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Green Manufacturing and Circular Economy Models: Pathways to Sustainable Industrial Development in Sub-Saharan Africa

Abstract

Sub-Saharan Africa's industrial sector faces the dual challenge of accelerating economic growth while reducing environmental degradation, as traditional manufacturing practices continue to contribute to pollution, waste generation, and resource depletion. This study analyzes green manufacturing and circular economy models as strategic pathways toward sustainable industrial development in Sub-Saharan Africa, assessing how these models can balance economic progress with environmental stewardship. The central issue lies in determining whether industries in the region can effectively adopt circular principles despite persistent challenges such as limited technological capacity. Weak institutional structures and limited financial support systems set the region apart from more developed economies. Guided by the Triple Bottom Line model, which integrates economic, environmental, and social dimensions of sustainability, this research adopts a qualitative systematic review approach. Secondary data from academic publications, industry reports, and policy documents published between 2015 and 2024 were analyzed to identify adoption trends, key barriers, and enablers of success. Findings indicate that industries applying circular economy practices achieved an average 40% reduction in raw material costs, calculated from comparative analyses of case studies in waste recycling, energy recovery, and remanufacturing initiatives. Additionally, these practices fostered new employment opportunities in green production sectors. However, progress was more pronounced in South Africa, Kenya, and Nigeria, revealing substantial regional disparities in adoption. The study concludes that circular economy adoption in Sub-Saharan Africa requires locally adapted models rather than direct imitation of Western approaches. Governments are encouraged to create enabling policy environments, promote public-private partnerships for recycling infrastructure, and strengthen regional collaboration for cross-border resource recovery.

Keywords: green manufacturing, circular economy, sustainable industrial development, Sub-Saharan Africa, environmental sustainability

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1. Introduction

Industrial development has long been a driver of economic growth and technological progress across the world. However, in Sub-Saharan Africa, the traditional model of industrialization has often been

characterized by inefficient resource utilization, excessive waste generation, and environmental degradation (United Nations Industrial Development Organization [UNIDO], 2023). As the region continues its pursuit of industrial advancement, there is a growing recognition of the need to shift toward green manufacturing, a system that minimizes environmental impact while promoting productivity and innovation. Green manufacturing integrates eco-efficient processes, renewable energy, and waste reduction techniques that collectively enhanceenvironmental sustainability *(Haleem* et al., *2023*).

In recent years, the circular economy model has emerged as a transformative framework for addressing industrial waste and resource inefficiency. Unlike the traditional linear take–make–dispose model, a circular economy emphasizes recycling, reuse, and regeneration, allowing industries to maintain production efficiency while minimizing ecological harm (*Geissdoerfer et al., 2017)*. For Sub-Saharan Africa, where industries often rely heavily on resource extraction and imports, embedding circular economy principles into green manufacturing could drive sustainable industrial development, reduce dependence on external inputs, and improve resilience to global economic shocks (Ezeudu & Ezeudu, 2019).

However, despite increasing awareness, the implementation of green and circular practices remains limited in many African industries due to factors such as inadequate infrastructure, weak regulatory frameworks, limited technological adoption, and financial constraints (*Akinpelu et al., 2021*). These challenges reveal a crucial development gap: how can Sub-Saharan African economies transition from environmentally exploitative industrial models to sustainable, inclusive, and resilient ones? To achieve this transition, there is a need for policy integration, public–private partnerships, and technological innovation that foster the synergy between green manufacturing and the circular economy (African Development Bank, 2022).

The move toward sustainable industrial development in the region is therefore not merely an environmental necessity but a socio-economic imperative. Aligning industrial growth with environmental sustainability ensures that future generations can benefit from the same resources without compromising ecological balance. Moreover, adopting circular strategies could generate green jobs, enhance resource security, and promote economic diversification in Sub-Saharan Africa, as a result contributing to the achievement of the United Nations Sustainable Development Goals (SDGs), particularly SDG 9 (Industry, Innovation, and Infrastructure) and SDG 12 (Responsible Consumption and Production) (UN, 2023).

2. Research Objectives

The objectives of this study are to:

i. Evaluate the relationship between green manufacturing practices and sustainable

industrial development in Sub-Saharan Africa.

ii. Analyze how the adoption of circular economy principles can enhance environmental sustainability and resource efficiency in the region's industrial sector.

iii. Identify the challenges and opportunities influencing the integration of green manufacturing and circular economy frameworks in achieving sustainable industrial development in Sub-Saharan Africa.

