JOURNAL OF ENVIRONMENTAL SCIENCES AND BUILT ENVIRONMENT RESEARCH (JESBER)
2026, Vol. 1, No. 1, pp. 202-213
Published by Faculty of Environmental Sciences, University of Calabar, Nigeria
Print ISSN: 3141-5547 | OPEN ACCESS
DOI: https://doi.org/10.83109/jesber.vol1no1.21

Research article

BARRIERS AND DRIVERS OF CIRCULAR ECONOMY ADOPTION IN OIL PALM PROCESSING COMMUNITIES N AKWA IBOM STATE, NIGERIA

Udoiwa, Monday Jonah[1]; Oko, Peter Ereh[1]* & Anake Clement Bekongfe[2]

[1] Department of Environmental Management, University of Calabar, Nigeria
[2] Department of Hospitality and Tourism Management, University of Calabar, Nigeria
*Corresponding author: okopeter36@yahoo.com

ABSTRACT

This study assessed the barriers and drivers of circular economy adoption in oil palm processing communities in Akwa Ibom State, Nigeria, with emphasis on waste generation and management practices. A cross-sectional research design were adopted, integrating quantitative and qualitative approaches. Data were collected from 224 respondents selected through an Enhanced Multi-Stage Proportionate–Power Stratification Technique across six Local Government Areas. Data were obtained through questionnaires and analyzed using descriptive statistics, Multivariate Analysis of Variance (MANOVA), and Structural Equation Modeling (SEM). Findings revealed that empty fruit bunches (88.4%), palm press fibre (78.6%), palm kernel shells (63.0%), and palm oil mill effluent (53.1%) were the major waste streams generated. Open dumping (46.9%) was the dominant disposal method, followed by reuse on farms (24.6%). MANOVA results showed significant variations in waste generation across locations, mill categories, and processing capacities ($p < 0.05$). Findings indicated that poor waste management practices significantly contributed to environmental degradation and socio-economic challenges in the study area. The study concludes that circular economy adoption remains limited due to inadequate waste management systems, weak institutional support, and low technological capacity. It recommends stronger policy enforcement, investment in waste valorisation technologies, and capacity-building programmes to promote sustainable waste management.

KEYWORDS

Circular economy, oil palm processing, waste management, waste valorisation, environmental sustainability, Akwa Ibom State, Nigeria.

Introduction

The increasing pressure on natural resources and the growing challenges of environmental degradation have necessitated a shift from the traditional linear “take–make–dispose” model of production to a more sustainable system known as the circular economy. Circular economy emphasizes resource efficiency, waste minimization, reuse, recycling, and recovery of materials to create a closed-loop system. In agricultural sectors such as oil palm processing, this approach offers significant opportunities for reducing waste and promoting sustainable livelihoods. (Amuyo, Okon & Oko 2013). Oil palm production is a major agro-industrial activity that contributes significantly to food systems, industrial raw materials, and rural livelihoods across tropical regions. However, the processing of oil palm fresh fruit bunches generates substantial quantities of waste, notably empty fruit bunches, palm kernel shells, mesocarp fibre, and palm oil mill effluent. When these wastes are poorly managed, they result in environmental problems such as surface and groundwater contamination, soil degradation, odour nuisance, and greenhouse gas emissions. Waste management strategies refer to organized methods for handling, treating, recycling, or converting these residues into useful products, while the circular economy framework promotes closing material loops by transforming waste into resources for energy, agriculture, and manufacturing (Mostaghimi, & Behnamian, 2023; Omang, 2023).

Nigeria is one of the leading producers of oil palm in Africa, and Akwa Ibom State is a major hub for oil palm processing activities. These activities generate substantial quantities of waste, including empty fruit bunches, palm kernel shells, palm oil mill effluent (POME), and fiber residues. Traditionally, much of this waste is either underutilized, openly burned, or disposed of in ways that contribute to environmental pollution, including water contamination, greenhouse gas emissions, and soil degradation, (Sabiani, Alkarimiah, Ayub, Makhtar, Aziz, Hung, & Wang, 2023). The adoption of circular economy practices in oil palm processing communities—such as converting waste to bioenergy, compost, or other value-added products—can significantly enhance environmental sustainability while creating economic opportunities. However, the transition to circular systems is influenced by a range of factors, including socio-economic conditions, institutional frameworks, technological capacity, cultural practices, and policy support. Understanding both the barriers and drivers of circular economy adoption is therefore essential for designing effective interventions and policies that promote sustainable waste management and resource recovery in oil palm-producing regions. Globally, the shift towards a circular economy has highlighted the need to transform agro-industrial waste into valuable resources rather than treating it as a disposal burden (de Oliveira, da Silva, Amorim, Yamaguti, Saloni, Pereira, & Dias Júnior, 2025). Despite this global push, oil palm waste management in many developing regions remains largely linear, inefficient, and environmentally unsustainable.

Circular Economy Adoption: Refers to the extent to which oil palm processors implement sustainable practices that minimize waste and maximize resource recovery through reuse, recycling, composting, and conversion of waste into valuable products.

