sciendo

Management Systems in Production Engineering

2024, Volume 32, Issue 1, pp. 33-44

Date of submission of the article to the Editor: 06/2023
Date of acceptance of the article by the Editor: 01/2024

DOI 10.2478/mspe-2024-0004

POTENTIAL OF ADVANCED TECHNOLOGIES FOR ENVIRONMENTAL MANAGEMENT SYSTEMS

Mariya Sira
Silesian University of Technology

Abstract:
Environmental management systems (EMS) are essential in promoting sustainable practices and mitigating the adverse effects of human activities on the environment. As technology continues to advance, there is an increasing opportunity to utilize advanced technologies to improve environmental management systems. This article examines the potential of different advanced technologies, such as artificial intelligence (AI), blockchain, big data, and the Internet of Things (IoT), within the context of environmental management systems. This article intends to offer valuable insights to researchers, practitioners, and policymakers by examining the potential uses of AI, blockchain, big data, and IoT in environmental management systems. The goal is to demonstrate how these advanced technologies can be leveraged to enhance sustainability, boost environmental performance, and yield favourable environmental results across different sectors and industries.

Key words: *advanced technologies, environmental management system, artificial intelligence, blockchain, Internet of Things*

INTRODUCTION

In the contemporary dynamic global landscape, organizations from diverse sectors recognize the utmost importance of prioritizing environmental management [1]. The pressing need to confront environmental issues, including but not limited to climate change, depletion of resources, and pollution, has catalysed the demand for solutions. Thanks to their exceptional capabilities, advanced technologies possess the vast potential to revolutionize conventional environmental management systems and establish resilient and sustainable frameworks [2].

The swift progress of technology, specifically in domains like artificial intelligence, the Internet of Things, blockchain, and big data, has created novel opportunities for environmental stewardship. These state-of-the-art technologies possess the capability to augment the decision-making procedures, continuously monitor environmental factors, optimize the consumption of resources, and foster cooperation among individuals and groups involved, ultimately resulting in enhanced environmental outcomes.

Advanced technologies have made significant advancements in data analytics, particularly in environmental management [3, 4]. The capacity to gather, evaluate, and interpret vast quantities of data from various sources has fundamentally transformed organizational approaches to this discipline. By utilizing complex algorithms and machine learning methodologies, valuable insights can be derived from environmental data. Consequently, organizations are empowered to detect patterns, anticipate potential hazards, and proactively develop strategies for minimizing environmental consequences.

As researchers further explore the possibilities of advanced technologies in environmental management systems, it becomes apparent that incorporating these technologies can revolutionise how organizations address sustainability. Through the utilization of artificial intelligence, blockchain, the Internet of Things, and big data, organizations can not only decrease their environmental footprint, but also foster innovation, improve engagement with stakeholders, and gain a competitive advantage in the market [5]. The utilization of advanced technologies in environmental management systems possesses immense and revolutionary potential.

The examination of the intersection between technology and environmental sustainability is of utmost importance. This article delves into the potential of advanced technologies in strengthening environmental management systems, fostering favourable ecological results, and empowering organizations to flourish in an ever-changing environment. This article aims to examine the uses and advantages of these technologies, offering valuable perspectives and directing organizations towards successful strategies for environmental management.

LITERATURE REVIEW

Advanced technological innovations hold tremendous potential in augmenting environmental management systems and tackling sundry environmental obstacles [6, 7, 8]. Through the utilization of sophisticated technologies, environmental management systems can enhance the gathering, examination, and decision-making procedures for environmental data. These systems facilitate more efficient monitoring, evaluation of risks, regulation of pollution, optimization of resources, and involvement of the public, thereby culminating in the adoption of sustainable environmental practices [9].

European Commission defines environmental management system as "a means of ensuring effective implementation of an environmental management plan or procedures and compliance with environmental policy objectives and targets" [10].

The utilization of cutting-edge technologies has the potential to facilitate environmental management systems. The integration of technologies such as the Internet of Things, industrial data, advanced manufacturing, robotics, 3D printing, blockchain technologies, and artificial intelligence provides a plethora of possibilities for organisations to bolster their dominance in burgeoning markets for innovative products and services [11]. Artificial intelligence has become a widely discussed topic in recent years due to advancements in other technologies, such as cloud computing, big data, the Internet of Things, and virtual reality [12]. These breakthroughs have allowed major advancements in artificial intelligence to develop effective monitoring systems. The Internet of Things (IoT) is a key technology for organizations to harness the potential of big data and improve their operations – including the implementation of an environmental management system [13]. They play a fundamental role in transitioning towards a more sustainable economy, aiding in the modernization of industrial foundations [3, 14].

Citation analysis with the application of the VOSViewer software allows for revealing the most cited articles that respond to the search query. Yazdani et al. [15] advocate for the implementation of a multi-faceted decision-making model within the supply chain industry to tackle intricate decision-making dilemmas. The model achieved such ranking indicators as environmental, social, cultural, and economic factors. Kumar et al. [16] determine Business Strategy and the Environment through five main thematic clusters. These clusters include business strategy and sustainability, corporate governance and sustainability reporting, green marketing and pro-environmental behaviour, innovation and environmental policy, and environmental management systems. This research paper by Wang et al. [17] presents a conceptual model for the Environmental Internet of Things (EIoT) and discusses crucial technologies such as Wireless Sensor Networks (WSN), network methodologies, Geographic Information Systems (GIS), WebGIS, and distributed database techniques. The EIoT has the potential to enhance comprehension of the urban environment and facilitate the development of innovative technological interventions to address the growing concerns of environmental degradation. Zhang et al. [18] offer valuable insights for supply chain professionals, policymakers, executives, and scholars, suggesting that organizations should consider implementing formal environmental management systems, big data analytics and artificial intelligence technologies, and environmental visibility strategies to enhance their market competitiveness, even during periods of crisis like the Covid-19 pandemic. Drobyazko and Hilorme [19] prove that the introduction of environmental management systems in space activities is necessary to prevent severe environmental consequences and minimize the negative impact of these threats.

Above the mentioned most cited papers the search in the Scopus database includes the following articles related to the same query. Das et al. [20] addresses the unexplored area in existing scholarly works, their research seeks to investigate the impact of environmental management systems on the relationship between Green Supply Chain Management practices and market competitiveness in China. Fenton et al. [21] highlight the necessity of a fundamental change in our chemical management systems and explore the integration of a standardized management system and recent technological advancements into environmental management system operations, intending to mitigate or eradicate associated risks and liabilities. Munodawafa and Johl [22] introduce a preliminary model of an Eco-innovation Management Information System, designed to facilitate the effective management and documentation of a company's eco-innovation achievements.

METHODOLOGY OF RESEARCH

The advanced technology used for enhancing environmental management systems study was based on data disclosed in articles and reports on artificial intelligence, blockchain, big data and the Internet of Things.

To conduct citation analysis and keyword cooccurrence the VOSViewer software (1.6.19) was applied. The Scopus database was used for the analysis. The relevant terms for the search query have been identified, and the search query has been constructed in the following manner (TITLE-ABS-KEY "advanced technolog*") OR TITLE-ABS-KEY ("artificial intelligence") OR TITLE-ABS-KEY ("blockchain") OR TITLE-ABS-KEY ("big data") OR TITLE-ABS-KEY ("internet of things") AND TITLE-ABS-KEY ("environmental management system*") AND (LIMIT-TO (LANGUAGE, "English") AND (LIMIT-TO (OA, "all"). The Scopus database returned 8 documents published.

To study the cutting-edge technologies application practices the content analysis method was applied. On the base of the collected information, the author singled out four main activities where the mentioned technologies are applied in terms of environmental aspects and environmental impact. The activities include transport, construction, office services and the chemical industry. The application of the technologies is analysed through the relevance of technologies application within the activity (Table 1).