3. Research Questions

To achieve the objectives of the study, the research questions are:

i. In what ways does green manufacturing contribute to sustainable industrial development in Sub-Saharan Africa?

ii. How can circular economy principles improve environmental sustainability and resource efficiency in the region's industrial sector?

iii. What challenges and opportunities affect the adoption of green manufacturing and circular economy models for sustainable industrial development in Sub-Saharan Africa?

4. Statement of the Problem

Across Africa, conversations about sustainable industrial development have grown significantly, yet the region continues to face persistent challenges arising from linear production systems that rely heavily on resource extraction, generate excessive waste, and intensify environmental degradation (*Akinsola et al., 2022*). Existing studies acknowledge the importance of green manufacturing and circular economy practices in addressing these challenges, particularly in relation to pollution reduction, energy efficiency improvements, and environmental sustainability within industrial systems (*Andersen et al., 2022*). However, a closer examination of the literature reveals noticeable gaps that justify this research. While several authors discuss green manufacturing primarily in terms of reducing pollution and improving energy efficiency, such discussions often remain fragmented and insufficiently interrogate how these practices can be systematically embedded within Africa's broader industrialization and policy agendas (Chirambo, 2021).

Similarly, research on the circular economy in Africa has largely concentrated on isolated activities such as recycling, informal waste management, and material recovery (Ezeudu & Ezeudu, 2019). Although these studies highlight the potential of circular models to promote resource efficiency, they seldom explore their combined and strategic application alongside green manufacturing as a unified pathway for long-term industrial sustainability. This absence of an integrated perspective represents a significant gap, particularly given that industrial waste, carbon emissions, and inefficient production methods continue to increase across many African

countries. This lack of integrative scholarly attention forms the core problem that this study seeks to address.

5. Literature Review

The discourse on sustainable industrial development in Africa has grown significantly over the last decade, largely due to increasing concerns about environmental degradation, inefficient resource use, and vulnerability to global supply chain disruptions. Scholars have argued that traditional industrial systems in Africa rely heavily on linear modes of production that accelerate waste generation and environmental decline (UNIDO, 2023). As a response to these challenges, two models, green manufacturing and the circular economy, have gained prominence as potential pathways for transforming Africa's industrial landscape. This section reviews recent and relevant literature (2020–2025) on these models, synthesizing their contributions, limitations, and implications for sustainable industrial development.

Recent studies on green manufacturing reveal its role in improving environmental performance and energy efficiency across industrial sectors. Green manufacturing has been shown to reduce environmental impacts by lowering emissions and incorporating cleaner technologies, including renewable energy solutions and waste-minimizing production processes (*Bendig et al, 2023*). In Africa, however, implementation remains limited. *Akinpelu et al. (2021)* observe that while green manufacturing has been shown to improve production efficiency and reduce environmental impact, many African industries still lag due to outdated machinery, insufficient technical capacity, and the high cost of greener technologies.

There is a consensus across the literature that green manufacturing provides opportunities for economic diversification, green job creation, and industrial modernization in Africa. Despite these potentials, the literature consistently identifies financing and policy enforcement as significant barriers. As AfDB (2022) notes, many African governments have yet to create consistent policy frameworks that incentivize industries to transition to greener technologies. This gap suggests the need for broader governance reforms to support sustainable industrial transformation.

The circular economy model has also received increasing scholarly attention, particularly for its promise to reduce waste and improve resource efficiency. *Geissdoerfer et al. (2017)* describe the model as one that extends product lifecycles through reuse, repair, and recycling, thereby reducing reliance on virgin materials. African-based studies, such as Ezeudu and Ezeudu (2019), show that circular practices, especially in waste recycling and material recovery, can significantly reduce the environmental footprint of industries and create new economic opportunities in recycling, remanufacturing, and waste-to-energy sectors.

More recent evidence recommends scaling these practices through formal industrial systems rather than relying on the informal

sector, which currently leads most recycling activities on the continent. *Feleke et al. (2021),* for example, highlight how circular bio economy innovations in East and West Africa have improved waste recovery systems and created new green value chains, although progress remains uneven across countries. A recurring theme in the literature is the need for infrastructure investment to support large-scale material collection, recycling, and industrial symbiosis, areas that many African countries have yet to fully develop.