Waste Valorisation: The process of transforming oil palm processing residues such as empty fruit bunches, palm kernel shells, fibre, and palm oil mill effluent into economically useful products including bioenergy, compost, biochar, and industrial raw materials.

Socio-economic Impacts: The positive or negative effects of oil palm waste management practices on the livelihoods, income, employment opportunities, public health, and overall well-being of individuals and communities within the study area.

Despite the large volume of waste generated from oil palm processing in Akwa Ibom State, the adoption of circular economy practices remains limited. Most processing communities continue to rely on conventional waste disposal methods, which are environmentally unsustainable and economically inefficient. This has resulted in persistent environmental challenges such as pollution of water bodies, emission of greenhouse gases, and degradation of land resources. Therefore, there is a need to systematically assess the factors that facilitate or hinder the adoption of circular economy principles in oil palm processing communities, in order to inform policy, enhance sustainable resource management, and improve environmental and socio-economic outcomes. The aim is to assess the barriers and drivers of circular economy adoption in oil palm processing communities in Akwa Ibom State, Nigeria. While the specific objectives

1. To identify the types and quantities of waste generated from oil palm processing in selected communities.
2. To examine the current waste management practices among oil palm processors.

Literature review

Oil palm (Elaeis guineensis) production is one of the most resource-intensive agricultural activities in the tropical world, generating a substantial quantity of biomass waste at various stages of production and processing. These wastes include empty fruit bunches (EFBs), palm press fiber (PPF), palm kernel shells (PK), palm oil mill effluent (POME), fronds and trunks, all of which constitute major by-products of the oil extraction process (Ayyildiz, Shoaib & Kara, 2023). According to Siagian, Wenten, & Khoiruddin, (2024), oil palm processing globally yields approximately 70% biomass waste relative to the total input of fresh fruit bunches (FFB), indicating that only about 30% of the fruit is converted into crude palm oil and kernels. This high waste ratio underscores the necessity for sustainable waste utilization strategies, particularly in developing economies like Nigeria, where oil palm serves as both a livelihood source and an industrial raw material.

Nigeria is the fifth-largest producer of palm oil globally, after Indonesia, Malaysia, Thailand, and Colombia (Hamidi, 2025). The country produces approximately 1.4 million metric tons of crude palm oil annually, with Akwa Ibom, Cross River, Edo and Ondo States accounting for over 60% of the total output (Jamiu, W. M. (2022). In Akwa Ibom State, oil palm cultivation is primarily carried out by smallholder and medium-scale processors, who use semi-mechanized or traditional extraction systems. These methods are characterized by high inefficiency in oil recovery often below 15% extraction rate resulting in significant waste generation (Samant, & Kaliappan, 2025).

According to García, Rojas, & González, (2025), the typical oil extraction process in small-scale mills involves sterilizing, threshing, digesting and pressing the fresh fruit bunches, followed by clarification and kernel recovery. Each of these stages produces distinct forms of waste. For every ton of FFB processed, it is estimated that approximately 230 kg of EFBs, 130 kg of palm press fiber, 60 kg of palm kernel shells, and about 0.6–1.0 cubic meters of POME are generated (Omar, et, al., 2025). Similarly, Houenou, et, al, (2025) noted that smallholder processors in Southeast Asia produce about 0.6 to 0.8 tons of EFB and 0.3 tons of fiber per ton of FFB, while the oil recovery rate remains at 18–20%. These data are consistent with findings in Nigeria, particularly in Akwa Ibom, where local processors often lack efficient oil recovery machinery, resulting in greater residual biomass.

Waste management practices within the oil palm sector vary considerably across production scales, levels of mechanization, and regional policy enforcement. In most developing economies, including Nigeria, the oil palm industry remains dominated by smallholder farmers and artisanal processors who depend on rudimentary technologies for palm oil extraction and waste disposal (Cheah, et, al,. 2023; Oko et al, 2023). These operators often lack access to modern waste treatment facilities and technical expertise, resulting in inefficient and environmentally detrimental practices. Large-scale plantations, on the other hand, are relatively better equipped and tend to integrate sustainable waste management systems such as composting, anaerobic digestion, and cogeneration (Andriamanohiarisoamanana, 2020).

In Akwa Ibom State, the prevalence of traditional waste handling methods among small- and medium-scale processors remains a major challenge to sustainable oil palm production. Field observations by Noah, (2022) indicate that a significant proportion of local mills engage in open burning of residues such as empty fruit bunches (EFB) and palm press fiber (PPF) as a means of disposal. This practice not only releases carbon emissions and particulate matter into the atmosphere but also depletes the soil of valuable organic matter. Palm kernel shells (PKS), which could serve as biomass fuel or feedstock for activated carbon production, are commonly used for direct heating in boiling operations or discarded into nearby farmlands and water channels.

According to Bassey and Etim (2023), over 65% of local processors use PKS as a low-grade fuel source, while the remainder dispose of them indiscriminately, thereby contributing to environmental degradation and resource wastage. Most rural processors in Akwa Ibom still depend on linear production systems characterized by take–use–dispose behavior. Azmi, et, al,. (2024) observed that palm oil mill effluent (POME), which is one of the most significant waste streams, is typically discharged untreated into open drainage systems or natural water bodies. This practice has severe implications for surface and groundwater quality due to high biochemical oxygen demand (BOD) and chemical oxygen demand (COD) concentrations. Tiwari, and Pal, (2022) noted that effluent discharge leads to eutrophication, fish kills, and soil acidification, particularly in local government areas such as Ikono, Etim Ekpo, and Oruk Anam where artisanal milling is concentrated.