Table 1
Environmental aspect and environmental impact within the activity

Activity	Environmental aspect	Environmental impact
Transport	Used oils for machinery. Carbon emissions of trucks and machinery	Soil, water, air pollution Greenhouse effect
Construction	Air emissions, noise, vibration etc. by construction machines Land use	Noise, soil, water, air pollution Land cover destruction Biodiversity loss
Office services	Use of materials such as paper, toner, etc. Electric power consumption (leading to indirect CO_2 emissions)	Mixed municipal waste pollution Greenhouse effect
Chemical industry	Waste water. Emission of volatile organic compounds Emission of ozone depleting substances	Water pollution Photochemical ozone Ozone layer depletion

RESULTS AND DISCUSSION

The keyword co-occurrence (Figure 1) showed that the keyword environment management system is linked with two of the above-mentioned advanced technologies: big data and artificial intelligence. In addition, there is a limited number of documents dealing with the potential of advanced technologies for environmental management systems. Therefore, there is a need to present how organizations can enhance the efficiency of resource allocation, foster creative breakthroughs, mitigate ecological hazards, and actively contribute to an environmentally friendly and enduring future by utilizing the functionalities of these technologies. To effectively implement an eco-management and audit scheme (EMAS), it is crucial to commence with a comprehensive assessment of an organization's internal framework and operations. The objective is to identify environmental factors linked to environmental effects, which serves as the foundation for establishing a structured environmental management system [23].

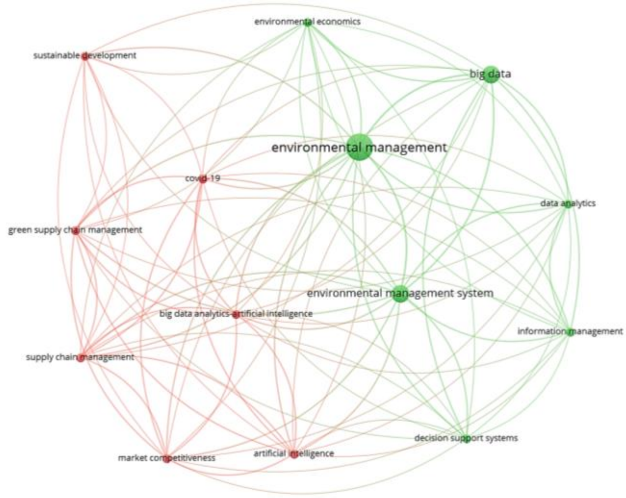

Fig. 1 Keywords cooccurrence

The results of the study are observed through the relation between activities, environmental aspects, and environmental impacts (Tables 2, 3, 4). In general, the application of advanced technologies is distinguished through the areas they are adopted or functions they can enhance. Applications of artificial intelligence technologies in environmental management systems include the following potential areas.

Table 2
AI application used for environmental management system

Activity	AI application	Description	Source
Transport	Application to reduce emissions	AI can optimize traffic flow, improve route planning, and promote the use of electric vehicles, resulting in reduced greenhouse gas emissions and air pollution	[24, 25, 26, 27, 28]
	Application to achieve energy efficiency	AI algorithms can optimize vehicle operations, reduce fuel consumption, and improve energy efficiency, leading to lower energy-related environmental impact	[29, 20, 30]
	Application to obtain sustainable mobility	AI applications can support the development of sustainable transportation solutions, such as ride-sharing services and intelligent transportation systems, which reduce the overall environmental impact of transportation activities	[31, 32, 33, 34]
Construction	Application to achieve energy efficiency	AI can optimize building energy management systems, monitor energy consumption, and identify opportunities for energy efficiency improvements, reducing the environmental impact associated with construction energy use	[35, 36, 37]
	Application to get waste reduction	AI tools can analyze construction data to identify opportunities for waste reduction, material recycling, and improved resource management, leading to reduced environmental impact through minimized construction waste generation	[38, 39]
	Application to carry out sustainable materials	AI can assist in the selection of sustainable building materials, considering factors such as embodied carbon, recycled content, and environmental certifications, thus promoting environmentally friendly construction practices	[40, 41]

cont. Table 2

Office services	Applications for energy management	AI technologies can optimize energy consumption in office buildings by monitoring and controlling HVAC systems, lighting, and equipment usage, resulting in energy savings and reduced environmental impact	[42, 43, 44]
	Applications for waste management	AI-powered systems can improve waste sorting, recycling, and disposal processes in office environments, contributing to reduced landfill waste and promoting sustainable waste management practices	[45, 46]
	Virtual Collaboration	AI tools enable remote collaboration and virtual meetings, reducing the need for business travel and associated carbon emissions, leading to a positive environmental impact	[47]
Chemical industry	Process Optimization	AI can optimize chemical manufacturing processes by analyzing data and identifying opportunities for energy and resource efficiency improvements. This results in reduced energy consumption and environmental impact associated with chemical production	[48, 49, 50]
	Environmental Monitoring	AI applications can monitor emissions, waste management, and pollution control in chemical industries, ensuring compliance with environmental regulations and reducing the impact on air, water, and soil quality	[51, 52]
	Product Innovation	AI can aid in the development of eco-friendly products and sustainable chemical alternatives, promoting a shift towards greener and less harmful chemical substances, thereby reducing the environmental impact of chemical industries	[53, 54]

Table 3

Blockchain application used for environmental management system

Activity	Blockchain application	Description	Source
Transport	Supply Chain Transparency	Blockchain can enhance transparency and traceability in the transportation industry by recording and validating every transaction and movement of goods. This reduces the potential for fraud, theft, and unauthorized activities, ultimately leading to a more secure and efficient supply chain	[55, 56]
	Carbon Emission Tracking	Blockchain can be used to create a decentralized system for tracking carbon emissions and verifying carbon offsets. This can incentivize organizations to reduce their carbon footprint and promote more sustainable transportation practices	[57, 58, 59]
	Peer-to-Peer (P2P) Ride-Sharing	Blockchain-based platforms can facilitate peer-to-peer ride-sharing, allowing individuals to share rides and reduce the number of vehicles on the road. This helps in reducing traffic congestion, fuel consumption, and overall emissions	[60]
Construction	Supply Chain Management	Blockchain can provide a transparent and immutable ledger for tracking construction materials throughout the supply chain. This ensures the use of sustainable materials, reduces waste, and promotes responsible sourcing	[61]
	Smart Contracts	Blockchain-enabled smart contracts can automate and streamline construction processes, ensuring adherence to sustainability standards and reducing paperwork. This can lead to more efficient resource utilization and minimize environmental impact	[62, 63]
	Energy Management	Blockchain can support decentralized energy management systems in construction projects, optimizing energy consumption, and enabling the integration of renewable energy sources. This reduces reliance on fossil fuels and promotes energy efficiency	[64, 65, 66]
Office services	Energy Tracking and Efficiency	Blockchain can be utilized to monitor and track energy usage in office buildings, promoting energy efficiency measures. This data transparency can facilitate the implementation of energy-saving practices, leading to reduced carbon emissions and lower energy costs	[67, 68, 69]
	Waste Management	Blockchain-based systems can improve waste management processes by enhancing transparency, traceability, and accountability. This can optimize waste disposal, recycling, and incentivize sustainable practices within office environments	[70, 71]
Chemical industry	Supply Chain Traceability	Blockchain can enable end-to-end traceability of chemical products, ensuring compliance with safety regulations and responsible handling throughout the supply chain. This reduces the risk of environmental pollution and facilitates proper waste management	[72]
	Chemical Management	Blockchain can facilitate secure and transparent record-keeping of chemical usage, storage, and disposal. This enhances safety measures, reduces the environmental impact of hazardous substances, and supports sustainable chemical management practices	[72]