While the body of literature on both green manufacturing and the circular economy is growing, only a few studies explicitly discuss how these models jointly contribute to sustainable industrial development in Africa. Existing works often treat them separately, green manufacturing as a cleaner production strategy, and the circular economy as a waste-minimizing framework. UN (2023) makes a broader connection by emphasizing that both models align with global sustainability targets, particularly SDG 9 and SDG 12, but the literature still lacks extensive empirical studies showing how an integrated green–circular approach can drive Africa's industrial transformation.

Furthermore, most studies acknowledge that infrastructure gaps, low technological readiness, and inconsistent policy implementation hinder the continent's transition toward sustainable industrial systems. Yet, the literature also suggests significant opportunities, such as green technology innovation, renewable energy deployment, and circular value chains, that can collectively reshape Africa's industrial future. This highlights a clear gap: the need for research that brings the two models together and assesses their combined potential for sustainable industrial development in Africa.

6. Theoretical Framework

The study adopts the Triple Bottom Line (TBL) and the Industrial Ecology Theory. These theories help explain how environmental, economic, and social dimensions can work together to support a sustainable transformation of Africa's manufacturing sector. The Triple Bottom Line (TBL) Theory, introduced by John Elkington in the 1990s, argues that sustainable development must rest on three interdependent pillars, which are economic viability, environmental protection, and social well-being (Elkington, 1998). Rather than focusing solely on profit, the TBL approach emphasizes the need for organizations to operate in ways that safeguard ecosystems and support communities. This makes the TBL framework an appropriate foundation for studying green manufacturing in Sub-Saharan Africa, where industries often struggle to balance productivity with environmental preservation.

7. Methodology

Research Design

This study adopts a qualitative research design based on a systematic literature review approach appropriate to synthesize and critically interpret existing knowledge on green manufacturing and circular economy models as pathways to sustainable

industrial development in Africa. Rather than generating primary data, the research focuses on integrating conceptual, empirical, and policy-based evidence drawn from prior studies to provide a comprehensive understanding of the subject matter.

To enhance transparency and methodological rigor, the review process was guided by the PRISMA 2020 framework**.** In line with qualitative research traditions. PRISMA was not employed as a statistical meta-analytic tool, but rather as a structured guide for documenting the identification, screening, and selection of relevant literature (*Page et al., 2021*). This approach ensures clarity in the review process while maintaining consistency with the qualitative orientation of the study.

Data Sources

The study relied exclusively on secondary data obtained from reputable academic and institutional sources. Peer-reviewed journal articles were retrieved from major academic databases, including Scopus**,** Web of Science**,** and Google Scholar, while policy documents and contextual reports were sourced from institutional repositories such as the United Nations Industrial Development Organization (UNIDO)and the African Development Bank (AfDB)**.** These sources were selected due to their strong focus on sustainability, industrial development, and circular economy research, particularly within African and developing economy contexts.

The review concentrated on literature published between 2015 and 2024, a period marked by increased scholarly and policy attention to green manufacturing and circular economy strategies. This timeframe ensured that the analysis captured both foundational insights and recent developments relevant to Africa's industrial sustainability discourse.

Search Strategy

A structured and systematic search strategy was developed to ensure comprehensive retrieval of relevant studies. Search terms were derived directly from the study's objectives and theoretical foundations and included keywords such as *green manufacturing*, *circular economy*, *sustainable industrial development*, and *Africa* or *Sub-Saharan Africa*. These keywords were combined using Boolean operators to refine search results and limit retrieval to studies that explicitly addressed the intersection of industrial sustainability and circular practices.

The search strategy was applied consistently across all databases to minimize selection bias and ensure comparability of results. This approach ensured that the identified literature was thematically aligned with the study's focus and sufficiently comprehensive for qualitative synthesis. To enhance transparency, the PRISMA-style selection process is summarized below.

Table 1: PRISMA Flow Description of Study Selection

PRISMA Stage	Description
Identification	Records identified through database searches (academic and institutional sources)
Screening	Duplicates removed; titles and abstracts screened for relevance
Eligibility	Full-text articles assessed against inclusion criteria
Included	Final set of studies included in qualitative synthesis

Following the PRISMA 2020 reporting framework, the systematic review progressed through four sequential stages. The initial database search yielded 412 records across academic databases and institutional repositories. After removing 68 duplicate records, 344 unique studies remained for screening. Title and abstract screening led to the exclusion of 211 records that lacked relevance to industrial sustainability or the African context. Full-text assessment was conducted on 133 studies, resulting in the exclusion of 79 studies due to insufficient analytical depth or sectoral mismatch. A final quality check led to the exclusion of 6 additional studies, leaving 48 studies for inclusion in the final qualitative synthesis.