Methodology

The study adopted a descriptive survey and cross-sectional research design, combining both quantitative and qualitative approaches. This mixed-method approach allows for a comprehensive understanding of both measurable factors and contextual issues influencing circular economy adoption.

The study was conducted in six Local Government Areas of Akwa Ibom State, namely Ibesikpo Asutan, Etinan, Abak, Etim Ekpo, Ika and Essien Udim. These LGAs are situated within the central and southern belts of the state and are strategically connected through a network of arterial and feeder roads that support agricultural and agro-industrial activities. Collectively, the study area covers an estimated landmass of over 2,500 square kilometres, characterized by gently undulating terrain, low-lying plains and extensive inland valleys. The geographical positioning of these LGAs within the oil palm belt of Akwa Ibom State makes them suitable locations for palm cultivation and processing activities, thereby justifying their selection for this study.

The population of registered oil palm mills in Akwa Ibom State for this study was obtained from the Office of the State President of the Oil Palm Millers Association of Nigeria (OPMAN), headquartered at the Secretariat in Ibesikpo Asutan Local Government Area. According to the 2025 registry, a total of 148 registered and operational oil palm mills were identified across the six sampled LGAs; Ibesikpo Asutan, Etinan, Abak, Etim Ekpo, Essien Udim, and Ika,. While the sample size was determined using an Enhanced Multi-Stage Proportionate–Power Stratification Technique (EMP²ST), arriving at 224 total of respondents. The study employed a Multi-Stage Proportionate–Power Stratified Sampling Technique (MP²ST). this includes stratified, purposive and simple random sampling.

The study adopted the Enhanced Multi-Stage Proportionate–Power Stratification Technique (EMP²ST) to ensure adequate representation of oil palm processors across different locations and mill categories. The technique combined purposive, stratified, and simple random sampling, thereby minimizing sampling bias and improving statistical reliability. Before analysis, MANOVA assumptions including multivariate normality, homogeneity of variance-covariance matrices, and independence of observations were verified. SEM model adequacy was also confirmed with acceptable fit indices (RMSEA = 0.048, CFI = 0.956, and TLI = 0.947), indicating a good fit between the model and the observed data.

Data for this study was sourced from both primary and secondary. The primary data for this study were collected using structured questionnaires, observational checklists, and key informant interviews (KII), specifically designed to capture information on oil palm waste generation, management practices, and utilization for circular economy purposes. The study employed a combination of descriptive and advanced inferential statistical techniques to analyze the data collected such as frequency/percentage table; charts and the hypotheses were tested using a Multivariate Analysis of Variance (MANOVA) and a Structural Equation Modeling (SEM) approach.

Ethical approval for the study was obtained from the appropriate departmental research ethics committee before data collection. Participation was voluntary, and informed consent was obtained from all respondents after explaining the purpose of the study. Participants were assured of confidentiality and anonymity, and all information collected was used strictly for academic purposes.

Results and discussion

Analysis of Figure 1, shows the age structure of respondents is important in understanding labour availability, decision-making capacity, and openness to adopting improved oil palm waste management strategies. Oil palm farming and processing are labour-intensive activities, and age often influences physical strength, experience, and willingness to adopt innovations such as waste reuse and recycling. The dominance of respondents within the economically active age brackets suggests a workforce capable of sustaining oil palm operations and engaging with circular economy practices if adequately supported. Younger respondents may be more receptive to modern waste utilization technologies, while older respondents contribute valuable indigenous knowledge and long-term experience in oil palm production systems.

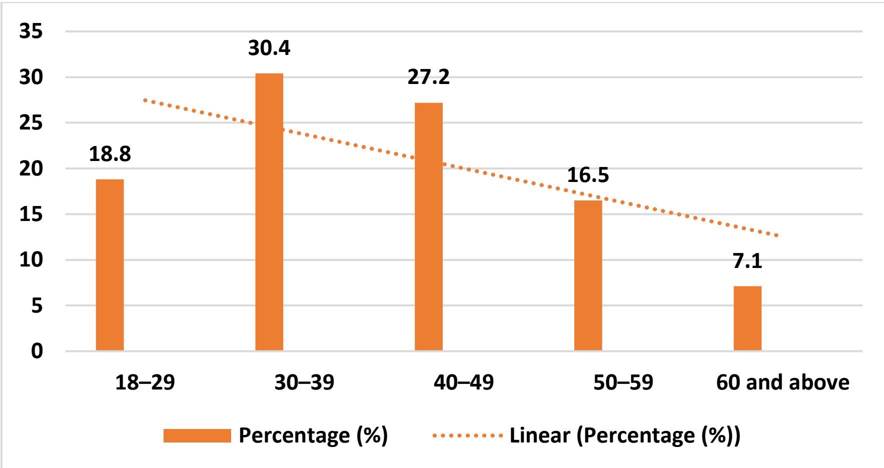

Figure 1. Age Distribution of oil palm mill workers

Source: Researcher's fieldwork, 2026

The gender differentiation as shown in Figure 2, shows that males were 156 representing 70 per cent, while females were 68 representing 30 per cent. The gender composition is therefore essential for designing inclusive waste management interventions and circular economy initiatives that recognizes the roles of both men and women. In Akwa Ibom State, oil palm processing is traditionally male-dominated, particularly in activities involving machinery and heavy lifting, while women are more involved in sorting, clarification, and by-product handling.