Table 4
Big data and IoT applications used for environmental management system

Activity	Big data, IoT	Description	Source
Transport	Traffic Optimization	IoT sensors and big data analytics can provide real-time traffic data, allowing for optimized route planning and traffic management. This helps reduce congestion, idling time, and fuel consumption, resulting in lower emissions and improved air quality	[73]
	Predictive Maintenance	IoT devices can monitor the condition of vehicles and infrastructure in real-time. Coupled with big data analytics, this enables predictive maintenance, preventing breakdowns and reducing the need for emergency repairs. As a result, it reduces the number of vehicles taken out of service, minimizing environmental impacts and resource consumption	[74, 75]
Construction	Smart Building Management	IoT sensors embedded in buildings can collect data on energy usage, temperature, and occupancy. Big data analytics can then analyze this information to optimize energy consumption, improve HVAC systems' efficiency, and reduce overall environmental impact	[76]
	Safety Monitoring	IoT devices can enhance safety on construction sites by collecting data on worker behavior, equipment usage, and environmental conditions. Big data analytics can identify potential hazards and optimize safety protocols, reducing accidents and their associated environmental consequences	[77]
Office services	Occupancy Optimization	IoT devices can track occupancy and space utilization in offices. By analyzing this data, companies can optimize office layouts, reducing the need for excess space and minimizing energy consumption and resource usage	[78]
	Energy Management	IoT sensors can monitor energy consumption in office buildings, providing real-time data for analysis. Big data analytics can identify areas of high energy usage, optimize energy systems, and enable smart grid integration, leading to reduced energy waste and lower carbon emissions	[79, 27]
Chemical industry	Process Optimization	IoT sensors can monitor various parameters in chemical processes, such as temperature, pressure, and chemical composition. Big data analytics can analyze this data to optimize processes, reduce energy consumption, and minimize waste generation	[80]
	Safety and Risk Management	IoT devices can collect real-time data on chemical storage conditions, emissions, and safety equipment status. Big data analytics can analyze this data to identify potential risks, improve safety protocols, and prevent environmental accidents	[80]

If we consider AI-based environmental management systems, we put AI applications into perspective with a few criteria. They include the way it works and what business problem it is meant to solve, the AI capability employed, and the innovation type [81].

Data collection and analysis are areas in which artificial intelligence can be utilized. AI can automate the collection of data from diverse sources, including sensors, remote sensing satellites, and public databases. Subsequently, AI algorithms can be employed to analyse the gathered data to discern patterns, trends, and possible environmental consequences.

The utilization of AI in conducting environmental impact assessments (EIAs) enables the evaluation of the environmental ramifications associated with various activities. Through the integration of environmental data and AI models, it becomes feasible to simulate and forecast the potential environmental outcomes resulting from actions or initiatives. As a result, organizations are empowered to make well-informed choices regarding their operations and effectively identify strategies for mitigating potential adverse effects.

Researchers investigate how environmental management systems have provided new opportunities for the application of artificial intelligence [82]. Identification of the benefits to be had by building a decision support tool onto an integrated database system containing details of material and energy flows in all manufacturing and non-manufacturing process is another research point.

With the growing use of machine learning and natural language processing, artificial intelligence has become an invaluable tool for providing decision support systems (DSS) that can help businesses make better decisions more quickly and efficiently. Concerning decision support in EMS, such tools as improvement of targets and activity-based costing always aroused interest [82]. According to research [83], environmental management systems that utilize artificial intelligence techniques can help improve decision-making processes.

The utilization of AI in environmental management systems offers the potential for optimization and decision support. AI algorithms can provide recommendations for reducing environmental impacts by considering factors such as resource usage, emissions, and regulatory requirements [84]. By implementing these AI-driven strategies, organizations can enhance their sustainability efforts and mitigate their environmental footprint.

Artificial intelligence has the potential to enhance risk management efforts through the creation of early warning systems designed to identify potential environmental hazards. By diligently monitoring environmental data and employing AI methodologies, it becomes feasible to identify irregularities or deviations that could signify environmental risks. Consequently, this enables prompt interventions and proactive measures to mitigate adverse effects.

Organizations require efficient monitoring systems that take full advantage of artificial intelligence and advanced technology to measure progress, check for compliance with regulations, and identify any inconsistencies in the system. Such systems enable organizations to identify, analyse, and establish parameters within the EMS. AI has the potential to streamline and enhance the monitoring and reporting procedures related to environmental compliance. Through the analysis of data obtained from multiple sources and its comparison with regulatory guidelines, AI technologies can support organizations in achieving adherence to environmental regulations and standards. Consequently, the utilization of AI can alleviate administrative complexities and enhance the precision of reporting activities.

AI has the potential to enhance sustainable resource management through the examination of data on the availability of resources, patterns of consumption, and alternative possibilities. This can be achieved by utilizing AI methodologies such as optimization algorithms and predictive modelling, thus enabling organizations to improve the efficacy of resource utilization, minimize wastage, and mitigate their ecological footprint.

Amazon Web Services (AWS) and Microsoft Azure are cloud computing platforms that provide pre-trained AI modules [85]. This assists the development of artificial intelligence solutions in business. AI solutions help a variety of industries where the capabilities of cloud computing platforms drive business growth and transformation. Digitalization on the cloud can be regarded as a priority for even small and medium businesses to gain efficiencies that reduce operating costs and make them more agile and competitive [86]. According to 451 Research, AWS can reduce customers' workload carbon footprints by up to 80% compared to enterprise data centres [87]. The use of AWS and Microsoft Azure cloud services can lead to increased sustainability due to economies of scale. A study from 2018 found that the use of Azure can be up to 93% more energy efficient and 98% more carbon efficient than on-premises solutions [88].

EMAS and ISO are effective instruments for the environmental governance of an entity and are founded on voluntary participation. Both EMAS and ISO/EN ISO 14001 have the common goal of promoting effective environmental management, but they are frequently perceived as being in competition with each other. However, in 1996, the Commission acknowledged that ISO/EN ISO 14001 could serve as a starting point for adopting EMAS [89]. Consequently, incorporating ISO/EN ISO 14001 as the management system component of EMAS enables organizations to seamlessly transition from ISO/EN ISO 14001 to EMAS without duplicating their efforts [89, 90, 91]. If an EMS is adopted from a managerial perspective, it depends on the organizational structure of a business.

Two standards, ISO and EMAS, allow for a clear improvement in environmental performance. However, many studies focus on the need for a broad environmental assessment linked to production processes and pollution, energy consumption, and waste management issues [92, 93].

In addition, both Amazon and Microsoft are committed to using 100% renewable energy to power their servers by 2025 [87, 94].

The following are some recommendations for using AI-based environmental management systems [95]:

- In terms of implementing an AI-based environmental management system, the industry can use management counsellors to help speed up the integration of document systems and increase price flexibility when negotiating accreditation fees with accrediting institutions.
- AI-based environmental management systems are expected to become a standard in environmental management in the future. They can provide sustainable development by balancing environmental protection and economic profit. Implementing these systems at an early stage can help organizations achieve sustainable efficiency.
- Governments and relevant authorities should work to proactively introduce measures to industry to promote the green enterprise model. This support needs to be coming from the top management of the industry, as well as employees who are trained and encouraged to adopt these systems. Proper maintenance and periodic updates of these systems are also reliant on the cooperation of company management.

There are several potential domains in which blockchain technology can find application, such as traceability and transparency, carbon emissions monitoring and trading, environmental certification and adherence, collaboration and data sharing among stakeholders, mechanisms to encourage sustainable behaviour, and ensuring the integrity and security of data.

Blockchain technology has the potential to enhance the ability to trace and understand environmental activities and their consequences across the entire supply chain [96]. Through the utilization of a decentralized ledger to record and securely store data, blockchain can establish a transparent and unalterable record of actions and their corresponding environmental factors and effects. This capability enables stakeholders to effectively monitor and validate assertions made about sustainability, thereby promoting increased responsibility and confidence.

The utilization of blockchain technology can enhance the monitoring and exchanging of carbon emissions credits [97]. Through the generation of digital tokens that represent specific emissions quantities, blockchain enables precise measurement and validation of carbon footprints. Moreover, the implementation of smart contracts automates the trading process, enabling organizations to buy and sell emission credits. This incentivizes the reduction of emissions and promotes a more effective carbon market.

