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WASTE RECYCLING AND ITS IMPACT ON ENVIRONMENTAL PROTECTION AND ECONOMIC DEVELOPMENT IN DEVELOPING COUNTRIES: A BIBLIOMETRIC ANALYSIS

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ABSTRACT

This study conducts a bibliometric analysis of waste recycling and environmental protection research in developing nations, synthesizing insights from two databases based on evolution, publication trends, collaborative networks, and thematic priorities. A total of 200 documents published between 1995 and 2025 were sourced from SCOPUS (174) and PubMed (26) using the search algorithm: TITLE-ABS-KEY ("Waste recycling" OR "environment" AND "environmental protection" OR "economic growth" OR "Developing countries"). Findings reveal that only 54.68% of publications involved international co-authorship, highlighting limited global collaboration. The analysis identifies key contributors to global research powerhouses, with top-performing countries ("China" and "United States"), leading institutions ("School of life sciences", "Saint Pierre", "School of Agriculture", "Department of Genetics", "Ecoimvelo Durban SA", and "Env. Consulting South"), and leading authors ("Wang Xu", "Wang Jing", "Sisani Federico", "Dimaria Francesco", "Feijoo Gumersindo", and "Gonzalez Sara"). Notable keyword trends include increasing emphasis on "circular economy," "sustainability," and "life cycle assessment," reflecting a shift from traditional waste management to proactive, systems-based strategies. This thematic evolution and cyclical patterns in scholarly activity align with global policy developments such as the Sustainable Development Goals and the Paris Climate Accord. Strong correlations emerge between concepts such as "recycling" and "waste management," emphasizing the need for interdisciplinary partnerships and targeted policy engagement in developing regions. The study concludes that academic trends not only reflect but often anticipate policy priorities, emphasizing the importance of adaptive keyword strategies and inclusive collaboration to advance sustainable waste management, guiding investment in circular economic practices, and aligning scientific inquiry with global sustainability goals.

KEYWORDS: Waste Recycling, Environmental Protection, Economic Development, Bibliometrics, Developing Countries.

1. INTRODUCTION

In recent years, waste recycling has emerged as a vital response to growing environmental challenges and the pursuit of sustainable economic development, particularly in developing countries. As the concept of a circular economy gains traction globally, recycling practices are increasingly recognized as a cornerstone of minimizing waste, conserving resources, and fostering environmental resilience (Tabish *et al.*, 2024). Effective recycling mitigates pollution, reduces reliance on virgin materials, and curtails the detrimental impacts of improper waste disposal (Jagun *et al.*, 2023). However, despite its promise, the implementation of robust recycling systems in developing regions faces persistent obstacles, including inadequate infrastructure, limited financing, and weak regulatory frameworks (Ogutu & Kathambi, 2022). These structural deficits often exacerbate environmental degradation and hinder inclusive economic progress.

Several studies underscore the catalytic potential of recycling to drive environmental sustainability and economic growth when effectively embedded within national waste management strategies (Adewole *et al.*, 2019). The environmental benefits, ranging from reductions in greenhouse gas emissions to improved energy efficiency, are especially crucial for climate-vulnerable developing nations. Aja *et al.* (2021) highlights that recycling materials like aluminum and plastic consumes significantly less energy compared to primary production, offering a clear pathway toward lower carbon footprints. Beyond ecological benefits, waste recycling presents far-reaching economic opportunities. It stimulates job creation across formal and informal sectors, fosters industrial diversification, and can alleviate poverty by engaging marginalized communities, particularly through inclusive value chains (Ikelle *et al.*, 2023). With the emergence of local enterprises and SMEs in the recycling domain, developing economies can strengthen domestic industries, reduce dependence on raw material imports, and improve trade balances (Adeyemi, 2023).

1.1. Unique Value Proposition of The Study

While these trends are well-documented, there remains a need for context-specific insights into how recycling can be leveraged more effectively as a dual strategy for environmental protection and economic development in developing regions. This study uniquely contributes by examining the interplay between waste recycling systems, environmental

resilience, and inclusive economic transformation. Building on recent empirical evidence, it identifies actionable strategies that can guide policymakers, entrepreneurs, and development actors toward sustainable and locally grounded recycling frameworks.

1.2. Problem Statement/Research Gap

Existing studies have explored the impact of waste recycling on environmental protection and economic development in developing countries; several critical gaps remain unaddressed, warranting further investigation. First, there is a notable lack of comprehensive bibliometric analyses focusing specifically on the relationship between waste recycling and sustainable development in the context of developing nations. While fragmented studies highlight the environmental and economic benefits, a systematic review and mapping of the academic landscape are still missing. Such an analysis would help identify dominant themes, emerging trends, and research collaborations that have shaped the discourse on waste recycling in these regions (Adelekan, 2020). Secondly, the interplay between technological advancements and waste recycling efficiency remains underexplored. Although studies have mentioned the potential of technology to enhance recycling processes, there is insufficient research evaluating the adoption of advanced technologies in developing countries. This includes the role of digital tools, automation, and artificial intelligence in optimizing waste management systems. Thirdly, there is a scarcity of research addressing the socio-cultural barriers to effective recycling practices in these regions. While the economic and environmental aspects of recycling are frequently discussed, limited attention has been given to societal factors, such as public perceptions, behavioral attitudes, and community participation. Understanding these factors is crucial for designing culturally sensitive and impactful recycling programs (Ogunseye *et al.*, 2024).

Additionally, the economic benefits of recycling, such as job creation and income generation, have been well-documented. However, these benefits' long-term sustainability and scalability in developing nations require further examination. This includes investigating how recycling initiatives can be integrated into broader economic development plans to ensure sustained impact (Noiki, 2021). Lastly, the comparative effectiveness of policy interventions across developing countries is under-researched. While some studies have highlighted successful case studies, a systematic comparison of

policies, regulations, and incentives across nations could provide actionable insights for policymakers aiming to replicate success stories in their regions (Ayodele *et al.*, 2018). This study aims to fill these gaps by conducting a bibliometric analysis to systematically review and synthesize existing literature, identify thematic trends, and uncover areas that require further exploration. Through this effort, the study seeks to provide a holistic understanding of the relationship between waste recycling, environmental protection, and economic development in the context of developing countries, paving the way for future research and practical applications.