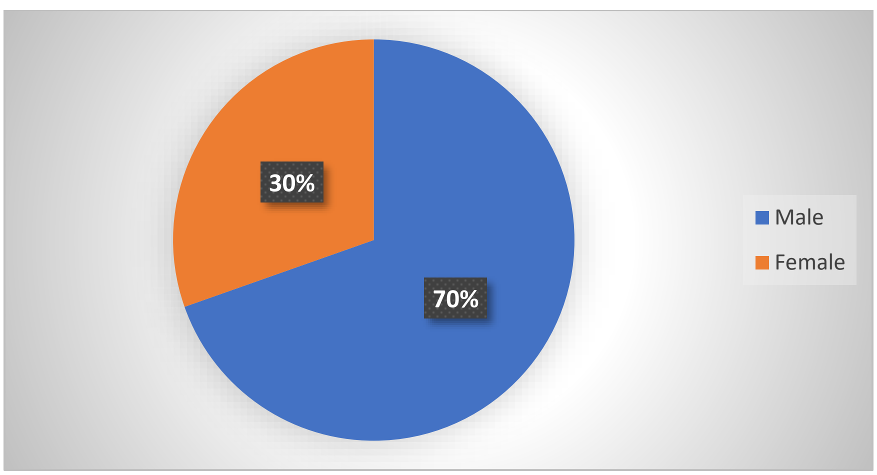

FIG 2: Gender Distribution of Respondents

Source: Researcher's fieldwork, 2026

The assessment of the types and quantities of oil palm waste generated reveals clear patterns in production, which are critical for designing targeted waste management and circular economy strategies. Among the respondents, empty fruit bunches (EFB) were the most frequently generated waste, reported by 88.4per cent of respondents, followed by palm press fibre at 78.6per cent, palm kernel shells at 63.0per cent, and palm oil mill effluent (POME) at 53.1per cent. Using a ranking scale, EFB was assigned 1st, indicating its overwhelming prevalence in daily operations, while press fibre was ranked 2nd, kernel shells 3rd, and POME 4th. The dominance of EFB is consistent with its bulk volume during the threshing of fresh fruit bunches.

Table 1: Ranking of Types and Quantities of Oil Palm Waste Generated by Respondents

Waste Type	Frequency of Selection*	Percentage (per cent)	Rank
Empty Fruit Bunch (EFB)	198	88.4	1st
Palm Press Fibre	176	78.6	2nd
Palm Kernel Shell	141	63.0	3rd
Palm Oil Mill Effluent (POME)	119	53.1	4th

Source: Researcher's, 2025

The assessment of average quantities of empty fruit bunches (EFB) generated per processing cycle across sampled oil palm mills in Akwa Ibom State as shown in Plate 5, highlights significant variation linked to mill size, production capacity, and processing frequency. A majority of respondents (42.4per cent) reported generating between 301–500 kg of EFB per cycle, reflecting medium-scale production patterns typical of most registered mills in the state. Smaller mills produced less than 100 kg per cycle (15.2per cent) or 100–300 kg (27.7per cent), while large-scale mills produced above 500 kg per cycle, accounting for 14.7per cent of respondents. Plate 3, shows the display the empty fruit bunches (EFB) generated at Royal Crest mill at Abak. This distribution indicates that larger processing facilities contribute disproportionately to solid waste accumulation, underscoring the importance of designing waste management strategies tailored to mill capacity.

Table 2: Average Quantity of Empty Fruit Bunch (EFB) Generated per Processing Cycle Across Sampled Oil Palm Mills (kg/cycle)

LGA	Mill Name	Category	<100 kg	100–300 kg	301–500 kg	>500 kg	Average Quantity (kg/cycle)
Ibesikpo Asutan	Golden Palm Mill	Small	1	4	2	0	238
Ibesikpo Asutan	Sunrise Agro Mill	Medium	0	2	7	4	412
Ibesikpo Asutan	Unity Palm Processing Ltd	Large	0	1	4	8	525
Etinan	Etinan Palm Works	Small	2	3	1	0	215
Etinan	Green Field Oil Mill	Medium	0	4	5	2	395
Etinan	Prosperity Palm Estate	Large	0	2	6	6	508
Abak	Abak Heritage Mill	Small	1	4	2	0	230
Abak	Royal Crest Palm Mill	Medium	0	3	6	5	448
Abak	Supreme Palm Industries	Large	0	1	5	9	532
Etim Ekpo	Etim Ekpo Palm Hub	Small	2	2	2	0	240
Etim Ekpo	New Dawn Oil Mill	Medium	0	3	5	3	398
Etim Ekpo	Evergreen Palm Ltd	Large	0	2	4	7	515
Ika	Ika Rural Palm Mill	Small	1	3	1	0	210
Ika	Prime Oil Processors	Medium	0	2	5	1	375
Ika	Solid Base Palm Co.	Large	0	1	4	6	500
Essien Udim	Essien Udim Palm Mill	Small	1	4	2	0	235
Essien Udim	Unity Farmers Oil Mill	Medium	0	2	6	5	440
Essien Udim	Heritage Palm Industries	Large	0	1	4	7	510

