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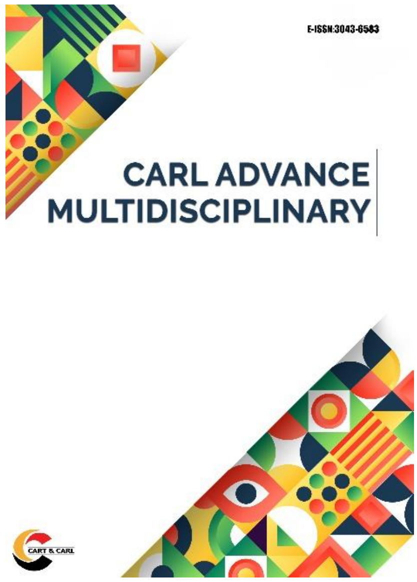

Effectiveness of Artificial Intelligence Technologies in Circular Economy Initiatives in Nigeria

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Abstract

The integration of Artificial intelligence (AI) as a circular economy (CE) strategy for plastic waste management optimized waste collection and sorting processes, improved material recovery rates and developed innovative and applicable realistic recycling technologies. The study examines the perceived effectiveness of artificial intelligence technologies in circular economy initiatives among various stakeholders in Nigeria. The study involves stakeholders in waste management and residents that were randomly selected from the Federal Capital Territory, Abuja and Lagos State, Nigeria. With 400 respondents, a questionnaire was adopted for data gathering while data analysis was carried out through descriptive statistics such as frequency count, percentage and mean. The finding revealed that the respondents agreed that AI can significantly reduce plastic waste in dumpsites (49.5%), optimize plastic recycling processes (51.8%), make waste management more data-driven and efficient (56.9%), facilitate a robust circular economy model (51.9%), use of AI technologies in waste management will increase with time (67.5%), AI can enhance real-time monitoring of plastic waste rates (50.0%) and AI-enabled platforms can reduce operational costs (52.7%); however, the respondents disagreed that AI can improve public awareness on plastic waste disposal (46.0%). In conclusion, the successful adoption of AI-driven solutions in plastic waste management will require concerted efforts across multiple sectors, including government, private industries, and civil society organizations.

Keywords : Circular Economy, Artificial intelligence, Plastic, Plastic Waste Management, Nigeria

Introduction

The concept of a circular economy offers a promising solution one that aims to minimize waste, maximize resource efficiency, and create a sustainable loop for plastic materials (European Parliament, 2015). A circular economy is an economic system that is aimed at reducing waste and pollution by keeping materials in use for as long as possible (Ellen Macarthur Foundation, 2019). It is a closed-loop system where materials are extracted for all the possible uses it can offer. A circular economy is a model that considers sustainability in resource exploration/exploitation as well as its usage to extend the life cycle of products/resources and to tackle climate change and other global challenges like biodiversity loss, waste and pollution, etc. by decoupling economic activity from the consumption of finite resources (Ogunola et al., 2021). The circular economy model is based on three principles driven by design: eliminate waste and pollution, circulate products and materials at their highest value, and regenerate nature (Ellen Macarthur Foundation, 2019). This model is applicable in business, biodiversity conservation, built environment, cities, design, climate, fashion, finance, food, and plastic to grow prosperity, jobs, and resilience while cutting greenhouse gas emissions, waste, and pollution (Pasqualotto et al., 2023).

Several circular economy strategies have been deployed so far in the bid to reduce plastic waste and pollution; they include the source reduction method which promotes the use of less plastics by preventing/reducing plastic wastes from being generated through promoting reusable options for packaging (Rezk et al., 2024), minimising the use of unnecessary package, only use packaging when it is entirely needed and, by designing products with less plastic materials (Oyebode, 2022). The Extended Producers Responsibility (EPR) is another circular economy strategy which allows manufacturers to take responsibility for the entire lifecycle of their products which includes proper disposal and recycling. This strategy has helped companies design products that are easier to recycle and recover. For instance, the Nigeria Bottling Company PLC Sprite bottles change from green to white PET bottles.