1.3. Research Objectives

The study seeks to achieve the following objectives:

- Describe the data obtained from the databases.
- Examine the synthesized insights from the databases based on co-authorship and co-occurrence relationships on all keywords, countries, authors, and organizations.
- Evaluate the bibliometrically derived challenges and opportunities in waste recycling.

2. REVIEW OF LITERATURE

2.1. Historical Evolution of Waste Management Practices in Nigeria

Waste management practices in Nigeria have evolved from traditional methods to modern approaches. In Nigeria, the history of waste management reflects a transition from traditional practices to formalized systems, influenced significantly by urbanization and population growth. Traditionally, waste disposal in Nigeria involved methods such as burning, burying, and using waste for agricultural purposes (Nnaji, 2015). Communities often relied on local practices emphasizing resource reuse, aligning with cultural norms and sustainability. However, as Nigeria experienced rapid urbanization in the late 20th century, particularly following the oil boom in the 1970s, waste generation increased dramatically. Urban centers became overwhelmed with the influx of people, leading to a surge in municipal solid waste. According to a study by Omole *et al.* (2016), the volume of waste generated in Nigerian cities rose significantly, resulting in severe environmental degradation, including pollution, flooding due to blocked drainage systems, and public health crises.

2.1.1. Current State of Waste Management

In response to these challenges, the Nigerian government began implementing formal waste management policies in the 1990s. This period marked the introduction of initiatives to establish structured waste collection and disposal systems. The National Environmental Sanitation Policy 2005 emphasized the need for comprehensive waste management strategies, yet implementation has often been inconsistent and plagued by corruption, lack of funding, and inadequate infrastructure (Adelekan, 2020). Consequently, many municipalities have struggled to manage waste effectively, leading to continued reliance on informal practices. The emergence of informal recycling sectors has significantly developed Nigeria's waste management landscape. Informal waste collectors and recyclers have become integral to the system, often collecting and sorting waste that formal systems fail to address. According to a report by the World Bank (2021), informal recycling accounts for a substantial portion of waste management in urban areas, which, despite the lack of support, would help to divert waste from landfills.

2.2. Theoretical Frameworks

Several theoretical frameworks underpin waste recycling initiatives in Nigeria. These frameworks include the circular economy model, the environmental justice framework, and the social practice theory.

2.2.1. Closed-Loop Economy

This is an essential framework for grasping the concepts of waste management and recycling. It minimizes waste and continually repurposes materials, encouraging resource efficiency and sustainability by promoting the ongoing use of materials through recycling, reuse, and regeneration (Geissdoerfer *et al.*, 2018). In Nigeria, embracing a circular economy approach could significantly lessen the environmental effects of waste by decreasing pollution linked to waste disposal (Oluwatayo & Ojo, 2024). This model highlights the ecological advantages of recycling and the economic potential of creating new sustainable business models.

2.2.2 Environmental Justice Framework

The Environmental Justice framework focuses on the social dimensions of waste management, particularly the inequities that arise in the distribution of environmental burdens. This

framework highlights how marginalized communities often bear the brunt of waste disposal impacts, facing higher exposure to pollution and health risks (Omole *et al.*, 2016). In Nigeria, informal waste workers, often from disadvantaged backgrounds, are particularly vulnerable, facing hazardous working conditions with little protection or support (Adelekan, 2020). Understanding waste management through an environmental justice lens underscores the need for equitable policies and advocates for inclusive practices that empower marginalized communities to participate in waste management and recycling initiatives. This approach fosters social equity and enhances community resilience against environmental degradation.

2.2.3. Social Practice Theory

This theory provides a valuable perspective on how social norms, behaviors, and cultural contexts influence waste recycling practices. This theoretical framework posits that individual behaviors are shaped by social practices deeply embedded in societal norms and routines (Ofoetie, 2022). In Nigeria, cultural attitudes toward waste, resource scarcity, and communal responsibilities often influence social practices around waste disposal and recycling. For instance, community-led initiatives that promote recycling can change perceptions and behaviors, encouraging greater participation in formal recycling programs (Ayodele *et al.*, 2018). By examining the social practices surrounding waste management, this framework helps identify barriers to recycling and offers insights into effectively engaging communities in sustainable waste management practices.

2.3. Empirical Evidence

Recent studies have significantly contributed to understanding waste recycling in Nigeria, revealing various dimensions of participation, effectiveness, and challenges. A survey conducted in 2021 found that approximately 60% of urban households in Nigeria participate in some form of recycling, primarily through informal channels (Alabi *et al.*, 2020). This high level of engagement in urban areas highlights the crucial role of informal waste collectors and local initiatives in promoting recycling practices. Informal recycling often involves scavenging and sorting materials like plastics, paper, and metals, which are then sold to recyclers or reused. This underscores the necessity of recognizing and integrating these

informal systems into broader waste management strategies. Research shows that recycling can significantly reduce waste sent to landfills, with estimates suggesting a decrease of about 30% (Ayeni & Ogunkunle, 2017). This reduction is vital for mitigating pollution and conserving natural resources, as landfill overflow contributes to soil and water contamination, threatening public health and the environment. By diverting waste from landfills, recycling practices alleviate these environmental concerns and promote a circular economy that prioritizes resource recovery.

Moreover, the relationship between recycling initiatives and community engagement has been identified. Studies indicate that public awareness campaigns are crucial in enhancing participation in recycling programs (Gbenga *et al.*, 2023). These campaigns raise awareness about the benefits of recycling, provide information on proper waste segregation, and mobilize community involvement, thereby fostering a culture of sustainability. The evidence suggests that when communities are educated about the positive impacts of recycling, their participation rates increase, leading to more effective waste management outcomes. However, empirical evidence also highlights notable regional disparities in recycling rates across Nigeria. Urban areas typically participate more in recycling initiatives than rural settings (Ogunseye *et al.*, 2024). This disparity can be attributed to several factors, including better access to recycling facilities, greater awareness of recycling benefits, and more robust city infrastructure, in contrast to those in rural areas, leading to lower participation rates. Addressing these disparities requires targeted policies that improve access to recycling services and educate rural communities about the importance of waste management.