Source: Researcher's, 2025

The management of oil palm waste among the mills in Akwa Ibom State shows a strong reliance on traditional disposal methods. As illustrated in Table 3, open dumping was the predominant practice, reported by 46.9per cent of respondents, highlighting the low adoption of environmentally sustainable disposal techniques. Reuse on farm was the second most common, at 24.6per cent, reflecting the utilisation of empty fruit bunches and other residues for soil fertility enhancement in nearby plantations. Sale to third parties accounted for 15.2per cent, indicating a small commercial market for biomass by-products. Composting, a more sustainable practice, was reported by only 9.8per cent, while burning, which poses significant environmental risks, was recorded at 3.5per cent.

Table 3: Method of Oil Palm Waste Disposal

Disposal Method	Frequency	Percentage (per cent)	Rank
Open dumping	105	46.9	1st
Reuse on farm/pig farm	55	24.6	2nd
Sale to third parties	34	15.2	3rd
Composting	22	9.8	4th
Burning	8	3.5	5th
Total	224	100.0	

Source: Researcher's fieldwork, 2026

The spatial arrangement of disposal sites significantly influences both environmental safety and operational efficiency. Table 4 shows that 37.1per cent of respondents dispose of waste within the mill premises, which can lead to pollution accumulation if not managed properly. Less than 100 m was reported by 29.5per cent, while 100–300 m was chosen by 22.8per cent, and only 10.6per cent of respondents disposed of waste beyond 300 m from processing areas. This distribution indicates that most mills lack adequate land for safe waste storage, and proximity to the mill increases the risk of effluent leaching and odour nuisance.

Table 4: Distance of Waste Disposal Site from Processing Area

Distance from Mill	Frequency (n = 224)	Percentage (per cent)	Rank
Within premises	83	37.1	1st
Less than 100 m	66	29.5	2nd
100–300 m	51	22.8	3rd
Above 300 m	24	10.6	4th
Total	224	100.0	

Source: Researcher's fieldwork, 2026

Hypothesis One examined whether the types and quantities of oil palm waste generated vary significantly across different farming and processing locations in Akwa Ibom State. To address this, a mixed-effects Multivariate Analysis of Variance (MANOVA) was applied, allowing the simultaneous assessment of multiple waste streams while accounting for both fixed and random effects. As presented in Table 5, the multivariate tests show that Local Government Area (LGA), mill category, and processing capacity all exert statistically significant effects on the combined dependent variables, namely Empty Fruit Bunches (EFB), Palm Press Fibre (PPF), Palm Kernel Shells (PKS), and Palm Oil Mill Effluent (POME). The low Wilks' Lambda and Pillai's Trace values, coupled with p-values well below the 0.05 significance threshold, indicate that variations in waste generation are not random but systematically influenced by spatial location and structural characteristics of oil palm processing operations. The significant interaction effect between LGA and mill category further suggests that the influence of mill type on waste generation differs across locations, reflecting localized production dynamics.

Table 5: Multivariate Tests of Fixed Effects (MANOVA Results)

Effect	Test Statistic	Value	F	Hypothesis df	Error df	Sig. (p-value)
LGA	Wilks' Lambda	0.612	4.87	24	594	0.000
Mill Category	Wilks' Lambda	0.543	7.32	12	412	0.000
Processing Capacity	Pillai's Trace	0.418	6.14	16	448	0.000
LGA × Mill Category	Wilks' Lambda	0.681	2.96	36	623	0.001

Hypothesis two assessed whether the waste management practices adopted by oil palm farmers and processors in Akwa Ibom State exert significant environmental and socio-economic impacts on surrounding communities. To test this hypothesis, a Structural Equation Modeling (SEM) approach was employed, as it allows for the simultaneous examination of complex relationships among observed and latent variables while accounting for measurement error. The structural path estimates presented in Table 6 further clarify the nature and strength of these relationships. Waste management practices show a strong and statistically significant positive effect on environmental impacts ($\beta = 0.71$, $p < 0.05$), indicating that improper disposal methods such as open dumping, uncontrolled burning, and direct discharge of effluents substantially intensify environmental degradation. The SEM analysis revealed that poor waste management practices were significantly associated with increased socio-economic impacts within oil palm processing communities. Although this finding may appear counterintuitive, several socio-cultural and economic mechanisms explain the relationship. First, improper waste disposal creates temporary informal employment opportunities for local waste collectors, transporters, and individuals involved in the recovery of reusable biomass materials. However, these short-term economic benefits are outweighed by long-term environmental and public health costs. Second, untreated palm oil mill effluent and indiscriminate dumping often contaminate agricultural land and water resources, reducing crop productivity, increasing household healthcare expenditures, and negatively affecting fisheries and other livelihood activities. Consequently, poor waste management indirectly undermines the economic resilience of rural households. Third, the absence of formal waste valorisation industries limits the conversion of palm waste into commercially valuable products such as compost, biochar, biogas, and biomass fuel. Thus, communities continue to experience economic losses associated with resource underutilization. The findings suggest that the observed socio-economic effects reflect both immediate livelihood interactions and the broader consequences of environmental degradation