The plastic recycling infrastructure is also a circular economy strategy that involves several processes where plastic wastes are collected through designated recycling centres, sorted and processed through collection systems and educating the public about recycling practices. The circular economy strategy for plastic waste reduction is also the innovative materials and alternatives strategy where the use of alternative materials such as biodegradable plastics, and plant-based material. Artificial intelligence is an emerging trend just like the circular economy. It is believed to have the ability to achieve an accelerated systematic transition to a circular economy by enhancing and accelerating the development of new products, components, and materials fit for a circular economy (Pregowska et al., 2022). It complements human skills and capabilities due to its ability to perform complex tasks.

The current linear economic model, characterized by the “take-make-waste” approach, is unsustainable. It depletes natural resources, generates excessive waste, and harms the environment. In contrast, the circular economy (CE) offers a sustainable alternative. CE principles aim to design out waste, keep products and materials in use, and regenerate natural systems (Shreyas et al., 2021). A circular economy is an economic system that is aimed at reducing waste and pollution by keeping materials in use for as long as possible. It is a closed-loop system where materials are extracted for all the possible uses it can offer. A circular economy is a model that considers sustainability in resource exploration/exploitation as well as its usage to extend the life cycle of products/resources and to tackle climate change and other global challenges like biodiversity loss, waste and pollution, etc. by decoupling economic activity from the consumption of finite resources. The circular economy model is based on 3 principles driven by design: eliminate waste and pollution, circulate products and materials at their highest value, and regenerate nature. This model is applicable in business, biodiversity conservation, built environment, cities, design, climate, fashion, finance, food, and plastic to grow prosperity, jobs, and resilience while cutting greenhouse gas emissions, waste, and pollution.

Traditional methods of plastic waste management such as open burning, open dumpsites, and incineration are even releasing more pollutants of concern into the environment hence they are not driving the needed solution to plastic waste management. Although recycling is growing in Nigeria, its rates are still at a low level due to contamination, economic viability and limited infrastructure To this effect, there is a need to address this problem with a paradigm shift of circular economy different from enhanced recycling infrastructure, product design and material innovation integrating by integrating Artificial Intelligence. Artificial intelligence (AI) as a circular economy strategy for plastic waste pollution and reduction. In the Nigerian context, it has not been fully explored but it has the potential to cause a paradigm shift in plastic waste management by optimized and efficient waste collection and sorting processes, improved material recovery rates and developing innovative and applicable realistic recycling technologies. The study aims to examine the perceived effectiveness of artificial intelligence technologies in circular economy initiatives among various stakeholders in Nigeria.

Methods and Materials

Study Area

The study area, Nigeria (Figure 1) stretches through the 923,769 Km^2 range of which 13,000 square kilometres is covered by water across 36 states from north to south (Merem et al., 2017). The country's large population and rapid urbanization contribute to high waste volumes, while inadequate infrastructure, lack of enforcement, and public awareness hinder efficient collection, treatment, and disposal (Merem et al., 2017). For the study purpose, Lagos State and Federal Capital Territory, Abuja of Nigeria were selected (Figure 2). Abuja, located centrally in Nigeria, is the nation's capital city. Abuja's population currently surpasses 2.5 million people and the population has grown by over 140%, making it the fastest-growing metropolis in Africa and one of the most rapidly expanding globally (Wambebe & Duan, 2020). Lagos, together with its neighbouring metropolis, is Nigeria's largest city and the country's most important economic centre, having the country's major seaports. According to Gbenga (2023), Lagos accounts for 10% of Nigeria’s Gross Domestic Product (GDP) and over 90% of Nigeria’s trade flow. The city is the fifth largest economy in Africa, having 65% of Nigeria’s manufacturing sector. The choice of Lagos and Abuja provides an insight between a highly commercial city and a government-centered city, both grappling with plastic waste issues but within different urban frameworks.

