CHEMICAL ENGINEERING TRANSACTIONS
VOL. 103, 2023
A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.cetjournal.it
Guest Editors: Petar S. Varbanov, Panos Seferlis, Yee Van Fan, Athanasios Papadopoulos

ISBN 979-12-81206-02-1; **ISSN** 2283-9216
DOI: 10.3303/CET23103084

AI Application to Pollution Reduction and Waste Management Toward Net Zero: A Systematic Review

Fidero Kuok[a,*], Buntoun Monyrath[b], Michael Angelo B. Promentilla[c]

[a]National Institute of Science, Technology and Innovation, Preah Norodom Boulevard, Sangkat Phsar Thmey III, Khan Daun Penh, Phnom Penh, CAMBODIA, Phnom Penh, Cambodia
[b]Tux Global Institute, 09, St. P03, Borey Peng Huoth The Star Premier, Chrang Chamres I, Russei Keo District, Phnom Penh, Cambodia
[c]Center for Engineering and Sustainable Development Research, De La Salle University, Manila 1004, Philippines
kuok.fidero@misti.gov.kh

In the midst of growing concern about global warming, which has become of great importance more than ever, a concerted international effort is needed to limit the temperature rise to around 1.5 degrees Celsius. To mitigate the worst impact of climate change, a global effort to achieve net zero by 2050 is a must, which is essential to cut the emissions to close to zero while the rest is captured from the atmosphere. This ambitious goal would not be possible without proper coordination and active participation from the waste management sector and industries, which significantly contribute to global greenhouse gas emissions. It is necessary that the net zero is aligned with all the actors to cover the scope of controlling emissions occurring at the source and emissions associated with the production of energy consumed by the industry. This also includes the indirect emissions derived from the industry's activities from sources that are not managed by the industry itself. It is understood that at this global scale, the collection of data, processing, and analytics to reach the targeted net zero becomes nearly impossible for humans to handle. The application of artificial intelligence (AI), especially machine learning and deep learning, among other subsets, could be instrumental in collecting, processing, and analysing big data in real-time with automation and optimisation and elucidating trends and patterns of emission and waste generation from industries, to name a few. This study aims to systematically assess and map the research trend, potentials of AI toward accomplishing net zero, and barriers to AI application in pollution reduction and waste management. This systematic review and mapping as complementary approaches could offer vital insights for further decision-making among inter-governmental agencies.

1. Introduction

While continuing to grapple with the economic impact of the COVID-19 pandemic, most countries continue to boost their recovery plan, among which the industry sector returns to its new normal, following various supporting schemes from the government. Environmental degradation, pollution, and inefficient waste management practices are back to normal and pose significant challenges to achieving sustainable development and mitigating climate change, attributed to the industrial sector, which is the main player in carbon dioxide emission. As such, the investment and economic recovery plan should be well harmonised with the net zero frameworks, and perhaps not only the policies but also the mandates and standards should be considered to make use of all available efficient technologies for pollution reduction and waste management. As energy consumption accounted for three-quarters of greenhouse gas emissions today, a complete transformation with the application of advanced technology to monitor, control, and optimise energy consumption at industry sources became ample important to limit the long-term increase in average global temperatures to 1.5 °C (IEA, 2021). One could imagine that such a synchronous system to collect and analyse data from different industrial processes to minimise pollution emission and waste generation in real-time is beyond human ability to handle. In recent years, there has been a growing interest in harnessing the power of artificial intelligence (AI) to address these pressing challenges. For example, AI was employed to identify the pollution sources in an industrial paper mill (Lotrecchiano et al., 2022a) and for the geo-linked analysis of air quality monitoring in Milan (Lotrecchiano

Paper Received: 14 April 2023; Revised: 30 June 2023; Accepted: 26 July 2023
Please cite this article as: Kuok F., Monyrath B., Promentilla M.A.B., 2023, AI Application to Pollution Reduction and Waste Management Toward Net Zero: A Systematic Review, Chemical Engineering Transactions, 103, 499-504 DOI:10.3303/CET23103084

et al., 2022b). By leveraging AI's capabilities in data processing, pattern recognition, and decision-making, innovative solutions can be developed to advance pollution reduction strategies and optimise waste management practices, contributing to the global goal of achieving net-zero emissions. This paper presents a systematic review of the research landscape surrounding the application of AI in pollution reduction and waste management. The study aims to provide researchers with background information and direction on the research trends, explore the potentials of AI in attaining net-zero emissions, and identify the barriers and challenges hindering the widespread implementation of AI in this domain.

