaka *et al.*, 2020)
The convergence of the IoT and AI facilitates energy efficiency.	Italy	Energy management systems	Widely used	Highly effective	The study shows that IoT paradigms and machine learning can help achieve self-sufficiency in energy efficiency. However, the results are from relatively simple settings, so more research is needed for energy-intensive operations, high fees, and other large infrastructures.	(Tomazzoli *et al.*, 2023)
Using AI to assist with predicting maintenance needs for renewable energy systems.	UK	Predictive maintenance	Emerging	Effective	This study shows that AI can predict renewable energy system maintenanceand suggests that more experimentation in different operational modes is needed to improve it.	(Shin *et al.*, 2021)
AI-driven methods for detecting and diagnosing faults in building energy systems.	China	Fault detection and diagnosis	Emerging	Effective	This study thoroughly examines AI-based energy system fault detection and diagnosis methods. However, these systems' efficacy, efficiency, scalability, and dependability in real-world scenarios need further study.	(Zhao *et al.*, 2019)
The employment of AI techniques in forecasting indoor thermal comfort in buildings.	South Korea	Occupancy and comfort control	Emerging	Effective	The study suggests that AI-based technology may regulate building comfort, but its economic viability needs further study.	(Ngarambe *et al.*, 2020)
AI application in the economic evaluation of energy efficiency and renewable energy technologies.	India	Renewable energy integration	Emerging	Promising	The study presents an AI-based evaluation model for effective energy efficiency and conservation predictions. The proposed model has 97.32% energy efficiency.	(C. Chen *et al.*, 2021)
A system for residential demand response that utilises AI technology is discussed in this study.	Spain	Demand response	Emerging	Promising	The study emphasises the potential of AI-based demand response systems in residential buildings and suggests further research in other building types.	(Esnaola-Gonzalez *et al.*, 2021)
AI anticipates, enhances, and manages thermal energy storage systems.	United Arab Emirates	Energy storage management	Emerging	Promising	AI is being used in thermal energy storage systems, according to research. AI accuracy depends heavily on input data quality, which is a major limitation.	(Olabi *et al.*, 2023)

4. Results and Discussion

According to the literature reviewed above and presented in Table 1, the literature review provides a comprehensive analysis of the multifaceted relationship between ES post-COVID-19 and AI. It underscores the potential for AI-driven solutions to create a more sustainable and resilient post-pandemic world while highlighting the importance of ethical considerations in AI deployment. At first, the multifaceted impact of the COVID-19 pandemic on ES was examined. It is evident that the pandemic has had a mixed effect on the environment. On the one hand, it offered a glimpse of the potential benefits of reduced human activity in reducing air pollution, improving water quality, and decreasing tourism-related environmental harm. However, on the other hand, it presented challenges such as resource reallocation away from environmental protection efforts, increased medical waste, delayed climate conferences, and disruptions in recycling programs.

Moreover, regarding the pivotal role of AI in addressing the environmental challenges and opportunities post-COVID-19, AI serves as a powerful tool for enhancing risk assessment, real-time monitoring, and renewable energy optimisation. It also plays a crucial role in biodiversity conservation and efficient resource management. AI's ability to process vast amounts of data and make predictions in real-time positions it as an asset in ensuring long-term security and resilience in the face of complex environmental issues. Furthermore, the literature review delved into specific AI applications within the realm of ES post-COVID-19. These applications span various domains, including energy efficiency, carbon sequestration and storage, weather forecasting, renewable energy integration, transportation optimisation, precision agriculture, biodiversity conservation, and sustainable resource management. AI's versatility and adaptability make it a cornerstone in developing innovative solutions for a more sustainable and resilient post-pandemic world. However, ethical considerations must be addressed in AI deployment.

The deployment of AI in ES post-COVID-19 era brings several ethical concerns that need careful consideration to ensure responsible and effective use of this technology. This could include data privacy, fairness and bias, transparency and explainability, accountability, equity, and access. AI-driven environmental monitoring systems require large datasets, raising privacy concerns for individuals and communities. Without consent, collecting and analysing sensitive data can violate privacy and raise surveillance concerns. Moreover, AI algorithms can unintentionally reinforce training data biases. Biased data can train AI models to make discriminatory decisions that hurt certain communities. This could mean unequal pollution or resource access in ES. Besides, complex AI algorithms like deep neural networks are hard to understand. Lack of transparency and explainability in AI decision-making can damage public trust. ES requires understanding environmental decisions. When something goes wrong, AI systems' autonomy can make responsibility difficult. An AI-driven system's decision that has negative consequences makes accountability difficult, potentially hindering response and redress. Lastly, AI deployment may not be accessible to all communities, deepening inequalities. Preventing disparities requires equitable access to AI-based ES systems (Floridi, 2023a, 2023b; Omrani *et al.*, 2022). Hence, Balancing AI automation with human oversight is crucial in post-COVID-19 ES. AI processes data and aids decisions, but human judgment is necessary to detect biases and ensure ethics. Responsible AI deployment requires addressing data privacy, bias, transparency, accountability, and human oversight to benefit the environment and society while protecting human rights and society.

A balanced strategy that combines technological progress with ethical safeguards is essential, primarily through well-defined policy frameworks governing AI in ES. These frameworks should cover privacy protection, bias mitigation, transparency standards, and accountability mechanisms. Therefore, this literature review underscores the profound impact of COVID-19 on ES and highlights the instrumental role of AI in addressing the challenges and opportunities that have emerged in the post-pandemic era. The synthesis of information through thematic analysis contributes to our understanding of how AI can drive innovation and sustainability for a more secure environment. In addition, responsible AI adoption necessitates a delicate equilibrium between AI's potential and ethical standards, ensuring alignment with human values, individual rights, and sustainability goals. Future studies should focus on predictive models, data integration, and improving AI decision clarity. Collaborative efforts between environmental scientists, AI experts, and ethicists can lead to enhanced algorithms, effective regulations, and innovative software solutions addressing environmental challenges holistically. This interdisciplinary approach holds promise for a more secure and resilient post-COVID-19 world.

5. Conclusion

In conclusion, the rapid advancement of AI has ushered in a new era of possibilities across diverse industries, with growing interest in its intersection with ES, especially after the COVID-19 pandemic. This review highlights the potential of AI in reshaping sustainability and resource management strategies within ES. While AI's contributions to climate modelling and disaster management, ethical concerns require attention. Responsible and ethical use of AI's transformative potential will enhance global ES, ensuring a sustainable and resilient future for all.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: **Study conception and design:** H.A.S.A.A. and H.S.; **data collection:** H.A.S.A.A.; **analysis and interpretation of results:** H.A.S.A.A.; **draft manuscript preparation:** H.A.S. A.A. and H.S.; **Supervision**: H.S. All authors reviewed the results and approved the final version of the manuscript.

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