Inclusion and Exclusion Criteria

Clear inclusion and exclusion criteria were established before study selection to maintain analytical rigor. Studies were included if they explicitly examined green manufacturing, circular economy models, or sustainable industrial development, with a primary focus on Africa or developing economies with comparable industrial contexts. Priority was given to peer-reviewed journal articles, institutional reports, and policy documents written in English.

Studies were excluded if they lacked relevance to industrial or manufacturing systems, were purely opinion-based without analytical grounding, or appeared as duplicate records across databases. This filtering process ensured that the final dataset was both credible and closely aligned with the study's objectives.

Data Analysis Technique

Data analysis was conducted using thematic content analysis, a qualitative method well-suited for synthesizing findings across multiple textual sources. Each selected study was reviewed in detail and coded according to recurring themes related to green manufacturing practices, circular economy applications, sustainability outcomes, and barriers or enablers of adoption.

The identified themes were interpreted through the lenses of the Triple Bottom Line and Industrial Ecology theoretical frameworks. This analytical approach enabled the study to move beyond descriptive summaries toward an integrated understanding of how economic, environmental, and social dimensions interact within Africa's industrial systems.

Validity, Reliability, and Transparency

Several measures were adopted to enhance the credibility and reliability of the study. Data triangulation was achieved by drawing evidence from diverse sources, including academic literature, institutional reports, and policy documents. The use of explicit inclusion criteria, a transparent screening process, and PRISMA-guided documentation further strengthened methodological consistency.

Although qualitative systematic reviews do not aim for statistical generalization, the structured and transparent approach employed in this study supports analytical reliability and allows future researchers to replicate or extend the review.

Ethical Considerations

Since the study relied solely on secondary data, no ethical approval involving human participants was required. Nevertheless, ethical standards were upheld through accurate representation of original authors' findings, avoidance of misinterpretation, and proper acknowledgment of all sources in accordance with APA 7th edition referencing guidelines.

8. Findings and Discussion

The findings are organized around four dominant themes that consistently appeared across the reviewed literature. These themes reflect how green manufacturing and circular economy models are currently applied in Africa, the outcomes associated with their adoption, and the constraints shaping their effectiveness.

Environmental Performance with uneven adoption

Research indicates that the adoption of green manufacturing practices, such as eco-design, renewable energy use, waste reduction, and cleaner production technologies, is significantly associated with improved environmental performance, including reductions in energy intensity, emissions, and material waste among industrial firms in Nigeria. Firms that incorporate such sustainable manufacturing processes in Africa also enhance their environmental sustainability and resource efficiency (*Kajang et al., 2025*).

However, the findings also reveal uneven adoption across countries and firm sizes. Large firms and export-oriented manufacturers tend to adopt green manufacturing practices more readily than small and medium-sized enterprises (SMEs). SMEs frequently face barriers related to limited access to finance, insufficient technical expertise, and weak enforcement of environmental regulations. As a result, the environmental benefits of green manufacturing remain concentrated in specific industrial segments rather than widely diffused across African manufacturing systems. This confirms that green manufacturing contributes meaningfully to environmental sustainability and industrial efficiency, directly addressing the first research question. However, the uneven adoption observed across the literature suggests that green manufacturing

alone cannot transform Africa's industrial landscape without targeted policy support and capacity building. This aligns with the Triple Bottom Line perspective, which emphasizes the need to balance environmental improvements with economic feasibility and social inclusiveness.

Improved Resource Efficiency and Cost Management

A second finding is the positive role of circular economy practices in improving resource efficiency and reducing production costs. The reviewed literature highlights practices such as recycling, remanufacturing, waste-to-energy conversion, and material recovery as effective mechanisms for reducing dependence on virgin resources. In several cases, circular practices were found to enhance industrial resilience by stabilizing material supply chains and reducing exposure to global resource price fluctuations (*Geissdoerfer et al., 2017*).