Recent empirical studies have examined the effectiveness and impact of waste recycling in Nigeria. These studies have highlighted the benefits of recycling, including reduced waste, conserved natural resources, and minimized pollution. Research by Ayodele *et al.* (2018) indicates that effective recycling practices can lead to a reduction of up to 30% in waste, significantly alleviating pressure on waste management systems. Additionally, the circular economy model, which emphasizes resource efficiency and sustainability, aligns closely with recycling initiatives, making it an attractive solution for Nigeria's waste management issues

(Oluwatayo & Ojo, 2024).

3. METHODOLOGY

This study employed a systematic bibliometric analysis to explore trends and relationships in the literature on waste recycling, environmental protection, and economic development in developing countries. The analysis focused on publications indexed in two prominent databases (Scopus and PubMed) due to their extensive coverage of multidisciplinary research and environmental sciences.

3.1. Search Strategy and Inclusion Criteria

A keyword-based search algorithm was used to identify relevant publications, with the following query applied across both databases: TITLE-ABS-KEY ("waste recycling" OR "environment") AND ("growth" AND ("environmental protection" OR "economic

growth" OR "developing countries").

As presented in Figure 1, documents were included if they:

- ❖ Were published between January 1995 and May 2025, ensuring both historical context and current trends were captured.
- ❖ Appeared in peer-reviewed journals, conference proceedings, books, or book chapters.
- ❖ They were written in English.
- ❖ Addressed waste recycling in the context of environmental or economic development in developing countries.

3.2. Exclusion Criteria Publications were excluded if they:

- ❖ Focused solely on developed economies without relevance to developing regions.
- ❖ Were editorial notes, commentaries, or non-peer-reviewed content.
- ❖ Fell outside the specified date range.

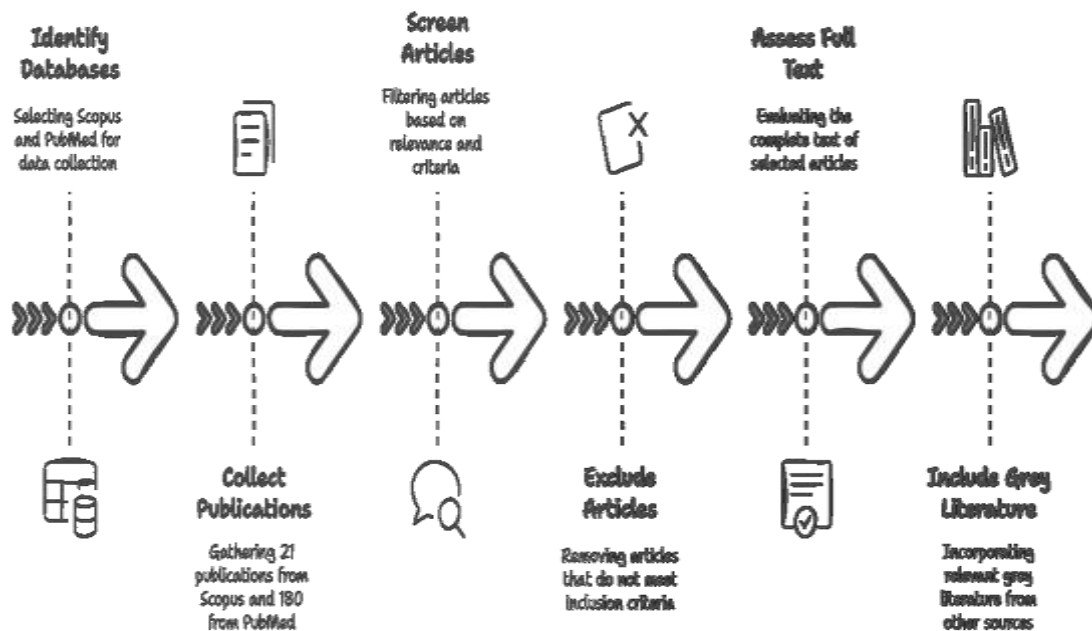


Figure 1: Data Collection Process.

3.3. Data Cleaning and Deduplication

Search results from Scopus and PubMed were exported in compatible formats and merged.

To ensure integrity, duplicate records identified through matching DOIs and titles were removed manually and cross-verified using bibliographic software.

The final dataset consisted of 200 unique publications.

3.4. Analytical Tools and Visualization

VOS viewer software was employed for bibliometric mapping and thematic analysis (Figure 2). The imported dataset was analyzed to visualize:

- ❖ Co-authorship networks by author, country and organization
- ❖ Keyword co-occurrence patterns
- ❖ Thematic clustering of research topics

These visualizations enabled the identification of

collaboration patterns, research hotspots, and emerging themes within the field.

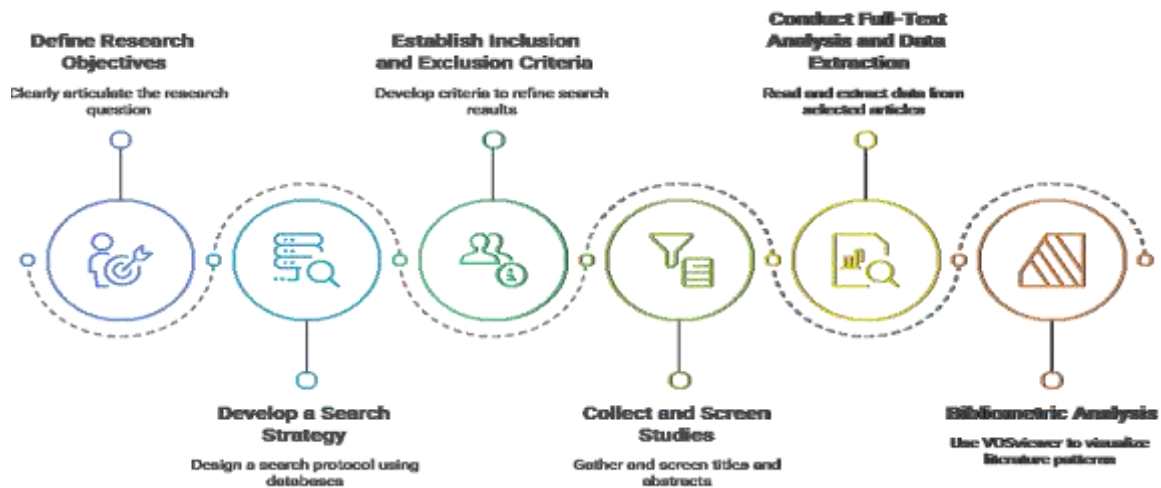


Figure 2: A Systematic Literature Review Process.