2. Methodology

The systematic review was conducted to have a systematic bird-eye view of the existing studies and further construct the empirical evidence and future research trend while considering, i.e., the limitation and challenges of AI application. Figure 1 illustrates the flowchart describing the stepwise process of systematic review and mapping (Garces et al., 2022). Note that the application of systematic mapping in the present study was to elucidate the research gap and serve as the foresight for future investigations. The research questions were concentrated on the research trend of AI applications and potentials toward net zero and barriers to AI applications to achieve this net zero (See Table 1). All relevant articles were searched and queried at the second step based on the identified keywords. The present study considered the return articles containing the pre-determined keywords in the abstract published during 2018 – 2022. Boolean operators were used during searching and querying in the Scopus database to limit the return result. The primary dataset for the research questions was then constructed using the search string ABS (AI applications and (net zero) OR (reducing pollution) OR (pollution reduction) OR (waste generation) OR (waste management))). Note that the string "ABS" was used to limit the search only to the abstracts of the papers in the Scopus database.
The primary dataset was then screened by reading the abstract, title, and keyword with the use of Mendeley software to exclude any unrelated or duplicated articles. The relevant articles were classified based on the research questions (See Table 1), and this extracted dataset was systematically reviewed to address the pre-determined research questions. This extracted dataset was classified according to schemes to construct the systematic mapping (See Figure 1). Systematic mapping of scientific publications was then conducted using VOSViewer (Donthu et al., 2021). A map of keyword co-occurrence was constructed based on all keywords retrieved from the bibliographic database and using fractional counting and at least five occurrences per keyword. The total strength of the co-occurrence linked among keywords was then calculated and presented.

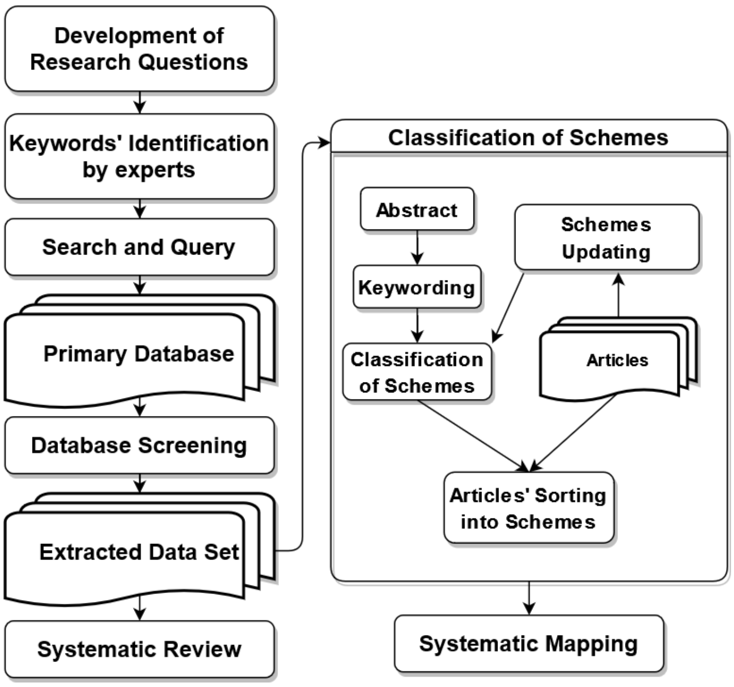

Figure 1: Systematic review and mapping processes

Table 1: Research questions on AI application to pollution reduction and waste management toward net zero

Research Questions (RQ)	
RQ1	What is the research trend of AI applications toward net zero?
RQ2	What are the potentials of AI applications in reducing pollution and waste generation at industry sources?
RQ3	What are the potentials of AI applications in pollution emission associated with the production of energy consumption by industry?
RQ4	What are the barriers to AI application to pollution reduction and waste management toward net zero?