Blockchain technology has the potential to facilitate the certification and verification of environmental standards and compliance [98]. By securely documenting certifications, permits, and regulatory requirements on a blockchain, the veracity and precision of claims can be easily confirmed. Consequently, this has the potential to streamline audit procedures, mitigate instances of fraudulent activity, and augment trust in environmental certifications.

Stakeholder collaboration and data sharing can be enhanced using blockchain technology [98, 99]. Specifically, blockchain can provide a secure and efficient platform for various stakeholders involved in environmental management to share data. By utilizing permissioned blockchain networks, organizations can securely exchange sensitive information about their activities, impacts, and aspects, while also preserving privacy and data ownership. This capability of blockchain can facilitate collective decision-making and collaboration, ultimately leading to improved effectiveness in environmental management practices.

Blockchain-based tokens or cryptocurrencies have the potential to establish effective incentive mechanisms to promote sustainable behaviour [100]. By utilizing these tokens, both organizations and individuals can be incentivized to adopt environmentally friendly practices or meet predetermined environmental goals, thereby receiving rewards. These rewards can be exchanged for various advantages, goods, or services, thereby fostering a self-sustaining system of incentivized endeavours towards sustainability.

Blockchain's decentralized and immutable characteristics have the potential to improve the reliability and protection of data in environmental management systems [101]. By eliminating a centralized vulnerability and providing cryptographic security, blockchain technology can guarantee the precision and legitimacy of environmental data. This is especially advantageous when handling confidential information about environmental effects and regulations adherence.

Several potential domains exist in which big data and IoT can be effectively implemented. Real-time environmental monitoring is facilitated through the Internet of Things (IoT), which allows for the gathering of real-time data from a range of sensors and devices deployed in the environment [102]. These sensors can capture data on various environmental factors such as air and water quality, temperature, humidity, and noise levels. By employing big data analytics, this extensive dataset can be analysed and processed to offer valuable insights into environmental aspects and their consequences. Consequently, this enables decision-makers to make more informed and timely decisions.

By integrating advanced data analytics with both historical and present environmental data, it becomes feasible to construct anticipatory models for evaluating environmental effects [103]. These models can detect patterns, interconnections, and tendencies, thereby providing projections of potential outcomes for various activities. Through an enhanced comprehension of the probable ramifications, entities can adopt pre-emptive strategies to alleviate adverse environmental consequences.

Using big data and the Internet of Things (IoT) presents an opportunity for environmental management systems to optimise resource consumption [104]. Through the collection and real-time analysis of data on resource usage, including energy and water consumption, organizations can effectively identify inefficiencies and devise strategies to mitigate waste and enhance resource efficiency. This not only results in cost savings but also serves to minimize the environmental impact.

The utilization of Internet of Things (IoT) devices and the application of big data analytics can facilitate the development of early warning systems aimed at identifying and predicting environmental risks [105, 106]. Through the continuous monitoring of sensor data and its integration with historical data, algorithms have the potential to identify abnormalities or deviations that could serve as indicators of potential environmental hazards. Consequently, this enables timely interventions and proactive measures to mitigate such risks.

Stakeholder engagement and citizen science initiatives in environmental management can be facilitated using big data and IoT technologies [107]. By utilizing IoT devices and mobile applications, citizens can collect and share environmental data, which in turn contributes to the creation of extensive datasets. Through the application of big data analytics, this collective data can be analysed to gain a more comprehensive comprehension of environmental factors and their effects. The involvement of citizens in environmental monitoring serves to cultivate a sense of responsibility and empowers communities to actively engage in the decision-making processes related to environmental matters.

Decision support and scenario analysis play a crucial role in leveraging big data analytics for effective decision-making in environmental management systems [108]. Through the integration of data from diverse sources, such as IoT devices, organizations are empowered to make informed decisions that optimize their activities, minimize environmental harm, and ultimately achieve sustainability objectives. Notably, scenario analysis offers the ability to simulate the potential outcomes of different strategies, aiding in the identification of the most efficient and environmentally conscious approaches.

CONCLUSIONS

This paper delves into the possibilities offered by cutting-edge technologies in enhancing environmental management systems. It is important to acknowledge that although AI technologies present considerable possibilities for environmental management systems, their effective adoption should be coupled with thorough deliberation of ethical and social consequences [109, 110], concerns regarding data privacy, and continual oversight and upkeep of AI systems.

It is crucial to acknowledge that although blockchain technologies hold promise for environmental management systems, their implementation must consider various considerations including scalability, energy usage, compatibility with current systems, and the necessity for standardization. Furthermore, effectively dealing with legal and regulatory obstacles associated with the use of blockchain in the environmental sector is essential for its widespread acceptance and integration into established frameworks.

When integrating big data and IoT solutions into environmental management systems, it is imperative to confront obstacles concerning the reliability of data, safeguarding privacy, and security, and promoting interoperability. Moreover, guaranteeing the ethical and responsible utilization of data and considering the viewpoints and requirements of various stakeholders are pivotal for the effective implementation and acceptance of these technologies.

The research limitation of this study is that the data for literature analysis has been derived from the Scopus database. Therefore, the future study should utilize various data sources and databases.

Suggestions regarding future directions of research may include analysis of strengths, limitations, and applicability of various advanced technologies for environmental management systems, including emerging technologies across diverse industries and environmental challenges. Other suggestions are to conduct long-term studies to evaluate the environmental, social, and economic impacts of advanced technologies and assess their effectiveness in achieving sustainability goals, potential risks, or unintended consequences, and identify strategies for continuous improvement.

REFERENCES

[1] C. Choi, C. Kim, and C. Kim, "Towards Sustainable Environmental Policy and Management in the Fourth Industrial Revolution: Evidence from Big Data Analytics," *The Journal of Asian Finance, Economics and Business*, vol. 6, no. 3, pp. 185-192, Aug. 2019, doi: https://doi.org/10.13106/jafeb.2019.vol6.no3.185.

[2] M. Javaid, A. Haleem, R.P. Singh, R. Suman, and E.S. Gonzalez, "Understanding the adoption of Industry 4.0 technologies in improving environmental sustainability," *Sustainable Operations and Computers*, vol. 3, no. 1, pp. 203-217, Jan. 2022, doi: https://doi.org/10.1016/j.susoc.2022.01.008.

[3] R.R. Hernandez, M.S. Mayernik, M.L. Murphy-Mariscal, and M.F. Allen, "Advanced Technologies and Data Management Practices in Environmental Science: Lessons from Academia," *BioScience*, vol. 62, no. 12, pp. 1067-1076, Dec. 2012, doi: https://doi.org/10.1525/bio.2012.62.12.8.

[4] P.V. Thayyib et al., "State-of-the-Art of Artificial Intelligence and Big Data Analytics Reviews in Five Different Domains: A Bibliometric Summary," *Sustainability*, vol. 15, no. 5, p. 4026, Jan. 2023, doi: https://doi.org/10.3390/su15054026.

[5] H. Berg, "Unlocking the potential of Industry 4.0 to reduce the environmental impact of production," The Wuppertal Institute for Climate, 2021. Available: https://www.eionet.europa.eu/etcs/etc-wmge/products/etc-wmge-reports/unlocking-the-potential-of-industry-4-0-to-reduce-the-environmental-impact-of-production/@@download/file/Final%20for%20website.pdf.

[6] E. Albelda Pérez, C. Correa Ruiz, and F. Carrasco Fenech, "Environmental management systems as an embedding mechanism: a research note," *Accounting, Auditing & Accountability Journal*, vol. 20, no. 3, pp. 403-422, Jun. 2007, doi: https://doi.org/10.1108/09513570710748562.