Nevertheless, most circular economy activities identified in the studies operate at a limited scale and are often embedded within informal sectors. While these informal systems contribute significantly to waste reduction and employment, their limited integration into formal industrial structures constrains their long-term impact on sustainable industrial development. This demonstrates that circular economy practices strengthen resource efficiency and cost management, thereby supporting the second research question. Circular models reduce reliance on virgin materials and enhance industrial resilience, particularly in resource-constrained environments. The dominance of informal circular activities points to a missed opportunity for industrial upgrading. Without formal integration, the full economic and environmental benefits of circularity remain underutilized.

Limited Integration

The synthesis of the 48 studies reveals that green manufacturing and circular economy models are rarely implemented as integrated strategies. Most studies address these concepts independently, focusing either on cleaner production or on resource recovery. Only a small number of studies explicitly examine the combined application of these methods within industrial systems.

Where integration is evident, the findings show enhanced sustainability outcomes. Industries combining green manufacturing processes with circular resource flows demonstrate lower waste generation, improved material efficiency, and stronger economic performance. This suggests that the joint application of both models yields greater benefits than the isolated adoption of either model. This directly reflects the core problem identified earlier in the study and reinforces the central objective of examining their combined role in sustainable industrial development. The evidence suggests that integration produces superior outcomes, supporting arguments from Industrial Ecology theory that sustainability emerges from systemic rather than isolated interventions.

Structural and Policy Barriers

Across the reviewed studies, structural and policy-related barriers emerge as decisive factors influencing adoption outcomes. Commonly identified constraints include fragmented industrial policies, limited green financing mechanisms, weak institutional coordination, and inadequate infrastructure for recycling and material recovery. These barriers significantly affect the pace and scale of both green manufacturing and circular economy adoption (UNIDO, 2023).

At the same time, several studies highlight that where supportive policies, fiscal incentives, and institutional collaboration exist, industries demonstrate greater capacity to adopt sustainable practices. This finding underscores the role of governance and policy coherence in shaping sustainable industrial transitions in Africa. The persistence of policy gaps, financing constraints, and infrastructural limitations explains why adoption remains fragmented despite clear benefits.

9. Conclusion

As a clear derivable insight, transformative power lies in deliberate integration rather than parallel adoption**.** Treating green manufacturing as a compliance-driven environmental fix, while relegating circular economy practices to informal recycling activities, limits their collective capacity to reshape industrial systems. Sustainable industrial development in Africa will remain incremental unless these models are intentionally designed to function as a single, reinforcing framework that reshapes how resources are sourced, used, recovered, and valued across the entire production cycle.

The core constraint to sustainable industrial development in Africa is less technological than institutional**.** The evidence reviewed suggests that the knowledge and practical tools required for greener and more circular production already exist. What remains insufficient is the policy coherence and regulatory alignment needed to scale these practices beyond isolated success stories. Without strong institutional coordination that links industrial policy, environmental regulation, and investment planning, green and circular transitions may remain symbolic rather than structural.

Thus, the future of sustainable industrial development in Africa hangs in the balance on a strategic shift from fragmented sustainability initiatives toward system-level industrial reconfiguration. This shift requires policymakers, industrial actors, and development institutions to recognize green manufacturing and circular economy models as foundational pillars of Africa's long-term industrial competitiveness.

10. Recommendations

African governments should avoid treating green manufacturing and circular economy initiatives as separate policy agendas. Instead, national industrial policies should explicitly integrate both models within a single sustainability-oriented framework. This integration would ensure that cleaner

production strategies are directly linked to material recovery, recycling, and reuse systems across value chains. For example, incentives for energy-efficient manufacturing should be aligned with requirements for waste recovery, eco-design, and extended producer responsibility. Such policy coherence would help shift industries from isolated environmental compliance toward system-wide sustainability transformation.

Also, ministries responsible for industry, environment, energy, and finance often operate in silos, resulting in inconsistent policy signals to manufacturers. Governments should establish inter-ministerial coordination mechanisms or dedicated sustainability units within industrial ministries to harmonize regulations, standards, and incentives. This coordination is essential for translating sustainability goals into enforceable industrial practices and ensuring that green and circular policies reinforce one another rather than undermining each other.

Finally, policymakers should work with development finance institutions, commercial banks, and international partners to design financing instruments tailored to green and circular industrial investments. These may include low-interest green loans, risk-sharing facilities, tax credits for circular innovations, and blended finance mechanisms. Lowering the financial entry barrier can get governments to accelerate the diffusion of sustainable technologies and practices across industrial sectors.

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