Table 6: Standardized Regression Weights (Structural Paths)

Path	Estimate (β)	S.E.	C.R.	p-value
Waste Practices → Environmental Impact	0.71	0.08	8.88	0.000
Waste Practices → Socio-economic Impact	0.63	0.07	9.00	0.000
Environmental Impact → Socio-economic Impact	0.49	0.06	8.17	0.000

The findings of this study reveal that oil palm milling activities in Akwa Ibom State are dominated by small- to medium-scale operators who are largely male, middle-aged, and with modest educational attainment, relying heavily on oil palm processing as a primary source of livelihood, a pattern consistent with agro-based livelihood structures reported in similar developing-country contexts (Giap & Ahmad, 2024; Obisesan et al., 2025). The study further found that significant quantities of oil palm wastes, particularly empty fruit bunches, palm kernel shells, fibre, and palm oil mill effluent (POME), are generated daily, with disposal practices largely characterized by open dumping, burning, or discharge into nearby land and water bodies. These practices mirror observations in previous studies that identified inadequate waste handling and low adoption of valorization technologies among smallholder processors (Lackner & Besharati, 2025; Tawo & Mbamalu, 2025). Although a few processors engage in rudimentary reuse such as fibre combustion for energy, the overall level of structured waste management and circular economy integration remains low, aligning with findings by Omokaro et al. (2025) and Anukwonke et al. (2025) on systemic waste management gaps in Nigeria. Environmentally, respondents reported soil degradation, water pollution, and offensive odour around milling sites, corroborating documented environmental and public health impacts of improper agro-industrial waste disposal (Bamotra et al., 2025; Ahmed & Khail, 2025). However, the study also identified strong latent potential for circular economy adoption, as respondents expressed willingness to adopt waste-to-wealth options such as biochar production, composting, and effluent treatment if supported with technology, training, and policy incentives an outcome that aligns closely with prior evidence on the role of institutional support and innovation in advancing sustainable oil palm waste utilization (Judijanto, 2025; Ayompe et al., 2025; Abatan et al., 2025).

The existing oil palm waste management practices among farmers and processors in Akwa Ibom State are largely informal, low-technology, and environmentally unsustainable, with open dumping, uncontrolled burning of solid residues, and direct discharge of palm oil mill effluent (POME) into nearby land and water bodies being the most commonly adopted methods. Only a small proportion of processors reported limited reuse practices, such as using fibre and shells as fuel for boiling, reflecting a survival-oriented rather than efficiency-driven approach to waste management. This pattern strongly aligns with national-level evidence of systemic failures in waste management systems and weak integration of circular economy pathways in Nigeria (Omokaro et al., 2025; Anukwonke et al., 2025; Isong, 2025). The near absence of advanced treatment options such as membrane-based POME recovery, composting, or structured biomass valorisation further corroborates findings that high capital costs, low technical capacity, and limited institutional support constrain technology adoption among smallholder agro-processors (Ho et al., 2025; Sahil & Ilampooranan, 2025).

Additionally, the disposal practices identified in this study mirror documented cases of river and soil contamination linked to agro-industrial waste mismanagement in southeastern Nigeria, where untreated effluents introduce heavy metals and organic pollutants into ecosystems (Nnenna et al., 2025; Ameen & Amoo, 2025). Overall, the findings align with previous studies indicating that while farmers and processors recognize the environmental consequences of improper waste disposal, practical adoption of sustainable waste management options such as commercial composting and resource recovery remains limited without coordinated policy intervention, extension services, and value-chain support (Saqib & Sadef, 2025; AlHajj Hassan et al., 2025).

The findings are consistent with previous studies reporting low adoption of circular economy practices among smallholder oil palm processors due to limited technology and weak institutional support. Unlike experiences in countries such as Malaysia and Indonesia, waste valorisation remains poorly developed in the study area. The results underscore the need for stronger environmental policies, investment in waste-to-resource technologies, and institutional collaboration to promote sustainable oil palm waste management.

Conclusion

This study concludes that oil palm waste generation in Akwa Ibom State is substantial and spatially uneven, reflecting differences in processing scale, technology, and concentration of mills across LGAs. The dominance of both solid and liquid waste streams presents a significant environmental management challenge, particularly in areas with high densities of small and medium-scale mills. The study also concludes that existing waste management practices are largely inadequate and environmentally harmful. The continued reliance on open dumping and burning exposes communities to pollution risks and undermines environmental sustainability. These practices persist mainly due to limited access to appropriate facilities, weak enforcement of regulations, and cost considerations among operators. Based on the study findings, the following recommendations were reached; (1) The Akwa Ibom State government agencies and oil palm cooperatives should establish standardized systems for routine monitoring and documentation of oil palm waste types and quantities across mills to foster effective planning and sustainable intervention. (2) The Ministry of Environment, in collaboration with local governments, should promote composting, controlled reuse, and regulated waste disposal through training programmes, incentives, and enforcement of environmental regulations.