3. Results and discussion

3.1 RQ1: What is the research trend of AI applications toward net zero?

The research trend of AI applications toward achieving net-zero emissions is characterised by the growing interest and multidisciplinary approaches during the last few years, as shown in the annual publication (See Figure 2). For example, researchers from various fields, primarily from computer science, environmental science, engineering, and energy, are actively exploring the potential of AI to address the challenges of pollution reduction and waste management in the pursuit of net-zero emissions, as it is illustrated in publications by subject areas (Figure 3). The co-occurrence analysis of all keywords considering at least five occurrences per keyword described in Figure 4 underscores the interconnected nature of these research domains. This highlights the pivotal role of AI in addressing pollution and waste-related challenges and emphasises the need for interdisciplinary collaboration to achieve sustainable solutions in optimising energy systems, smart cities, environmental monitoring, and pollution control, among others. China, which is followed closely by India and the United States, is leading in published research output related to AI applications in pollution reduction and waste management (see Table 2). Chinese researchers are actively investigating the application of AI for pollution monitoring with the use of self-powered flexible sensors (Zheng et al., 2022), waste classification with future work on the improvement of image recognition at low-level information of edges and boundaries of objects and materials (Lu et al., 2022), sustainable waste management practices, and circular economy integration, especially in the current research trend of Digital Twin Technology (Cheah et al., 2022).

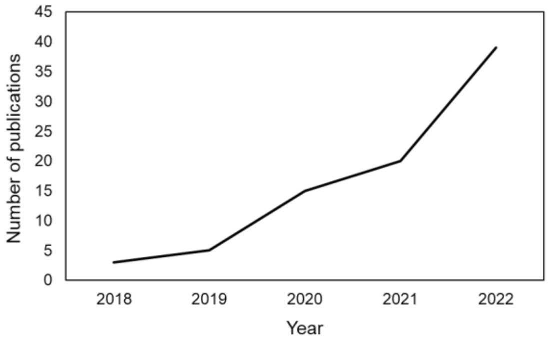

Figure 2: Annual publication on AI Application to Pollution Reduction and Waste Management toward Net Zero