[7] R. Canestrino, M. Ćwiklicki, P. Kafel, M. Wojnarowska, and P. Magliocca, "The digitalization in EMAS-registered organizations: evidences from Italy and Poland," *The TQM Journal*, vol. 32, no. 4, pp. 673-695, May 2020, doi: https://doi.org/10.1108/tqm-12-2019-0301.

[8] R.Z. Szabó, B. Szedmák, A. Tajti, and P. Bera, "Environmental Sustainability, Digitalisation, and the Entrepreneurial Perception of Distances as Drivers of SMEs' Internationalisation," *Sustainability*, vol. 15, no. 3, p. 2487, Jan. 2023, doi: https://doi.org/10.3390/su15032487.

[9] O. Diófási-Kovács and N. Judit, "Beyond CO2 emissions – The role of digitalization in multi-dimensional environmental performance measurement," *Environmental and Sustainability Indicators*, vol. 18, p. 100252, Apr. 2023, doi: https://doi.org/10.1016/j.indic.2023.100252.

[10] European Environment Agency, "environmental management system — European Environment Agency," www.eea.europa.eu. https://www.eea.europa.eu/help/glossary/eea-glossary/environmental-management-system (accessed Apr. 01, 2023).

[11] European Commission, "Advanced technologies," single-market-economy.ec.europa.eu. https://single-market-economy.ec.europa.eu/industry/strategy/advanced-technologies_en.

[12] P. Boucher, "Artificial intelligence: How does it work, why does it matter, and what can we do about it?," 2020. Available: https://www.europarl.europa.eu/RegData/etudes/STUD/2020/641547/EPRS_STU(2020)641547_EN.pdf.

[13] A. Sestino, M.I. Prete, L. Piper, and G. Guido, "Internet of Things and Big Data as enablers for business digitalization strategies," *Technovation*, vol. 98, no. 102173, p. 102173, Dec. 2020, doi: https://doi.org/10.1016/j.technovation.2020.102173.

[14] A. Kuzior and A. Kwilinski, "Cognitive Technologies and Artificial Intelligence in Social Perception," *Management Systems in Production Engineering*, vol. 30, no. 2, pp. 109-115, May 2022, doi: https://doi.org/10.2478/mspe-2022-0014.

[15] M. Yazdani, C. Kahraman, P. Zarate, and S.C. Onar, "A fuzzy multi attribute decision framework with integration of QFD and grey relational analysis," *Expert Systems with Applications*, vol. 115, pp. 474-485, Jan. 2019, doi: https://doi.org/10.1016/j.eswa.2018.08.017.

[16] S. Kumar, R. Sureka, W.M. Lim, S. Kumar Mangla, and N. Goyal, "What do we know about business strategy and environmental research? Insights from Business Strategy and the Environment," *Business Strategy and the Environment*, vol. 30, no. 8, May 2021, doi: https://doi.org/10.1002/bse.2813.

[17] H. Wang, T. Zhang, Y. Quan, and R. Dong, "Research on the framework of the Environmental Internet of Things," *International Journal of Sustainable Development & World Ecology*, vol. 20, no. 3, pp. 199-204, Apr. 2013, doi: https://doi.org/10.1080/13504509.2013.783517.

[18] Z. Zhang, H. He, J. Guo, and R. Han, "Velocity prediction and profile optimization based real-time energy management strategy for Plug-in hybrid electric buses," *Applied Energy*, vol. 280, p. 116001, Dec. 2020, doi: https://doi.org/10.1016/j.apenergy.2020.116001.

[19] S. Drobyazko and T. Hilorme, "Influence of Sustainable Development of Space Activities on Earth Ecology," *ProQuest*, vol. 940, Dec. 2021, doi: https://doi.org/10.1088/1755-1315/940/1/012014.

[20] G. Das, S. Li, R.A. Tunio, R.H. Jamali, I. Ullah, and K.W.T. Fernando, "The implementation of green supply chain management (GSCM) and environmental management system (EMS) practices and its impact on market competitiveness during COVID-19," *Environmental Science and Pollution Research*, vol. 30, May 2023, doi: https://doi.org/10.1007/s11356-023-27077-z.

[21] K. Fenton, S. Simske, and J. Luu, "Mitigation of Chemical Reporting Liabilities through Systematic Modernization of Chemical Hazard and Safety Data Management Systems," ACS omega, vol. 8, no. 5, pp. 4928-4936, Jan. 2023, doi: https://doi.org/10.1021/acsomega.2c07244.

[22] R.T. Munodawafa and S.K. Johl, "Design and Development of an Eco-innovation Management Information System to Accelerate Firms' Digital Transformation Strategy," *IEEE Access*, vol. 10, pp. 1-1, 2022, doi: https://doi.org/10.1109/access.2022.3163248.

[23] EUR-Lex, "Document 32013D0131," eur-lex.europa.eu, 2013. https://eur-lex.europa.eu/eli/dec/2013/131(1)/oj/eng

[24] M.K. Nasir, R. Md Noor, M.A. Kalam, and B.M. Masum, "Reduction of Fuel Consumption and Exhaust Pollutant Using Intelligent Transport Systems," *The Scientific World Journal*, vol. 2014, pp. 1-13, 2014, doi: https://doi.org/10.1155/2014/836375.

[25] M.M. Gandhi, D.S. Solanki, R.S. Daptardar, and N.S. Baloorkar, "Smart Control of Traffic Light Using Artificial Intelligence," in *2020 5th IEEE International Conference on Recent Advances and Innovations in Engineering* (ICRAIE), Dec. 2020. doi: https://doi.org/10.1109/icraie51050.2020.9358334.

[26] S. Khan, A. Adnan, and N. Iqbal, "Applications of Artificial Intelligence in Transportation," *IEEE Xplore*, Jul. 01, 2022. https://ieeexplore.ieee.org/abstract/document/9872928 (accessed Oct. 05, 2022).

[27] T. C. Truong, "The Impact of Digital Transformation on Environmental Sustainability," *Advances in Multimedia*, vol. 2022, pp. 1-12, May 2022, doi: https://doi.org/10.1155/2022/6324325.

[28] E.K. Nti, S.J. Cobbina, E.E. Attafuah, E. Opoku, and M.A. Gyan, "Environmental sustainability technologies in biodiversity, energy, transportation and water management using artificial intelligence: A systematic review," *Sustainable Futures*, vol. 4, p. 100068, 2022, doi: https://doi.org/10.1016/j.sftr.2022.100068.

[29] I.P. Chochliouros et al., "V2X Communications for the Support of GLOSA and Intelligent Intersection Applications," in Artificial Intelligence Applications and Innovations. *AIAI 2021 IFIP WG 12.5 International Workshops*, 2021, pp. 138-152. doi: https://doi.org/10.1007/978-3-030-79157-5_13.

[30] V. Magaña and M.M. Organero, "Reducing Stress and Fuel Consumption Providing Road Information," *Advances in Intelligent Systems and Computing*, vol. 376, pp. 23-31, Jan. 2015, doi: https://doi.org/10.1007/978-3-319-19695-4_3.

[31] G. Guido, D. Rogano, A. Vitale, V. Astarita, and Demetrio Carmine Festa, "Big data for public transportation: A DSS framework," in *5th IEEE International Conference on Models and Technologies for Intelligent Transportation Systems*, Jun. 2017. doi: https://doi.org/10.1109/mtits.2017.8005635.

[32] F. Baumgarte, R. Keller, F. Röhrich, L. Valett, and D. Zinsbacher, "Revealing influences on carsharing users' trip distance in small urban areas," Transportation Research Part D: *Transport and Environment*, vol. 105, p. 103252, Apr. 2022, doi: https://doi.org/10.1016/j.trd.2022.103252.

[33] A. Tsakiri, N. Lampiris, J. Prantalos, P. Mylonas, G. Aifadopoulou, and Michalis Fousteris, "Versatile Car Sharing Modelling for Sustainable Mobility with Embedded Intelligent Modules," in *ACM International Conference Proceeding* Series, Sep. 2022. doi: https://doi.org/10.1145/3549737.3549791.