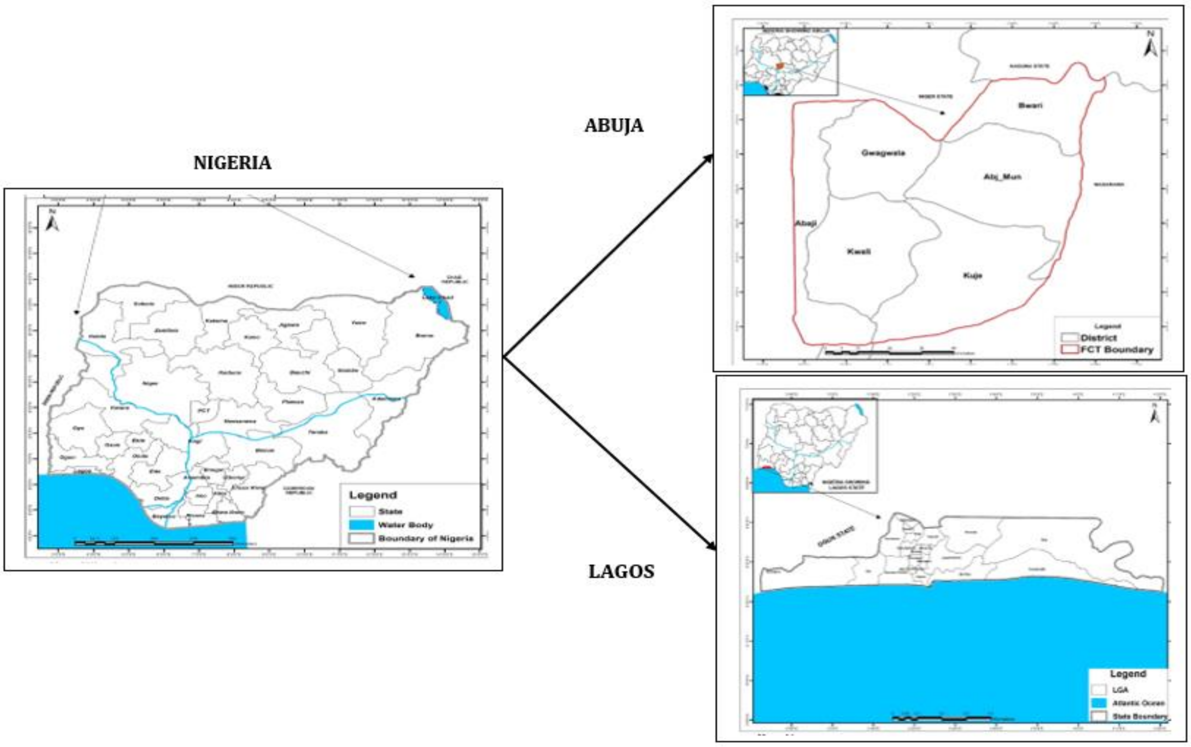

Figure 1: Overview of the Study Area and Selected State (Cities)

Research Design and Study Population

The cross-sectional survey research method was adopted in carrying out the study. Cross-sectional survey research is a specific type of field study that involves the collection of data from a sample of elements drawn from a well-defined population through the use of a questionnaire (Visser et al., 2002). The population of the study comprised of individuals (respondents) representing plastic recycling companies, waste management agencies (private and public), circular economy initiative groups, technology solution providers, environmental regulatory agencies (such as LASEPA, NESREA), community-based waste collectors and informal recyclers and residents involved or affected by waste management initiatives which were randomly selected from the urban area of Abuja (Asokoro, Wuse and Gwarinpa) and Lagos State (Agege, Oworonsoki and Ikotun).

Sample and Sampling Technique

Purposive sampling ensures that the study gathers rich, relevant, and expert insights. Based on the sampling techniques adopted for the study, four hundred (400) respondents were targeted which was equally distributed between Abuja (200 respondents) and Lagos State (200 respondents).

Data Collection and Analysis

A questionnaire was used to elicit information from respondents. The questionnaire adopted for the study made use of a closed-ended format. The retrieved questionnaires were coded and subjected to Statistical Package for the Social Sciences (SPSS) for proper analysis. The questionnaire coding was done with MS Excel before being transferred to the Data entry of SPSS. The data were analysed using descriptive statistics such as frequency counts, percentages, mean and charts. The use of such statistics allows the researcher to present the evidence of the study in a way that can be understandable and make a conclusion concerning the variables of the study.