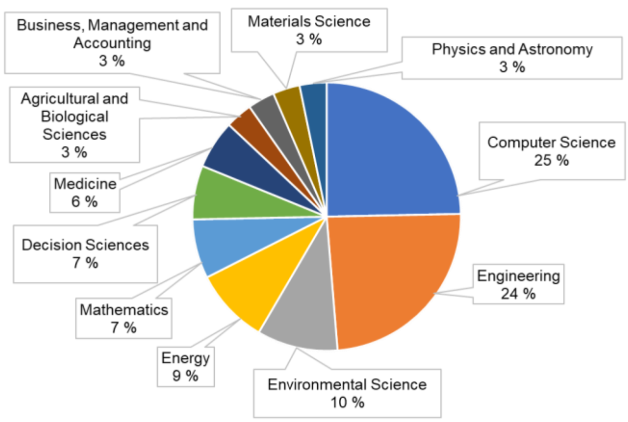

Figure 3: Publications by subject areas

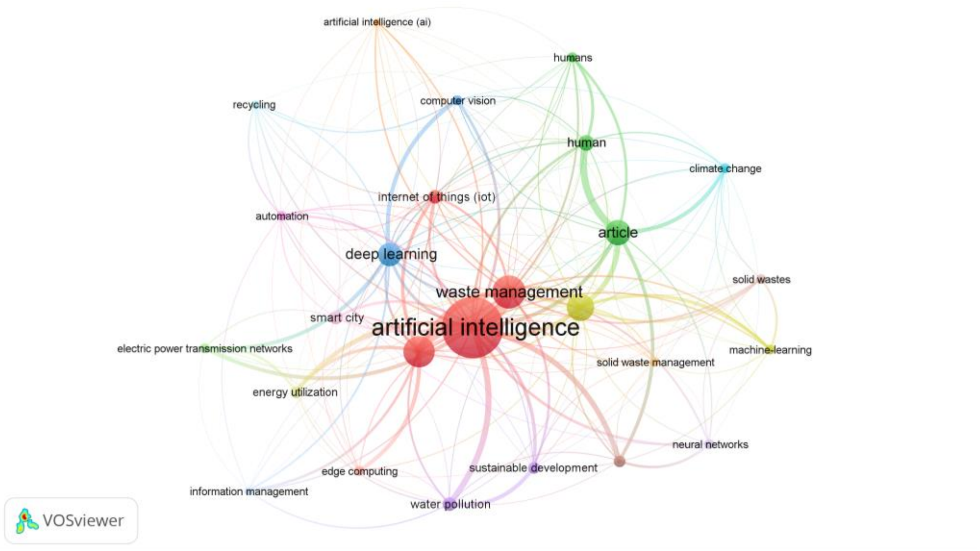

Figure 4: Co-occurrence analysis of all keywords considering at least five occurrences per keyword

Table 2: Top ten publication countries

Country/Territory	Number of Articles Published
China	17
India	14
United States	13
United Kingdom	6
Germany	5
Saudi Arabia	5
Malaysia	4
France	3
Italy	3
South Korea	3

3.2 RQ2: What are the potentials of AI applications in reducing pollution and waste generation at industry sources?

The rapid advancement of artificial intelligence (AI) includes its traditional uses and has been recognised as a crucial technology in reducing waste generation, particularly at industrial sources. A recent study by Abou et al. (2021) demonstrated that AI techniques, specifically transfer learning, can facilitate the development of circular, smart cities and a circular economy by enabling automated recycling. Initially, this approach could be applied to recycling smartphones and other electronic waste industries. Cheng et al. (2021) stressed the importance of adopting a green intelligent production design strategy based on service design. This strategy transforms traditional manufacturing into smart industries by incorporating technologies like the Internet of Things (IoT), AI, and others. In fact, Cheng et al. (2021) utilised system service design thinking to provide managerial and technical guidance, aiming to reduce pollution and waste generation at each stage of the manufacturing process, achieving the goals and values of intelligent green manufacturing. To achieve net-zero emissions, the use of AI in industries, particularly through the adoption of robotics, has proven instrumental in reducing carbon intensity (Liu et al., 2022). This study also indicated that AI applications effectively decreased carbon intensity in labor- and technology-intensive industries. While exploring the implementation of AI in production flow management within the automotive industry, Amejwal et al. (2022) indicated that AI, along with other technologies such as the Internet of Things (IoT), radio-frequency identification (RFID), and cyber-physical systems (CPS), was commonly used to minimise production time and ensure on-time delivery. In addition to its extensive application in the manufacturing sector, AI has also proven to be a valuable tool in on-site construction waste management (Ali et al., 2019). This advanced implementation system, integrated with AI technology, can assist the construction industry in using fewer resources, reducing waste, and improving productivity (Vickranth et al., 2019).

3.3 RQ3: What are the potentials of AI applications in pollution emission associated with the production of energy consumption by industry?

The significant potential of AI applications in addressing pollution emissions associated with industrial energy consumption lies in energy optimisation, which involves optimising energy usage while minimising pollution emissions throughout industrial processes. One early example is the utilisation of an AI control strategy with an application program interface (API) protocol based on the nearly zero energy building technology in smart microgrids (Yu et al., 2020). By harnessing the computational power of machine learning algorithms to analyse large amounts of data and identify patterns, a supervisory control and data acquisition (SCADA) system structure with online monitoring of energy consumption and environmental parameters proved effective in monitoring and optimising power management control strategies and heat recovery efficiency in real-world buildings. Additionally, a recent study highlighted that AI has the potential to reduce carbon emissions, particularly in advanced technology mega-infrastructure, by optimising industrial structures, enhancing information infrastructure, and fostering green technology innovation (Chen et al., 2022). The monitoring and control aspects and predictive maintenance become increasingly challenging for humans in the context of mega-infrastructure. Also, the loss of energy due to human error or mismanagement of industrial processes could no longer be detected; however, an end-to-end solution of an anomaly detection system, an unsupervised learning model, could be a solution to detect these anomalies as it was a proof of concept in a German manufacturing company (Kaymakci et al., 2021). The potential of AI applications could also be observed in renewable energy integration and smart grid management. For example, smart grid AI technologies enable effective connection and management of renewable energy sources such as solar, wind, and hydrogen. These technologies allow for real-time balancing and optimisation of power supply and demand (Liu et al., 2022).