4. RESULTS AND DISCUSSIONS

4.1. Descriptive Data

The study analyzed 200 documents from two databases (SCOPUS=174, PubMed=26) published between 1995 and 2025. The analysis unveiled that a total of 766 authors made contributions to the literature in this field, with an approximate average

of 5 co-authors per document. Single-authored documents made up only 15.32% of the total analyzed documents. The study found that international co-authorship accounted for only 54.68% of the analyzed documents, highlighting the need for more international collaboration. These findings have important implications for researchers, policymakers, and practitioners.

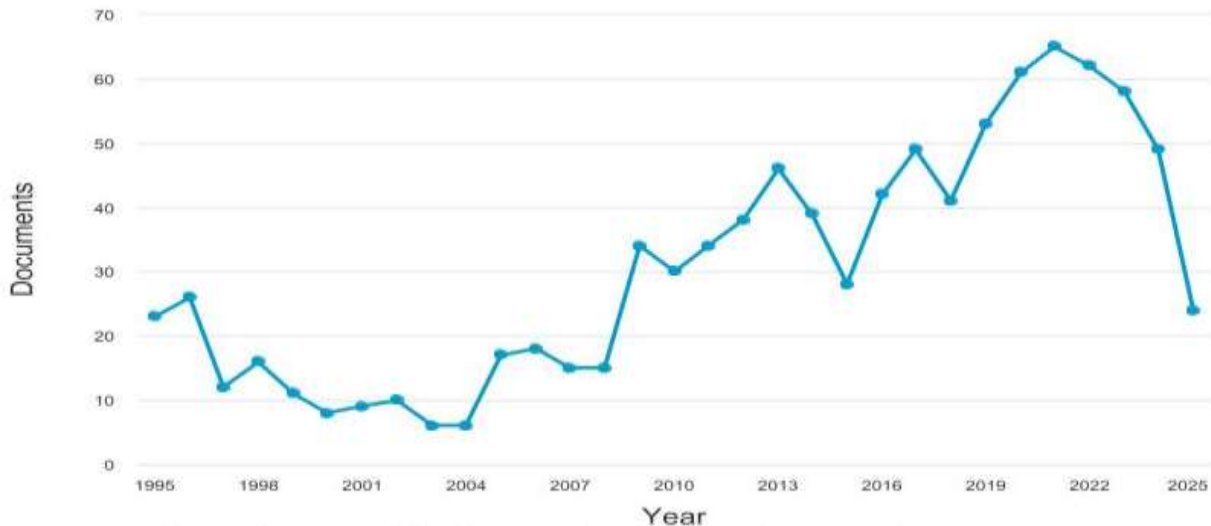


Figure 3: Trend Of Publications (Per Document) Over Time.

The trend, as presented in Figure 3, reveals a compelling temporal evolution of academic interest in waste recycling and its intersections with environment and economic growth between 1995 and 2025. These were grouped as follows:

4.1.1. Foundational Phase (1995–2005)

This decade reflects modest and steady scholarly output, fluctuating between 10 and 30 documents

annually. This could correlate with early awareness-raising efforts around environmental issues, particularly following the 1992 Rio Earth Summit. However, developing countries were still grappling with basic waste management infrastructure, which may explain the limited academic engagement during this period.

4.1.2. Emergence Of Integrated Discourse (2006–

2015)

Around 2010, there's a noticeable uptick in publications. This surge likely aligns with the global policy momentum toward sustainability, notably the adoption of the Millennium Development Goals (MDGs) and growing advocacy for green economy transitions. During this phase, keywords such as "waste-to-energy", "resource efficiency", and "inclusive recycling" began gaining traction as technological innovation in material recovery and policy support frameworks expanded.

4.1.3. Peak Attention and Policy Convergence (2016–2020)

The steep climb peaking around 2020, reaching about 65 documents, suggests a zenith in scholarly engagement. This corresponds with intensified global climate action dialogues, especially post-Paris Agreement (2015), and increased funding for circular economy research. Many developing countries began formalizing national waste strategies around this time, and donor agencies started backing integrated recycling infrastructure. The prevalence of keywords like "circular economy", "climate resilience", and "urban waste systems" likely surged here.

4.1.4. Abrupt Decline (Post-2020)

The sharp decline after 2020, down to approximately 10 documents by 2025, may reflect a number of intersecting shifts as follows:

Pandemic Disruptions: For example, during COVID-19, academic and funding priorities were rerouted, possibly diverting attention away from recycling to public health and emergency response themes.

Keyword Evolution: Researchers may have shifted to newer terms like "material circularity", "extended producer responsibility", or framed recycling within broader systemic terms, causing keyword-based searches to miss these newer articulations.

Technological Maturity: As recycling technologies plateau or integrate into broader sustainability systems, academic focus may have moved toward scalability, finance models, or digital waste tracking topics that may not appear under traditional recycling tags.

4.2. Synthesized Insights Across Scopus and Pubmed Analyses

4.2.1. Evolution Of Research Themes Through Keyword Co-Occurrence

Overlay visualizations from both Scopus and PubMed reveal a cohesive temporal transition in research themes related to waste recycling and sustainability. Earlier studies in both datasets emphasized foundational waste management concepts, evident in dominant keywords such as "landfill", "municipal solid waste", and "resource recovery" (Figure 4), often color-coded blue to indicate pre-2010 focus areas (Tabish et al., 2024).