Result

Socio-Demographic Details of the Respondents

The socio-demographic details of the respondents are presented in Table 1. From the analysis, 59.5% of the respondents were male while 40.5% were female. The age range of the respondents showed that 5.3% of the respondents are within the age range of 18-25years, 30.4% are age range of 26-35years, 46.0% are age range of 36-45years while 14.0% and 4.2% of the respondents are within the age range of 46-55years and 56year above respectively. Considering the respondent's occupations, 9.5% of the respondents indicated waste management professional, 6.6% indicated tech/AI specialist, 12.4% indicated environmental agency staff, 17.2% indicated informal waste workers while 39.4% and 14.8% of the respondents are self-employed and other forms of occupations respectively. On educational qualification, 43.4% of the respondents revealed to have attained a bachelor's degree, 18.8% attained a Higher National Diploma (HND), 25.9% attained a Master's degree, 7.4% attained a Doctorate degree (PhD) while 2.9% and 1.6% of the respondents revealed to have attained technical diploma and other educational qualification respectively. Overall, 59.8% of the respondents indicated Lagos State as their city of residence while 40.2% of the respondents indicated FCT, Abuja as their city of residence.

Perceived Effectiveness of AI Technologies in Circular Economy Initiatives

From Table 2, the perceived effectiveness of AI in circular economy initiatives was examined among the respondents. From the study, 49.5% of the respondents agreed that AI can significantly reduce plastic waste in dumpsites while 40.0% and 10.5% of the respondents disagreed and were undecided respectively. The finding revealed that 51.8% of the respondents agreed that AI-driven systems can optimize plastic recycling processes while 38.9% and 9.3% of the respondents disagreed and were undecided respectively. 56.9% of the respondents indicated to agreed that AI can make waste management more data-driven and efficient while 30.9% and 12.2% of the respondents disagreed and were undecided respectively. Similarly, 51.9% of the respondents indicated AI platforms can facilitate a robust circular economy model while 41.8% and 6.3% of the respondents disagreed and were undecided respectively. From the study, 38.4% of the respondents agreed that AI can improve public awareness of plastic waste disposal while 46.0% and 15.6% of the respondents disagreed and were undecided respectively. The finding revealed that 67.5% of the respondents agreed that The use of AI technologies in waste management will increase with time while 27.2% and 5.3% of the respondents disagreed and were undecided respectively. 50.0% of the respondents indicated to agreed that AI can enhance real-time monitoring of plastic waste rates while 39.7% and 10.3% of the respondents disagreed and were undecided respectively. Similarly, 52.7% of the respondents indicated that AI-enabled platforms can reduce operational costs while 38.4% and 8.9% of the respondents disagreed and were undecided respectively.

Table 1: Socio-Demographic Details of the Respondents

Variable	Frequency (n=378)	Percentage (%)
Sex of Respondents		
Male	225	59.5
Female	153	40.5
Age of Respondents		
18–25 years	20	5.3
26–35 years	115	30.4
36–45 years	174	46.0
46–55 years	53	14.0
56 years and above	16	4.2
Occupation		
Waste Management Professional	36	9.5
Tech/AI Specialist	25	6.6
Environmental Agency Staff	47	12.4
Informal Waste Worker	65	17.2
Self-employed	149	39.4
Others	56	14.8
Education Qualification		
Bachelor's Degree	164	43.4
HND	71	18.8
Master's Degree	98	25.9
PhD	28	7.4
Technical/Diploma	11	2.9
Other	6	1.6
City of Residence		
Lagos State	226	59.8
Federal Capital Territory, FCT	152	40.2