3.4 RQ4: What are the barriers to AI application to pollution reduction and waste management toward net zero?

Despite the potential benefits of using AI for pollution reduction and waste management, several significant challenges need to be addressed. One such challenge is integrating AI with IoT devices, which involves overcoming technical barriers such as coordination issues among IoT devices in real-time applications, the heterogeneity and interoperability of IoT devices, security and privacy protocols in various wireless environments, as well as accuracy and latency problems when transferring data in real-time (Albreem et al., 2021). Due to the complex nature of waste characteristics and the diverse sources of pollution, a substantial amount of data is required to train the machine and deep learning algorithms. The lack of sufficient data poses another barrier to implementing AI in waste management applications, such as predicting waste generation, detecting trash bins, optimizing routes for dump trucks, and classifying waste (Ihsanullah et al., 2022). In such a case, government regulatory policies on data sharing and AI implementation in waste management could be a solution. Additionally, the reliability and quality of data obtained from the internet present another obstacle for machine learning, as errors can occur due to data format and collection methods. The selection of an appropriate AI model is also challenging due to the opaque nature of AI, often referred to as a black box. Estimating the importance of individual input parameters becomes difficult, leading to uncertainty in applying such models (Ihsanullah et al., 2022). The implementation of AI technology in the waste industry is hindered by the diversity and disparity of technologies used worldwide, while the shortage of skilled AI workers remains a prominent barrier for the waste industry. Therefore, in-depth collaborative research and development between multidisciplinary approaches could potentially address this AI technology development and adoption.

4. Conclusions

This study provides an insight into the research landscape surrounding the application of AI in pollution reduction and waste management, with a specific focus on achieving net-zero emissions. Through systematic mapping, valuable insights into the prevailing research trends, potentials of AI, and barriers hindering its widespread implementation are presented. This analysis not only showcases the current state of knowledge but also highlights gaps that warrant further investigation. By identifying these research trends, we can guide future studies and foster interdisciplinary collaborations to address critical knowledge gaps and push the boundaries of AI applications in pollution reduction and waste management. For example, optimising energy systems, integrating circular economy practices, advancing pollution monitoring and control mechanisms, and enhancing waste management efficiency are just a few areas where AI can contribute significantly. However, the successful implementation of AI in pollution reduction and waste management is not without its challenges. Through the identification of technological, economic, policy, and social barriers, future work needs to understand these barriers that impede the widespread adoption of AI solutions. Understanding these challenges is crucial for policymakers, practitioners, and researchers to devise strategies and interventions that address these barriers effectively. The findings imply the need for continued research and development to unlock the full potential of AI in tackling environmental challenges and advancing sustainable practices toward net zero.

References

Abou B.N., Szabo-Müller P., Handmann U., 2021, A Feature-Fusion Transfer Learning Method as a Basis to Support Automated Smartphone Recycling in a Circular Smart City, Conference paper, Institute for Computer Sciences, Social-Informatics and Telecommunications Engineering, LNICST, 372, 422 – 441.

Albreem M.A., Sheikh A.M., Alsharif M.H., Jusoh M., Yasin M.M., 2021, Green Internet of Things (GIoT): Applications, Practices, Awareness, and Challenges, IEEE Access, 9, 38833 – 38858.

Ali T.H., Akhund M.A., Memon N.A., Memon A.H., Imad H.U., Khahro S.H., 2019, Application of Artificial Intelligence in Construction Waste Management, 8th International Conference on Industrial Technology and Management, 2-4 March, Cambridge, UK, 50 – 55, 10.1109/ICITM.2019.8710680.