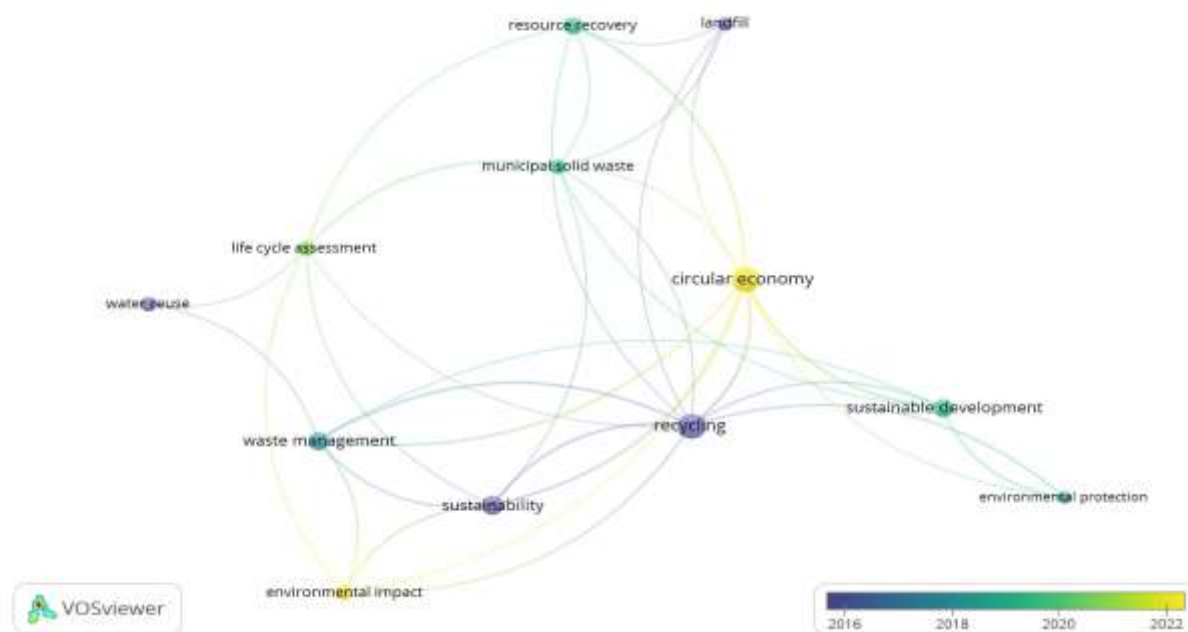


Figure 4: Overlay Visualization of Author Keyword Analysis From SCOPUS.

In contrast, recent literature across both platforms gravitates toward strategic and innovative concepts

such as “circular economy”, “resource recovery”, and “environmental protection” (Figure 5) clustered in yellow, reflecting post-2015 interest. This shift aligns with global sustainability movements and landmark

agreements like the Paris Climate Accord and the SDGs, confirming observations by Gonzalez-Sanchez et al. (2023) regarding the move from a linear to a circular paradigm.

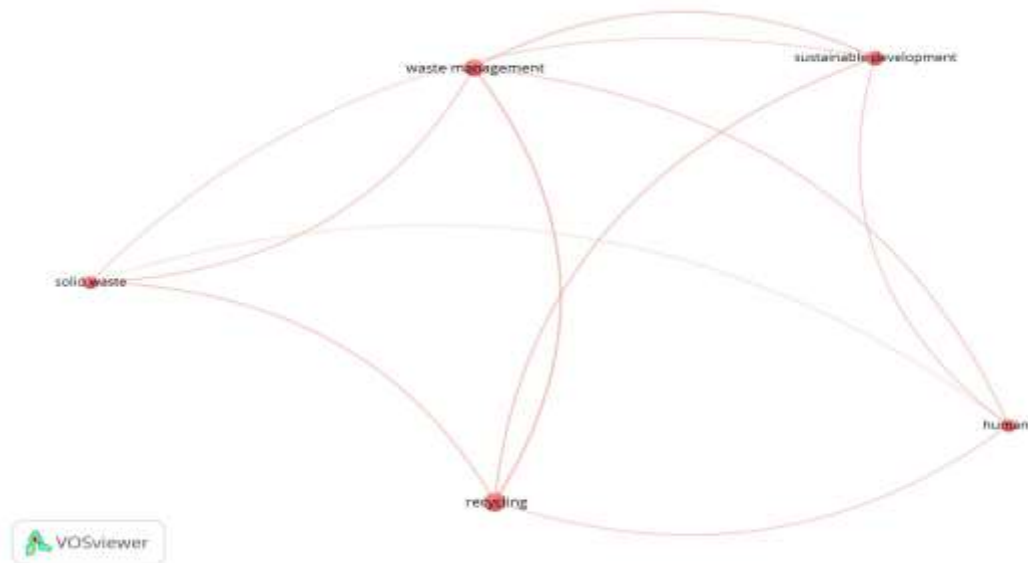


Figure 5: Overlay Visualization of Author Keyword Analysis from Pubmed.

Scopus data emphasized methodological keywords like “life cycle assessment” and “circular economy”, while PubMed captured human-centric terms such as “sustainable development”, “solid waste”, and “humans”. Together, they illustrate a balanced evolution from operational logistics to holistic environmental and socio-economic approaches.

4.2.2. Co-Authorship Networks and Collaboration Intensity

Both databases consistently highlighted the critical role of collaboration in advancing waste recycling research. In Scopus, author density visualizations spotlight prolific scholars who were “Wang Xu” and “Wang Jing” (Figure 5) whose centrality and citation impact suggest influence in shaping interdisciplinary dialogues. Thematic clusters emerged around applied technologies and policy frameworks, often with strong North–South collaborative footprints (Adewole et al., 2019).