Discussion

The finding revealed that the respondents agreed that AI can significantly reduce plastic waste in dumpsites, optimize plastic recycling processes, make waste management more data-driven and efficient, facilitate a robust circular economy model, use of AI technologies in waste management will increase with time, AI can enhance real-time monitoring of plastic waste rates and AI-enabled platforms can reduce operational costs; however, the respondents disagreed that AI can improve public awareness on plastic waste disposal. Reducing dumpsite plastic waste, optimising recycling processes, and fostering a data-driven approach to waste management have been reported in the study conducted by Milovantseva and Saphores (2013) arguing that digital technologies can increase recycling efficiency while promoting sustainable material use. Similarly, Das and Bera (2020) noted that AI systems facilitate predictive analytics that optimizes logistics and resource allocation in circular economy models. Also, AI's real-time monitoring capability was highlighted, consistent with the findings of Sharma and Vaid (2021), who emphasized the critical role of real-time data in enhancing waste flow management and reducing operational inefficiencies. Moreover, AI's ability to reduce operational costs aligns with the observations by Fatimah et al. (2021), who pointed out that AI technologies can significantly decrease labour and transportation costs through automation and intelligent routing. However, the respondents' disagreement regarding AI's ability to improve public awareness is noteworthy. This observation aligns with Reike et al. (2018), who posited that technological tools alone are insufficient to drive behavioural change unless accompanied by effective public outreach and education programs. The findings share similarities with the observation made by Olawade et al. (2024) which indicated that AI holds significant promise for enhancing waste management practices, addressing challenges such as data quality, privacy concerns, and cost implications is paramount.

Table 2: Perceived Effectiveness of AI in Circular Economy Initiatives

Variable	A	D	U	Total	Mean	Decision
AI can significantly reduce plastic waste in dumpsites	187 (49.5)	151 (40.0)	40 (10.5)	378 (100)	3.18	Agreed
AI-driven systems can optimize plastic recycling processes.	196 (51.8)	147 (38.9)	35 (9.3)	378 (100)	3.28	Agreed
AI can make waste management more data-driven and efficient.	215 (56.9)	117 (30.9)	46 (12.2)	378 (100)	3.32	Agreed
AI platforms can facilitate a robust circular economy model.	196 (51.9)	158 (41.8)	24 (6.3)	378 (100)	3.21	Agreed
AI can improve public awareness of plastic waste disposal.	145 (38.4)	174 (46.0)	59 (15.6)	378 (100)	2.93	Disagreed
The use of AI technologies in waste management will increase with time	255 (67.5)	103 (27.2)	20 (5.3)	378 (100)	3.42	Agreed
AI can enhance real-time monitoring of plastic waste rates.	189 (50.0)	150 (39.7)	39 (10.3)	378 (100)	3.19	Agreed
AI-enabled platforms can reduce operational costs.	199 (52.7)	145 (38.4)	34 (8.9)	378 (100)	3.29	Agreed

Agreed (A): Agreed + Strongly Agreed, Disagreed (D): Disagreed + Strongly Disagreed; Undecided (U). The range of interpretation of the Likert Scale based on the mean score is given as 0.1 – 1.9 (Neutral), 2.0 – 2.9 (Disagreed) and 3.0 – 3.9 (Agreed)

Conclusion

AI is an emerging trend just like the circular economy and both offer strategies for plastic waste reduction and effective management. This study has revealed critical insights into the current state of waste management practices and the potential for integrating AI-driven platforms into waste management and circular economy initiatives. Respondents underscored the importance of AI in enhancing recycling processes, identifying waste types, real-time waste monitoring, and fostering a more efficient circular economy. Nevertheless, technological solutions alone are insufficient without parallel initiatives aimed at public engagement and education. The successful adoption of AI-driven solutions in plastic waste management will require concerted efforts across multiple sectors, including government, private industries, and civil society organizations. There is a need to create platforms for knowledge exchange and pilot projects to demonstrate the tangible benefits of AI integration in real-world waste management scenarios.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Credit Authorship Contribution Statement

Animashaun-Oshiyemi, A. F.: Conceptualization, Methodology, Formal analysis, Investigation, Resources, Data curation, Visualization, Project administration, Writing - original draft. **Adesope, O.M., Osuji, L.C.** and **Obafemi, A.A.**: Supervision, Methodology, Validation, Formal analysis, Data curation, Visualization, Review & Editing.