[34] L. Bohm, F. Peters, P. Bossauer, D. Lawo, C. Pakusch, and G. Stevens, "Designing a Mobility Intelligence System for Decision-making with Shared Mobility Data," in *2022 International Conference on ICT for Sustainability*, ICT4S 2022, Jun. 2022. doi: https://doi.org/10.1109/ict4s55073.2022.00017.

[35] H. Gökçe and K.U. Gökçe, "Software Interoperability for Energy Efficient Building Operations Based on the IFC Data Model Standard," in *Progress in Sustainable Energy Technologies* Vol II: Creating Sustainable Development, Jan. 2014, pp. 309-318. doi: https://doi.org/10.1007/978-3-319-07977-6_21.

[36] S. Agostinelli, F. Cumo, G. Guidi, and C. Tomazzoli, "Cyber-Physical Systems Improving Building Energy Management: Digital Twin and Artificial Intelligence," *Energies*, vol. 14, no. 8, p. 2338, Apr. 2021, doi: https://doi.org/10.3390/en14082338.

[37] L. Farahzadi and M. Kioumarsi, "Application of machine learning initiatives and intelligent perspectives for CO2 emissions reduction in construction," *Journal of Cleaner Production*, p. 135504, Dec. 2022, doi: https://doi.org/10.1016/j.jclepro.2022.135504.

[38] S. Bang and B. Andersen, "Utilising Artificial Intelligence in Construction Site Waste Reduction," *Journal of Engineering, Project, and Production Management*, vol. 12, no. 3, Sep. 2022, doi: https://doi.org/10.32738/jeppm-2022-0022.

[39] P. Desai, S. Sandbhor, and A. Kaushik, "AI and BIM-based Construction defects, rework, and waste optimization," in International Conference on Emerging Smart Computing and Informatics (ESCI), Pune, India, Mar. 2023, pp. 1-6. doi: https://doi.org/10.1109/esci56872.2023.10099726.

[40] M. I. Shah et al., "Performance Evaluation of Soft Computing for Modeling the Strength Properties of Waste Substitute Green Concrete," *Sustainability*, vol. 13, no. 5, p. 2867, Mar. 2021, doi: https://doi.org/10.3390/su13052867.

[41] L. Farahzadi and M. Kioumarsi, "Intelligent Initiatives to Reduce CO2 Emissions in Construction," in ECCOMAS: *European Community on Computational Methods in Applied Sciences*, Scipedia, Jan. 2022. doi: https://doi.org/10.23967/eccomas.2022.150.

[42] C. Gomez-Otero, R. Uría-Martínez, and J. Caffarel, "ClimApp: A novel approach of an intelligent HVAC control system," in *Iberian Conference on Information Systems and Technologies*, Jun. 2012, pp. 1-6.

[43] Y.-Y. Chen, Y.-H. Lin, C.-C. Kung, M.-H. Chung, and I-Hsuan. Yen, "Design and Implementation of Cloud Analytics-Assisted Smart Power Meters Considering Advanced Artificial Intelligence as Edge Analytics in Demand-Side Management for Smart Homes," *Sensors*, vol. 19, no. 9, p. 2047, May 2019, doi: https://doi.org/10.3390/s19092047.

[44] S. Arvidsson, M. Gullstrand, B. Sirmacek, and M. Riveiro, "Sensor Fusion and Convolutional Neural Networks for Indoor Occupancy Prediction Using Multiple Low-Cost Low-Resolution Heat Sensor Data," *Sensors*, vol. 21, no. 4, p. 1036, Feb. 2021, doi: https://doi.org/10.3390/s21041036.

[45] A. Chopde, N. Bharate, S. Bhattar, A. Kunvar, and S. Bhadwal, “Trash Can! An AI system for automatic classification of waste,” *IEEE Xplore*, May 01, 2022. https://ieeexplore.ieee.org/abstract/document/9844351?casa_token=-nN6OC4O6roAAAAA:aGlEDxGRh7gUFBL28JWMycJuUn4A8p2wMpkDgdCiXURfpbcU4sn3graRgTiJjmNNS1d9Q56NUQ (accessed May 18, 2023).

[46] S. Sen, Dharmendra Yadeo, P. Kumar, and M. Kumar, “Machine learning and predictive control-based energy management system for smart buildings,” in *Artificial Intelligence and Machine Learning in Smart City Planning*, Jan. 2023, pp. 199-220. doi: https://doi.org/10.1016/b978-0-323-99503-0.00015-6.

[47] A.M. Suduc and M. Bizoi, “AI shapes the future of web conferencing platforms,” *Procedia Computer Science*, vol. 214, pp. 288-294, Jan. 2022, doi: https://doi.org/10.1016/j.procs.2022.11.177.

[48] D.E. Blanco, B. Lee, and M.A. Modestino, “Optimizing organic electrosynthesis through controlled voltage dosing and artificial intelligence,” Proceedings of the National Academy of Sciences, vol. 116, no. 36, pp. 17683-17689, Aug. 2019, doi: https://doi.org/10.1073/pnas.1909985116.

[49] Z. Ye, J. Yang, N. Zhong, X. Tu, J. Jia, and J. Wang, “Tackling environmental challenges in pollution controls using artificial intelligence: A review,” *Science of The Total Environment*, vol. 699, p. 134279, Jan. 2020, doi: https://doi.org/10.1016/j.scitotenv.2019.134279.

[50] W. Qing, “Global Practice of AI and Big Data in Oil and Gas Industry,” in Machine Learning and Data Science in the Oil and Gas Industry: *Best Practices, Tools, and Case Studies*, Jan. 2021, pp. 181-210. doi: https://doi.org/10.1016/b978-0-12-820714-7.00009-1.

[51] K.L. Johnston, M.L. Phillips, N.A. Esmen, and T.A. Hall, “Evaluation of an Artificial Intelligence Program for Estimating Occupational Exposures,” *The Annals of Occupational Hygiene*, vol. 49, no. 2, Dec. 2004, doi: https://doi.org/10.1093/annhyg/meh072.

[52] M.T. Gaudio, G. Coppola, L. Zangari, S. Curcio, S. Greco, and S. Chakraborty, “Artificial Intelligence-Based Optimization of Industrial Membrane Processes,” Earth systems and environment, vol. 5, no. 2, pp. 385-398, Jun. 2021, doi: https://doi.org/10.1007/s41748-021-00220-x.

[53] J.L. McDonagh, W.C. Swope, R.L. Anderson, M.A. Johnston, and D.J. Bray, “What can digitisation do for formulated product innovation and development?” *Polymer International*, vol. 70, no. 3, pp. 248-255, Jul. 2020, doi: https://doi.org/10.1002/pi.6056.

[54] R. Arboretti et al., “Machine learning and design of experiments with an application to product innovation in the chemical industry,” *Journal of Applied Statistics*, vol. 49, no. 10, pp. 2674-2699, Mar. 2021, doi: https://doi.org/10.1080/02664763.2021.1907840.

[55] M. Pournader, Y. Shi, S. Seuring, and S.C.L. Koh, “Blockchain applications in supply chains, transport and logistics: a systematic review of the literature,” *International Journal of Production Research*, vol. 58, no. 7, pp. 1-19, Aug. 2019, doi: https://doi.org/10.1080/00207543.2019.1650976.

[56] A. Noor, “Adoption of Blockchain Technology Facilitates a Competitive Edge for Logistic Service Providers,” *Sustainability*, vol. 14, no. 23, pp. 15543-15543, Nov. 2022, doi: https://doi.org/10.3390/su142315543.

[57] W. Li, L. Wang, Y. Li, and B. Liu, “A blockchain-based emissions trading system for the road transport sector: policy design and evaluation,” *Climate Policy*, vol. 21, no. 3, pp. 337-352, Nov. 2020, doi: https://doi.org/10.1080/14693062.2020.1851641.