Declarations

Ethical approval: Ethical clearance was obtained from the appropriate research ethics structure before data collection. Community entry permission was obtained from relevant community leaders and local authorities. Participation was voluntary and respondents were informed about the purpose of the study before questionnaire administration.

Informed consent: Informed consent was obtained from all participating households. Respondents were informed that they could withdraw at any stage without penalty and that their responses would be used only for academic purposes.

Confidentiality: No personal identifiers were reported. Data were analysed and presented in aggregate form to protect respondents and communities.

Competing interests: The authors declare no competing interests.

Funding: The study did not receive specific external funding.

Authors' contributions: All authors contributed to the conception, fieldwork, data interpretation, manuscript preparation and approval of the final version.

Data availability: The datasets generated during the study are available from the corresponding author on reasonable request.

References

Abatan, O., Adeboyejo, A. T., & Akindele, A. O. (2025). The Role of Stakeholders and Technological Innovations in Enhancing Waste Governance and Service Delivery. Pan-African Journal of Health and Environmental Science, 4(1), 106-121.

Ahmed, A. J., & Khail, F. I. (2025). Olive Oil Mill Contamination in Geo-science: Impact on Groundwater and Soil. Knowledge-Based Engineering and Sciences, 6(2), 84-115.

AlHajj Hassan, S., Verduijn, R., Nazirov, A., Amadio, A., Alabidalimam, A., AlJorani, K., & Ben Aicha, K. (2025). Agricultural value chain assessment in Iraq 2024. Food & Agriculture Org..

Ameen, A. B., & Amoo, A. F. (2025). Environmental Assessment Of Heavy Metals, Phthalate Esters, And Polychlorinated Biphenyls At Waste Disposal Sites. Техника, (3), 76-117.

Amuyo, U.A., Okon A.E & Oko P.E (2013). An Appraisal of the Role of the Environmental Education in the Sustainable Utilization of Land Resources in Rural Areas of Nigeria. Vol. 4(6)

Andriamanohiarisoamanana, F. J., Yasui, S., Yamashiro, T., Ramanoelina, V., Ihara, I., & Umetsu, K. (2020). Anaerobic co-digestion: a sustainable approach to food processing organic waste management. Journal of Material Cycles and Waste Management, 22(5), 1501-1508.

Anukwonke, C., Igwe, P., Maduka, N., & Obidiegwu, M. C. (2025, June). Innovative Technologies And Circular Economy Strategies For Sustainable Waste Management In Nigerian Urban Centers. In FESCON Conference Proceedings (Vol. 5, No. 1, pp. 294-306).

Ayompe, L. M., Nkongho, R. N., Acobta, A. N., Masso, C., & Egoh, B. N. (2025). Transforming palm oil production: sustainable techniques and waste management strategies for Cameroon's smallholder farmers. Frontiers in Sustainable Food Systems, 9, 1606323.

Ayyildiz, H. F., Shoaib, H., & Kara, H. (2023). Bioactive Phytochemicals from Palm Oil Processing By-products. In Bioactive Phytochemicals from Vegetable Oil and Oilseed Processing By-products (pp. 235-268). Cham: Springer International Publishing.

Bamotra, S., Yadav, S., & Tandon, A. (2025). Air pollution from dumping sites in India: implications on environmental health. Water, Air, & Soil Pollution, 236(10), 624.

Cheah, W. Y., Siti-Dina, R. P., Leng, S. T. K., Er, A. C., & Show, P. L. (2023). Circular bioeconomy in palm oil industry: Current practices and future perspectives. Environmental Technology & Innovation, 30, 103050.

de Oliveira, P. R. S., da Silva, K. C. A., Amorim, G. A., Yamaguti, S. T., Saloni, D., Pereira, A. K. S., & Dias Júnior, A. F. (2025). Agro-industrial Waste as a Potential Raw Material for Multiple Products and Promotion of a Circular Economy. In Agro-industrial Waste for New Pharmaceuticals: Sustainable Sources of Bioactive Compounds (pp. 1-30). Cham: Springer Nature Switzerland.

García-Maza, S., Rojas-Flores, S., & González-Delgado, Á. D. (2025). From Viability to Resilience: Technical–Economic Insights into Palm Oil Production Using a FP2O Approach. Processes, 13(12), 4056.

Giap, S. G. E., & Ahmad, M. F. (2024). Agroecological Practices in Malaysia–Case Studies. Journal of Soil, Environment & Agroecology, 1(1), 1-14.

Ho, Q. N., Lau, W. J., Jaafar, J., Othman, M. H. D., & Yoshida, N. (2025). Membrane Technology for Valuable Resource Recovery from Palm Oil Mill Effluent (POME): A Review. Membranes, 15(5), 138.

Houenou, S., Aholoukpe, H. N., Alladassi, F. K., Akplo, T. M., Saïdou, A., & Houngnandan, P. (2025). Soil fertility management under oil palm (Elaeis guineensis) plantations in sub-Sahara Africa. Agronomy Journal, 117(2), e270030.