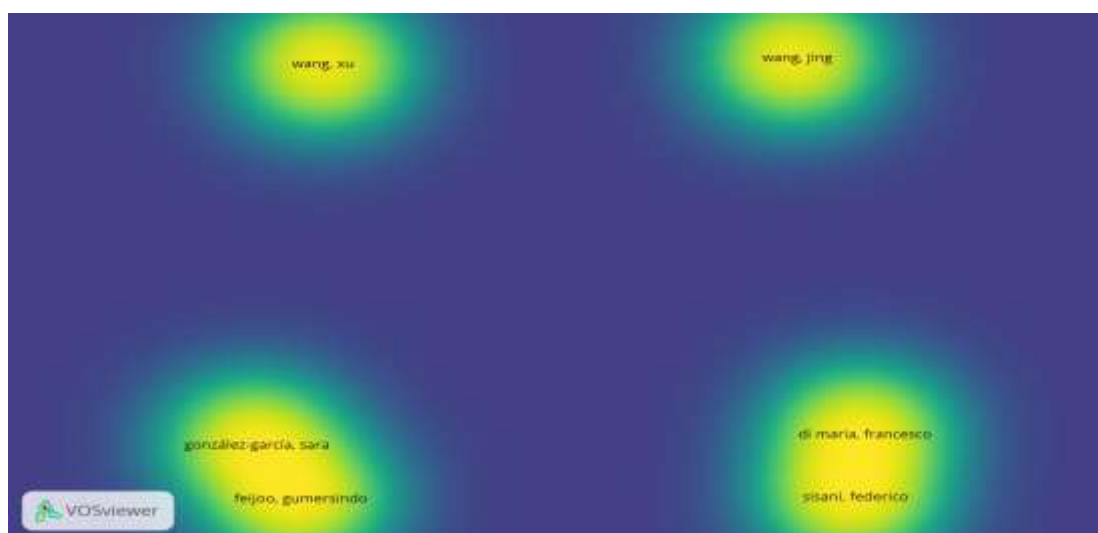


Figure 6: Density Visualization of Authors From SCOPUS.

PubMed, while showcasing fewer documents per author, revealed tightly knit regional teams, notably

from East Asia and Sub-Saharan Africa. Authors like “Liu Taoze” and “Miao Haiying” (Figure 7) exhibited high co-authorship densities, suggesting leadership

in transdisciplinary projects, particularly in environmental health, agricultural systems, and climate resilience.

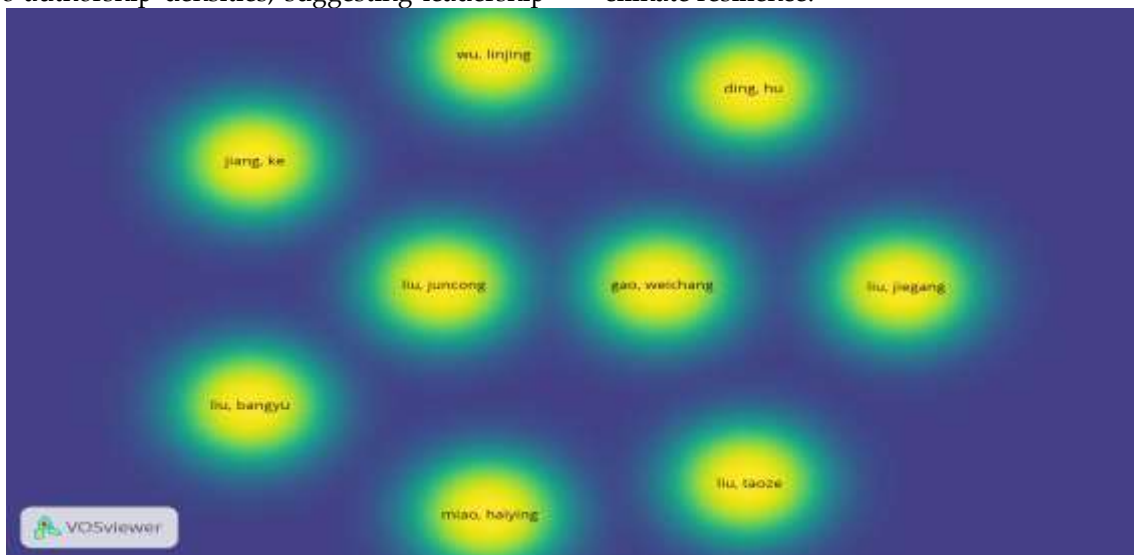


Figure 7: Density Visualization Analysis of Authors from Pubmed.

Across both datasets, a common challenge emerges: despite the presence of cross-border collaboration, most high-density clusters are concentrated in upper-middle-income regions. There is a discernible gap in representation from low-income developing countries, echoing earlier findings by Ogutu & Kathambi (2022) on structural inequities in sustainability research partnerships.

4.2.3. Institutional And Country-Level Linkages

At the institutional level, both databases identified strong collaboration networks, but with varied thematic priorities. Scopus highlighted intergovernmental and policy-oriented institutions, with frequent co-publications from Chinese, American, and European universities (Figure 8). PubMed's overlay visualization emphasized bio-environmental institutes, such as “CIRAD” and “Ecolmvelo” (Figure 9), involved in localized ecological or health-centered research, especially in African contexts.

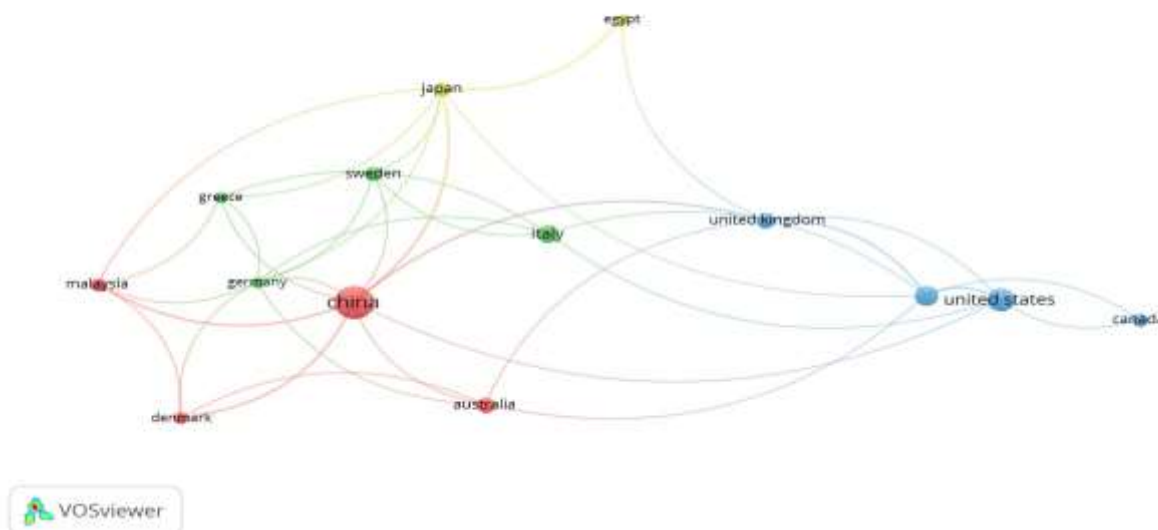


Figure 8: Network Visualization of Countries From SCOPUS.