[58] Y. Li, M.K. Lim, and C. Wang, “An intelligent model of green urban distribution in the blockchain environment,” Resources, Conservation and Recycling, vol. 176, no. 176, p. 105925, Jan. 2022, doi: https://doi.org/10.1016/j.resconrec.2021.105925.

[59] X. Yu and X. Wang, “Research on Carbon-Trading Model of Urban Public Transport Based on Blockchain Technology,” *Energies*, vol. 16, no. 6, pp. 2606-2606, Mar. 2023, doi: https://doi.org/10.3390/en16062606.

[60] S.A. Renu and B.G. Banik, “Implementation of a Secure Ride-Sharing DApp Using Smart Contracts on Ethereum Blockchain,” *International Journal of Safety and Security Engineering*, vol. 11, no. 2, pp. 167-173, Apr. 2021, doi: https://doi.org/10.18280/ijsse.110205.

[61] A. Lanko, N. Vatin, and A. Kaklauskas, “Application of RFID combined with blockchain technology in logistics of construction materials,” *MATEC Web of Conferences*, vol. 170, p. 03032, 2018, doi: https://doi.org/10.1051/matecconf/201817003032.

[62] L. Pellegrini, S. Campi, M. Locatelli, G. Pattini, G.M. Di Giuda, and L. C. Tagliabue, “Digital Transition and Waste Management in Architecture, Engineering, Construction, and Operations Industry,” *Frontiers in Energy Research*, vol. 8, Nov. 2020, doi: https://doi.org/10.3389/fenrg.2020.576462.

[63] F. Elghaish, M.R. Hosseini, T. Kocaturk, M. Arashpour, and M. Bararzadeh Ledari, “Digitalised circular construction supply chain: An integrated BIM-Blockchain solution,” *Automation in Construction*, vol. 148, p. 104746, Apr. 2023, doi: https://doi.org/10.1016/j.autcon.2023.104746.

[64] Y. Matsuda, Y. Yamazaki, H. Oki, Y. Takeda, D. Sagawa, and K. Tanaka, “Demonstration of Blockchain Based Peer to Peer Energy Trading System with Real-Life Used PHEV and HEMS Charge Control,” Energies, vol. 14, no. 22, p. 7484, Nov. 2021, doi: https://doi.org/10.3390/en14227484.

[65] A. Kuzior, M. Sira, and P. Brozek, “Using Blockchain and Artificial Intelligence in Energy Management as a Tool to Achieve Energy Efficiency,” *Virtual Economics*, vol. 5, no. 3, pp. 69-90, 2022.

[66] W. Du, X. Ma, H. Yuan, and Y. Zhu, “Blockchain technology-based sustainable management research: the status quo and a general framework for future application,” *Environmental Science and Pollution Research*, vol. 29, no. 39, pp. 58648-58663, Jul. 2022, doi: https://doi.org/10.1007/s11356-022-21761-2.

[67] M. Marzband, E. Yousefnejad, A. Sumper, and J.L. Domínguez-García, “Real time experimental implementation of optimum energy management system in standalone Microgrid by using multi-layer ant colony optimization,” *International Journal of Electrical Power & Energy Systems*, vol. 75, pp. 265-274, Feb. 2016, doi: https://doi.org/10.1016/j.ijepes.2015.09.010.

[68] E. Schiller, E. Esati, S. R. Niya, and B. Stiller, “Blockchain on MSP430 with IEEE 802.15.4,” in Conference on Local Computer Networks, LCN. *45th IEEE Conference on Local Computer Networks*, Sydney: LCN, Nov. 2020. doi: https://doi.org/10.1109/lcn48667.2020.9314805.

[69] W. Konhäuser, “Digitalization in Buildings and Smart Cities on the Way to 6G,” Wireless Personal Communications, vol. 121, no. 2, Sep. 2021, doi: https://doi.org/10.1007/s11277-021-09069-9.

[70] G. Ongena, K. Smit, B. Jarno, G. Adams, Y. Roelofs, and P. Ravesteyn, "Blockchain-based Smart Contracts in Waste Management: A Silver Bullet?," *Business Strategy and the Environment*, vol. 31, no. 1, Jun. 2018, doi: https://doi.org/10.18690/978-961-286-170-4.23.

[71] S. Shrivastava, A. Tripathi, and R. Yamini, "Blockchain-based Smart Waste Management System," International *Journal of Innovative Technology and Exploring Engineering*, vol. 8, no. 11S, pp. 1030-1034, Oct. 2019, doi: https://doi.org/10.35940/ijitee.k1212.09811s19.

[72] L. Alves, E. Ferreira Cruz, S. I. Lopes, P. M. Faria, and A. M. Rosado da Cruz, "Towards circular economy in the textiles and clothing value chain through blockchain technology and IoT: A review," Waste Management & Research: *The Journal for a Sustainable Circular Economy*, vol. 40, no. 1, p. 0734242X2110528, Oct. 2021, doi: https://doi.org/10.1177/0734242x211052858.

[73] D. Nallaperuma et al., "Online Incremental Machine Learning Platform for Big Data-Driven Smart Traffic Management," *IEEE Transactions on Intelligent Transportation Systems*, vol. 20, no. 12, pp. 4679-4690, Dec. 2019, doi: https://doi.org/10.1109/tits.2019.2924883.

[74] P. Killeen, B. Ding, I. Kiringa, and T. Yeap, "IoT-based predictive maintenance for fleet management," *Procedia Computer Science*, vol. 151, pp. 607-613, 2019, doi: https://doi.org/10.1016/j.procs.2019.04.184.

[75] S. Proto et al., "REDTag: A Predictive Maintenance Framework for Parcel Delivery Services," IEEE Access, vol. 8, no. 58, pp. 14953-14964, 2020, doi: https://doi.org/10.1109/access.2020.2966568.

[76] M.Y.L. Chew and K. Yan, "Enhancing Interpretability of Data-Driven Fault Detection and Diagnosis Methodology with Maintainability Rules in Smart Building Management," *Journal of Sensors*, vol. 2022, pp. 1-48, Jan. 2022, doi: https://doi.org/10.1155/2022/5975816.

[77] M. Martínez-Rojas, M. J. Gacto, A. Vitiello, G. Acampora, and Jose Manuel Soto-Hidalgo, "An Internet of Things and Fuzzy Markup Language Based Approach to Prevent the Risk of Falling Object Accidents in the Execution Phase of Construction Projects," *Sensors*, vol. 21, no. 19, pp. 6461–6461, Sep. 2021, doi: https://doi.org/10.3390/s21196461.

[78] J. Kim et al., "Occupant comfort and behavior: High-resolution data from a 6-month field study of personal comfort systems with 37 real office workers," *Building and Environment*, vol. 148, pp. 348-360, Jan. 2019, doi: https://doi.org/10.1016/j.buildenv.2018.11.012.

[79] S.A. Hashmi, C.F. Ali, and S. Zafar, "Internet of things and cloud computing-based energy management system for demand side management in smart grid," *International Journal of Energy Research*, vol. 45, no. 1, pp. 1007-1022, Oct. 2020, doi: https://doi.org/10.1002/er.6141.

[80] Q. Lele and K. Lihua, "Technical Framework Design of Safety Production Information Management Platform for Chemical Industrial Parks Based on Cloud Computing and the Internet of Things," *International Journal of Grid and Distributed Computing*, vol. 9, no. 6, pp. 299–314, Jun. 2016, doi: https://doi.org/10.14257/ijgdc.2016.9.6.28.

[81] European Commission and Executive Agency for Small and Medium-sized Enterprises, Artificial intelligence: critical industrial applications : report on market analysis of prioritised value chains, the most critical AI applications and the conditions for AI rollout. LU: Publications Office of the European Union, 2020. Available: https://op.europa.eu/en/publication-detail/-/publication/09a1b19f-93fa-11ea-aac4-01aa75ed71a1/language-en.