Isong, I.A., Olim, D.M., Nwachukwu, O.I., Onwuka, M.I Afu, S.M., Otie, V.O., Oko, P.E., Brandon Heung & Kingsley John (2025). Delineating Soil Management Zones for Site-Specific Nutrient Management in Cocoa Cultivation Areas with A Long History of Pesticide Usage. Vol. 14 (7) pg 1366.

Jamiu, W. M. (2022). Value Chain Analysis of Palm Oil in Ondo State, Nigeria. Unpublished Doctoral dissertation, Department of Agricultural Economics and Extension, Faculty of Agriculture, Bayero University Kano, Nigeria.

Judijanto, L. (2025). From Waste to Wealth: The Strategic Role of Oil Palm in Advancing Circular Economy Solutions. J Mat Sci Eng Technol, 3(3), 1-7.

Lackner, M., & Besharati, M. (2025, June). Agricultural Waste: Challenges and Solutions, a Review. In Waste (Vol. 3, No. 2, p. 18). MDPI.

Mostaghimi, K., & Behnamian, J. (2023). Waste minimization towards waste management and cleaner production strategies: a literature review. Environment, Development and Sustainability, 25(11), 12119-12166. Waste minimization towards waste management and cleaner production strategies: a literature review. Environment, Development and Sustainability, 25(11), 12119-12166.

Nnenna, E. T., Chijioke, N. M., & Uche, C. O. (2025). An Investigation of Nwangene River Pollution in Onitsha, Anambra State, Southeastern Nigeria: Causes, Effects, and Preventive and Remedial Approaches. The Asian Review of Civil Engineering, 14(1), 9-19.

Noah, A. S. (2022). Oil Palm Empty Fruit Bunches (OPEFB)–Alternative Fibre. Elaeis guineensis, 18 3.

Obisesan, O. O., Ogundele, O. O., & Akintayo, O. J. (2025). Rice Processing Techniques and Efficiency Differentials: A Case Study from Nigeria. Sustainable Bioeconomy Development in the Global South: Volume II Bioeconomy Techniques, 409-429.

Oko P.E; T. Asaasuen; B.T Ako; D.U Odey & E.A Robert (2023). Population Growth and the Changing Pattern of Environmental Degradation in Gboko Local Government Area of Benue State. World Environment Journal. Vol. 3(1) pg 171-178.

Omang, B.O., Effiom, H., Omeka, M.E., Oko, P.E., Asinya, E.A., Ojikutu L.T., & Kave, G.T (2023). Trace Element Geochemical Imprints and Multi-Path Elements in Soils from the Polymetallic Area of Tashan-Jatau, North Western Nigeria. Vol. 21 pg 91-115. DOI- https://dx.doi.org//10.4314//gigs:v21i1.7

Omar, M. F., Ali, F., Jami, M. S., Azmi, A. S., Ahmad, F., Marzuki, M. Z., ... & Kim, M. P. (2025). A Comprehensive Review of Natural Rubber Composites: Properties, Compounding Aspects, and Renewable Practices with Natural Fibre Reinforcement. Journal of Renewable Materials, 13(3).

Omokaro, G. O., Michael, I., Efeni, O. S., Adeyanju, O. I., & Obomejero, J. (2025). Waste management in Nigeria: Systemic failures, circular economy pathways and sustainable solutions. Environmental Development, 101363. pg 0268-0274.

Sabiani, N. H. M., Alkarimiah, R., Ayub, K. R., Makhtar, M. M. Z., Aziz, H. A., Hung, Y. T., ... & Wang, M. H. S. (2023). Treatment of palm oil mill effluent. In Waste Treatment in the Biotechnology, Agricultural and Food Industries: Volume 2 (pp. 227-284). Cham: Springer International Publishing.

Sahil, F. M., & Ilampooranan, I. (2025). Managing Agri-Biomass: Alternative Approaches to Improve Environmental Sustainability Through Resource Recovery. In Integrated Land and Water Resource Management for Sustainable Agriculture Volume 1 (pp. 181-214). Singapore: Springer Nature Singapore.

Samant, B. S., & Kaliappan, R. (2025). The use of surfactants in the extraction of active ingredients from natural resources: a comprehensive review. RSC advances, 15(29), 23569-23587.

Saqib, Z., & Sadef, Y. (2025). Sustainable waste management through commercial composting: Challenges, opportunities, and future directions for circular economy. European Journal of Sustainable Development Research, 9(4).

Siagian, U. W. R., Wenten, I. G., & Khoiruddin, K. (2024). Circular economy approaches in the palm oil industry: Enhancing profitability through waste reduction and product diversification. Journal of Engineering and Technological Sciences, 56(1), 25-49.

Tawo, O. E., & Mbamalu, M. I. (2025). Advancing waste valorization techniques for sustainable industrial operations and improved environmental safety. Int. J. Sci. Res. Arch, 14(02), 127-149.

Tiwari, A. K., & Pal, D. B. (2022). Nutrients contamination and eutrophication in the river ecosystem. In Ecological significance of river ecosystems (pp. 203-216). Elsevier.