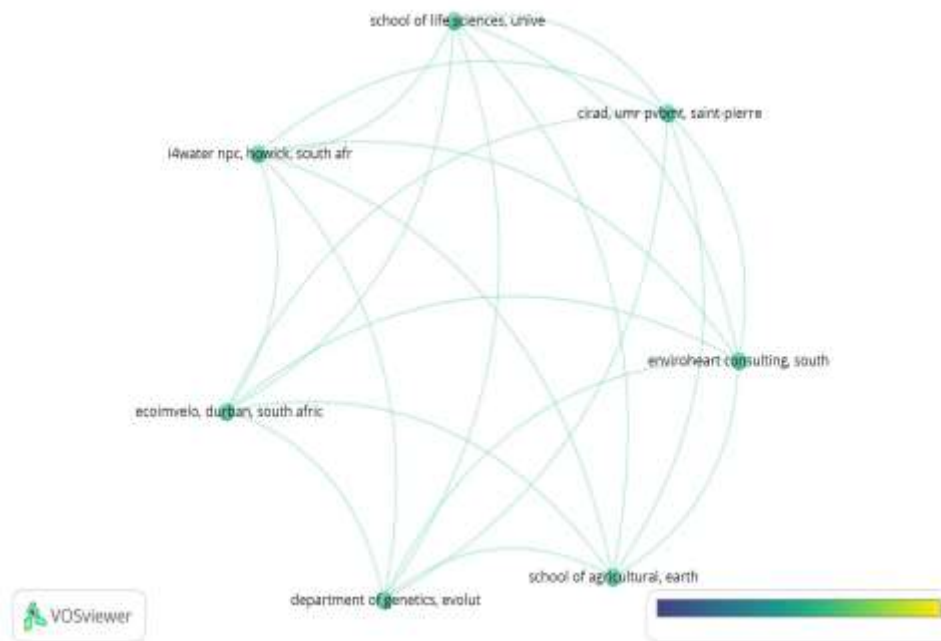


Figure 9: Overlay Visualization for The Organization from Pubmed.

Geographically, both datasets confirmed “China” and “the United States” as dominant research hubs. However, interesting nuances surface, such as “Germany”, “Sweden”, and “Malaysia” played pivotal roles as bridging nodes in Scopus; South African and Indian institutions showed robust regional networking in PubMed, particularly around biodiversity, waste valorization, and rural innovation (Ikelle *et al.*, 2023).

However, in terms of policy implications, there is an indication that the synthesized keyword and co-authorship patterns across databases reveal how academic focus mirrors and, in some cases, anticipates policy movements. From early waste containment efforts to today’s circularity, research intensity and collaboration density track closely with climate negotiations, regional development funding cycles, and the scaling of waste-to-energy technologies.

This alignment reaffirms the critical role of academic networks in guiding evidence-based environmental policy. At the same time, the observed semantic drift, where newer terms may not be captured by legacy keyword strategies, cautions against static bibliometric methodologies and calls for adaptive analytical frameworks.

5. CONTRIBUTION TO THE FIELD

This study offers a multifaceted contribution to the academic and policy landscape of waste recycling

and sustainability, particularly in developing countries. Beyond mapping the dominant themes, it surfaces critical under-researched areas and underutilized collaborations, broadening the scope for future inquiry with the following contribution to knowledge.

5.1. Uncovering Overlooked Research Frontiers

The keyword cluster analysis exposed a concentration on established domains such as “waste management”, “recycling”, and “sustainability”, while revealing the relative absence of emerging or socially grounded terms. Topics such as “informal economy integration”, “waste worker health risks”, “digital waste tracking”, and “climate justice” remain marginal despite their growing relevance in development and policy discourse. These gaps highlight the need for expanded research on the socio-technical and governance dimensions of recycling systems. In particular, the limited presence of “behavioral change”, “gender equity”, and “community-based innovation” suggests that research has yet to fully integrate human-centered design and participatory approaches. These areas hold potential for addressing implementation gaps in recycling programs, especially in underserved regions.

5.2. Revealing Gaps in Global Research Collaboration

Co-authorship analysis indicated that academic

partnerships remain highly concentrated among institutions in the Global North, especially China and the United States. This centralization limits the flow of diverse knowledge and excludes insights from context-specific innovations in regions such as Sub-Saharan Africa, Southeast Asia, and the Pacific Islands. The study thus contributes by highlighting the structural gap in author collaboration, suggesting untapped opportunities for South-South academic partnerships and interdisciplinary consortia. Encouraging cross-regional co-authorship networks can help bridge the knowledge divide and yield more locally adaptive waste management strategies.

5.3. Laying The Groundwork for Future Interdisciplinary Synthesis

Finally, by combining bibliometric insights from both Scopus and PubMed, this work models an integrative approach that merges technological, economic, and socio-environmental perspectives. It establishes a methodological blueprint for future research to incorporate diverse data sources, ensuring that scholarship reflects the full complexity of waste recycling systems. In summary, the study

strengthens the field not only by synthesizing current knowledge but by surfacing neglected themes and underexplored relationships, thereby setting a richer, more inclusive agenda for next-generation research.

5.4. Bibliometrically Derived Challenges and Opportunities in Waste Recycling

Waste recycling has faced several challenges (Fig. 9) and plays a vital role in conserving natural resources, mitigating greenhouse gas emissions, and reducing pollution. Studies have proven that recycling can significantly lower greenhouse gas emissions, with recycling plastic waste reducing emissions by up to 40% (Ayeleru *et al.*, 2020). Similarly, by reusing materials, recycling reduces the need for extracting, processing, and transporting raw materials, thereby minimizing environmental degradation (Adeyemi, 2023). Studies by Ayeleru *et al.* (2020) have also shown that recycling plastic waste can reduce the amount of plastic waste that enters waterways by up to 80%. Another study by Noiki *et al.* (2021) found that composting organic waste can reduce soil pollutants by up to 60%.