References

Das, P., & Bera, S. (2020). Role of artificial intelligence in sustainable waste management. Materials Today: Proceedings. https://doi.org/10.1016/j.matpr.2020.09.129

Ellen MacArthur Foundation. (2019). *Artificial intelligence and the circular economy*. www.ellenmacarthurfoundation.org. https://www.ellenmacarthurfoundation.org/artificial-intelligence-and-the-circular-economy

European Commission Eco-design for Sustainable Products (2022). https://commission.europa.eu/energy-climate-change-environment/standards-tools-and-labels/products-labelling-rules-and-requirements/sustainable-products/ecodesign-sustainable-products_en

Fatimah, Y. A., Govindan, K., Murniningsih, R., & Setiawan, A. (2021). Industry 4.0-based sustainability and green initiatives: A review. *Technological Forecasting and Social Change*, 166, 120573. https://doi.org/10.1016/j.techfore.2021.120573

Merem, E. C., Twumasi, Y., Wesley, J., Isokpehi, P., Shenge, M., Fageir, S., Crisler, M., Romorno, C., Hines, A., Hirse, G., Ochai, S., Leggett, S. and Nwagboso, E. (2017). Analyzing Water Management Issues Using GIS: The Case of Nigeria. Geosciences, 7(1), 20-46. DOI: 10.5923/j.geo.20170701.03

Milovantseva, N., & Saphores, J.-D. (2013). E-waste bans and U.S. households' preferences for disposing of their E-waste. Journal of Environmental Management, 124, 8–16. https://doi.org/10.1016/j.jenvman.2013.03.003

Ogunola, S. I., Ajanaku, K. O., & Bello, A. B. (2021). Plastic waste management in Nigeria: A review. *Frontiers in Environmental Science*, 9, 761957.

Olawade, D. B., Fapohunda, O., Wada, O. Z., Usman, S. O., Ige, A. O., Ajisafe, O., & Oladapo, B. I. (2024). Smart waste management: A paradigm shift enabled by artificial intelligence. *Waste Management Bulletin*, *2*(2). https://doi.org/10.1016/j.wmb.2024.05.001

Oyebode, O. J. (2022). Sustainable Waste Management Towards Circular Economy in Nigerian Context: Challenges, Prospects and Way Forward. Springer EBooks, 237–248. https://doi.org/10.1007/978-3-030-95820-6_20

Pasqualotto, C., Callegaro, D., & Stephanus, C. (2023). An Overview and Categorization of the Drivers and Barriers to the Adoption of the Circular Economy: A Systematic Literature Review. *Sustainability*, *15*(13), 10532–10532. https://doi.org/10.3390/su151310532

Pregowska, A., Osial, M., & Urbańska, W. (2022). The Application of Artificial Intelligence in the Effective Battery Life Cycle in the Closed Circular Economy Model—A Perspective. Recycling, 7(6), 81. https://doi.org/10.3390/recycling7060081

Reike, D., Vermeulen, W. J., & Witjes, S. (2018). The circular economy: New or refurbished as CE 3.0? Exploring controversies in the conceptualization of the circular economy through a focus on history and resource value retention options. Resources, Conservation and Recycling, 135, 246–264. https://doi.org/10.1016/j.resconrec.2017.08.027

Rezk, M. R. A., Piccinetti, L., Salem, N., Omoruyi, T. U., & Santoro, D. (2024). Nigeria's transition to a circular economy: challenges, opportunities and future perspectives. *Insights into Regional Development*, *6*(2), 11–23. https://doi.org/10.9770/ird.2024.6.2(1)

Sharma, P., & Vaid, U. (2021). Emerging role of artificial intelligence in waste management practices. *IOP Conference Series: Earth and Environmental Science*, *889*(1), 012047. https://doi.org/10.1088/1755-1315/889/1/012047

Shreyas Madhav, A., Rajaraman, R., Harini, S., & Kiliroor, C. C. (2021). Application of artificial intelligence to enhance collection of E-waste: A potential solution for household WEEE collection and segregation in India. *Waste Management & Research: The Journal for a Sustainable Circular Economy*, *40*(7), 0734242X2110528. https://doi.org/10.1177/0734242x211052846

Visser, P. S., Krosnick, J. A. & Lavraws, P. J. (2002). Survey research. Indicators Research, 22, 199-2 12.

Wambebe, N. M., & Duan, X. (2020). Air Quality Levels and Health Risk Assessment of Particulate Matters in Abuja Municipal Area, Nigeria. Atmosphere, 11(8), 817-823. https://doi.org/10.3390/atmos11080817