Amejwal M., Jaouhari A.E., Arif J., Fellaki S., Jawab F., 2022, Production Flow Management Based on Industry 4.0 Technologies, Conference paper, 14th International Colloquium of Logistics and Supply Chain Management, 25-27 May, EL JADIDA, Morocco, 1 – 7, 10.1109/LOGISTIQUA55056.2022.9938064.

Cheah C.G., Chia W.Y., Lai S.F., Chew K.W., Chia S.R., Show P.L., 2022, Innovation designs of industry 4.0 based solid waste management: Machinery and digital circular economy, Environmental Research, 213, 113619.

Chen P., Gao J., Ji Z., Liang H., Peng Y., 2022, Do Artificial Intelligence Applications Affect Carbon Emission Performance?—Evidence from Panel Data Analysis of Chinese Cities, Energies, 15, 1 – 16.

Cheng W., Zhang J., Gao W., 2021, Green Intelligent Production Design Strategy Based on Service Design, Conference paper, Networks and Systems, 261, 345 – 352.

Donthu N., Kumar S., Mukherjee D., Pandey N., Lim W.M., 2021, How to conduct a bibliometric analysis: An overview and guidelines, Journal of Business Research, 133, 285 – 296.

Garces J.I.T., Tigue A.A.S., Promentilla M.A.B., 2022, A Systematic Mapping Study of Geopolymers for Radioactive Waste Management, Chemical Engineering Transactions, 94, 1345 – 1350.

Ihsanullah I., Alam G., Jamal A., Shaik F., 2022, Recent advances in applications of artificial intelligence in solid waste management: A review, Chemosphere, 309, 1 – 18.

IEA, 2021, Net Zero by 2050 A Roadmap for the Global Energy Sector, IEA Publications, Paris, France <iea.blob.core.windows.net/assets/deebef5d-0c34-4539-9d0c-10b13d840027/NetZeroby2050-ARoadmapfortheGlobalEnergySector_CORR.pdf> accessed 30.05.2023.

Kaymakci C., Wenninger S., Sauer A., 2021, Energy Anomaly Detection in Industrial Applications with Long Short-term Memory-based Autoencoders, Procedia CIRP, 104, 182 – 187.

Liu J., Liu L., Qian Y., Song S., 2022, The effect of artificial intelligence on carbon intensity: Evidence from China's industrial sector, Socio-Economic Planning Sciences, 83, 1 – 8.

Liu Z., Gao Y., Liu B., 2022, An artificial intelligence-based electric multiple units using a smart power grid system, Energy Reports, 8, 13376 – 13388.

Lotrecchiano N., Barletta D., Poletto M., Sofia D., 2022a, Artificial Intelligence for the Pollution Source Identification, Chemical Engineering Transactions, 96, 439 – 444.

Lotrecchiano N., Barletta D., Poletto M., Sofia D., 2022b, Innovative Process for the Geo-linked Analysis of Air Quality Assisted by Ai Techniques, Chemical Engineering Transactions, 96, 445 – 450.

Lu W., Chen J., Xue F., 2022, Using computer vision to recognize composition of construction waste mixtures: A semantic segmentation approach, Resources, Conservation and Recycling, 178, 1 – 13.

Vickranth V., Bommareddy S.S.R., Premalatha V., 2019, Application of lean techniques, enterprise resource planning and artificial intelligence in construction project management, International Journal of Recent Technology and Engineering, 7, 147 – 153.

Yu Q., Liu Y., Jiang Z., Long G., 2020, Design and Accomplishment of AI Control Strategy with API in Nearly Zero Energy Building Smart Grid, IEEE 6th International Conference on Control Science and Systems Engineering, 17-19 July, Beijing, China, 222 – 226, DOI: 10.1109/ICCSSE50399.2020.9171989.

Zheng Q., Hou Y., Yang H., Tan P., Shi H., Xu Z., Ye Z., Chen N., Qu X., Han X., Zou Y., Cui X., Yao H., Chen Y., Yao W., Zhang J., Chen Y., Liang J., Gu X., Wang D., Wei Y., Xue J., Jing B., Zeng Z., Wang L., Li Z., Wang Z.L., 2022, Towards a sustainable monitoring: A self-powered smart transportation infrastructure skin, Nano Energy, 98, 1 – 13.