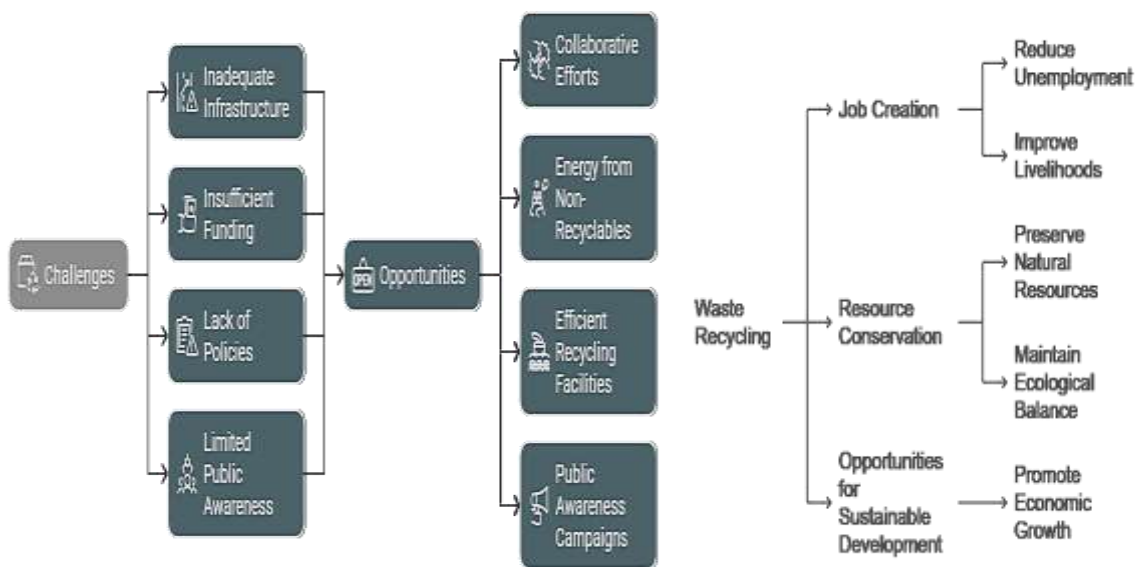


Figure 9: Challenges, Opportunities, And Economic Benefits of Waste Recycling.

6. CONCLUSION

This study underscores the pivotal role of waste recycling in driving environmental sustainability and economic development in developing countries. Recycling offers a critical pathway toward environmental protection by reducing pollution, conserving natural resources, and mitigating the adverse effects of improper waste disposal. Simultaneously, the economic benefits, including job

creation, poverty alleviation, and industrial growth, showcase its potential as a tool for economic empowerment in resource-constrained regions. However, significant challenges such as limited infrastructure, financial constraints, weak regulatory frameworks, and socio-cultural barriers must be addressed to realize the full benefits of recycling. This research identifies gaps and trends in the existing literature by conducting a systematic bibliometric analysis, providing actionable insights for targeted

interventions and future studies. However, to enhance the efficacy and sustainability of waste recycling initiatives in developing countries, the study highlights critical insights with actionable policy implications for developing countries seeking to accelerate sustainable waste recycling practices. Drawing from global patterns in research and practice, the following policy and practical implications were proposed:

6.1. Integrating The Informal Sector into Formal Waste Policy

A key finding from both bibliometric and co-authorship analyses is the growing recognition of informal waste workers as vital actors in the recycling ecosystem. In many developing regions, particularly in Sub-Saharan Africa, Southeast Asia, and Latin America, informal recyclers provide the primary form of material recovery yet operate without legal protection or access to financial and technical resources. Scalable integration can be achieved through formal recognition, fair remuneration, and capacity-building initiatives. Colombia's "Bogotá Recycling Program" offers a successful precedent: by formalizing waste picker cooperatives, the city improved recycling rates while enhancing social inclusion. Similarly, South Africa's *Waste Picker Integration Guidelines*, developed by the Department of Forestry, Fisheries, and the Environment (DFFE), provide a replicable framework for including informal workers in municipal waste strategies.

6.2. Leveraging Public-Private Partnerships (Ppps) To Strengthen Infrastructure

The transition to circular waste systems demands infrastructure investment beyond the scope of many local governments. Policy frameworks should incentivize PPPs to modernize waste collection, processing, and recycling infrastructure. For instance, Vietnam's *National Strategy on Integrated Solid Waste Management* encouraged private-sector participation, leading to the development of energy recovery facilities and sustainable landfill alternatives. Incentives could include tax breaks for green investments, innovation grants for recycling technologies, and outcome-based subsidies linked to environmental performance metrics.

6.3. Embedding Circular Economy Principles in Urban Development

Urban policy should mainstream circularity in housing, industry, and urban planning. Land-use zoning can prioritize recycling hubs, while building codes can require recycled construction materials. The *Amsterdam Circular Strategy 2020–2025* serves as a compelling model for embedding circularity in citywide systems, including procurement, construction, and waste valorization, demonstrating how localized policies can support national environmental objectives.

6.4. Enhancing Data Systems and Research-Policy Linkages

Bibliometric findings revealed the importance of interdisciplinary collaboration and evidence-based strategies. Governments should invest in national data platforms for tracking recycling flows, mapping informal sector contributions, and guiding policy calibration. Strategic partnerships with universities and think tanks can ensure continuous policy learning and innovation. Countries such as India, through its *Swachh Bharat Mission* and *Digital India* initiatives, have demonstrated the impact of linking digital monitoring platforms with local waste governance, especially in urban slums and peri-urban areas.

6.5. Strengthening Climate and Trade Policy Synergies

Finally, recycling policies should be nested within broader climate adaptation and trade strategies. Waste recycling reduces emissions, supports material efficiency, and can position countries to access green finance. Policymakers should align recycling legislation with Nationally Determined Contributions (NDCs), enabling access to climate funding streams. Regional trade agreements can also be leveraged to promote cross-border recycling supply chains and technology transfer. These policy implications collectively underscore that inclusive, data-driven, and locally grounded strategies, particularly those that valorize informal actors, are not only feasible but fundamental to achieving sustainable waste systems in the Global South. Let me know if you'd like help adapting these into a policy brief or grant proposal next.

Data Availability Statement: Data for the study will be made available at the reviewer's request.

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Conflicts Of Interest: There was no conflict of interest in the cause of this research

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