[82] J. Hart, I. Hunt, and V. Shankararaman, ". Environmental management systems-A role for AI?," in Workshop Binding Environmental Sciences and Artificial Intelligence (BESAI'98), 1998, pp. 1-10.

[83] U. Cortés and M. Sànchez–Marrè, "Binding Environmental Sciences and Artificial Intelligence in Environmental Modelling & Software." *Environmental Modelling and Software*, vol. 14, pp. 335-337, Jan. 1999.

[84] U. Cortés, M. Sànchez-Marrè, L. Ceccaroni, I. R-Roda, and M. Poch, "Artificial Intelligence and Environmental Decision Support Systems," *Applied Intelligence*, vol. 13, no. 1, pp. 77-91, 2000, doi: https://doi.org/10.1023/a:1008331413864.

[85] Amazon, "Artificial Intelligence Services," Amazon Web Services, Inc. https://aws.amazon.com/machine-learning/ai-services/?nc1=h_ls (accessed Apr. 06, 2023).

[86] Microsoft, "Azure AI Platform – Artificial Intelligence Service | Microsoft Azure," azure.microsoft.com. https://azure.microsoft.com/en-us/solutions/ai/#overview.

[87] 451 Research, "The Carbon Reduction Opportunity of Moving to Amazon Web Services," 2019.

[88] W. Hoek, "Digitalisation on the cloud must absolutely become a priority.," www.amcsgroup.com, 2020. https://www.amcsgroup.com/blogs/why-smbs-need-to-move-to-the-cloud-with-amcs-platform/#amcs-platform (accessed Apr. 06, 2023).

[89] European Commission Environment Directorate-General, "What is EMAS?" 2001. Accessed: Jul. 17, 2023. [Online]. Available: https://www.isprambiente.gov.it/contentfiles/01377800/1377885-fs-iso-en.pdf.

[90] F. Testa, F. Rizzi, T. Daddi, N.M. Gusmerotti, M. Frey, and F. Iraldo, "EMAS and ISO 14001: the differences in effectively improving environmental performance," *Journal of Cleaner Production*, vol. 68, pp. 165-173, Apr. 2014, doi: https://doi.org/10.1016/j.jclepro.2013.12.061.

[91] A. Erauskin-Tolosa, E. Zubeltzu-Jaka, I. Heras-Saizarbitoria, and O. Boiral, "ISO 14001, EMAS and environmental performance: A meta-analysis," *Business Strategy and the Environment*, vol. 29, no. 3, pp. 1145-1159, Dec. 2019, doi: https://doi.org/10.1002/bse.2422.

[92] F.F. Fagioli, L. Paolotti, and A. Boggia, "Trends in Environmental Management Systems Research. A Content Analysis," *Environmental and Climate Technologies*, vol. 26, no. 1, pp. 46-63, Jan. 2022, doi: https://doi.org/10.2478/rtuect-2022-0005.

[93] F. Gualandri and A. Kuzior, "Home Energy Management Systems Adoption Scenarios: The Case of Italy," *Energies*, vol. 16, no. 13, pp. 4946-4946, Jun. 2023, doi: https://doi.org/10.3390/en16134946.

[94] C. Welsch, "As the world goes digital, datacenters that make the cloud work look to renewable energy sources," Microsoft News Centre Europe, Nov. 23, 2022. https://news.microsoft.com/europe/features/as-the-world-goes-digital-datacenters-that-make-the-cloud-work-look-to-renewable-energy-sources/.

[95] W.-Y. Chang, "A Data Envelopment Analysis on the Performance of Using Artificial Intelligence-Based Environmental Management Systems in the Convention and Exhibition Industry," *Ekoloji*, vol. 28, no. 107, pp. 3515-3521, 2019.

[96] J. Lohmer, E. Ribeiro da Silva, and R. Lasch, "Blockchain Technology in Operations & Supply Chain Management: A Content Analysis," *Sustainability*, vol. 14, no. 10, p. 6192, May 2022, doi: https://doi.org/10.3390/su14106192.

[97] S. Pu and J. S. L. Lam, "The benefits of blockchain for digital certificates: A multiple case study analysis," *Technology in Society*, vol. 72, p. 102176, Feb. 2023, doi: https://doi.org/10.1016/j.techsoc.2022.102176.

[98] World Economic Forum, "How technology is enabling multistakeholder engagement," World Economic Forum, 2023. https://www.weforum.org/agenda/2023/01/how-technology-is-enabling-multi-stakeholder-engagement-davos2023/.

[99] A. Kuzior, S. Arefiev, and Z. Poberezhna, "Informatization of innovative technologies for ensuring macroeconomic trends in the conditions of a circular economy," *Journal of Open Innovation: Technology, Market, and Complexity*, vol. 9, no. 1, pp. 10-20, Mar. 2023, doi: https://doi.org/10.1016/j.joitmc.2023.01.001.

[100] A. Parmentola, A. Petrillo, I. Tutore, and F. De Felice, "Is blockchain able to enhance environmental sustainability? A systematic review and research agenda from the perspective of Sustainable Development Goals (SDGs)," *Business Strategy and the Environment*, vol. 31, no. 1, Sep. 2021, doi: https://doi.org/10.1002/bse.2882.

[101] T. Kawabata et al., "Blockchain Technology and Environmental Sustainability," 2020. Available: https://wedocs.unep.org/bitstream/handle/20.500.11822/34226/FB019.pdf?sequence=1&isAllowed=y.

[102] Q. Jones, "IoT-Based Environmental Monitoring: Types and Use Cases," www.digi.com, Apr. 15, 2022. https://www.digi.com/blog/post/iot-based-environmental-monitoring.

[103] A. Kawasaki et al., "Data Integration and Analysis System (DIAS) Contributing to Climate Change Analysis and Disaster Risk Reduction," *Data Science Journal*, vol. 16, Sep. 2017, doi: https://doi.org/10.5334/dsj-2017-041.

[104] O. Farooq, P. Singh, M. Hedabou, W. Boulila, and B. Benjdira, "Machine Learning Analytic-Based Two-Staged Data Management Framework for Internet of Things," *Sensors*, vol. 23, no. 5, p. 2427, Feb. 2023, doi: https://doi.org/10.3390/s23052427.

[105] M. Esposito, L. Palma, A. Belli, L. Sabbatini, and P. Pierleoni, "Recent Advances in Internet of Things Solutions for Early Warning Systems: A Review," *Sensors*, vol. 22, no. 6, p. 2124, Mar. 2022, doi: https://doi.org/10.3390/s22062124.

[106] C. Chandrakumar, R. Prasanna, M. Stephens, and M.L. Tan, "Earthquake early warning systems based on low-cost ground motion sensors: A systematic literature review," *Frontiers in Sensors*, vol. 3, Nov. 2022, doi: https://doi.org/10.3389/fsens.2022.1020202.

[107] OECD, "Enhancing the contribution of digitalisation to the smart cities of the future," 2019.

[108] G. Grander, L.F. da Silva, and E.D.R. Santibañez Gonzalez, "Big data as a value generator in decision support systems: a literature review," Revista de Gestão, vol. 28, no. 3, pp. 205-222, Jul. 2021, doi: https://doi.org/10.1108/rege-03-2020-0014.

[109] A. Kuzior and J. Zozuľak, "Adaptation of the Idea of Phronesis in Contemporary Approach to Innovation," *Management Systems in Production Engineering*, vol. 27, no. 2, pp. 84-87, Jun. 2019, doi: https://doi.org/10.1515/mspe-2019-0014.

[110] P. Fobel and A. Kuzior, "The future (Industry 4.0) is closer than we think. Will it also be ethical?" in *AIP Conference Proceedings*, 2019, doi: https://doi.org 10.1063/1.5137987.

Mariya Sira
ORCID ID: 0000-0002-9970-1549
Joint Doctoral School
Silesian University of Technology
Faculty of Organization and Management
Department of Applied Social Sciences
Roosevelt 26 Street, 41-800 Zabrze, Poland
e-mail: mariya.sira@polsl.pl