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Exploring the circular economy's promise and challenges in Ghana from company and policy expert interviews

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Abstract

This paper investigates how and why circular economy (CE) practices, particularly inter-firm waste exchange and industrial symbiosis (IS), are emerging yet remain constrained in Ghana, and identifies policy-relevant pathways to scale these practices in support of green industrialization. Empirically, the study is based on qualitative field research combining semi-structured interviews with 23 Ghanaian firms across agriculture, manufacturing, and waste recycling, including three in-depth mini case studies of recycling companies, complemented by four structured interviews with policymakers and sector experts. The findings show that production companies in Ghana already exchange, or have strong potential to exchange, diverse waste streams. Organic agricultural and food-processing waste is reused for compost and biofuel, while plastics, paper, textiles, metals, and sewage sludge are recycled into secondary raw materials, fertilizers, biochar, or irrigation water, linking agriculture, industry, and waste management. However, the scaling of waste exchange is constrained by high transportation and processing costs, especially labor-intensive collection, sorting, and handling, alongside inconsistent waste quality, weak certification systems, competition for valuable waste streams, and inadequate collection and sorting infrastructure. The paper identifies key enablers for scaling IS, including targeted financial incentives focused on labor-intensive processing stages, improved waste management infrastructure, integration of informal waste workers, clear quality standards, and supportive regulatory frameworks. By providing a grounded, country-level analysis, the study contributes empirical evidence to CE and IS scholarship in Sub-Saharan Africa and offers concrete policy insights for aligning waste management, employment creation, and green industrialization in Ghana and comparable contexts.

Highlights

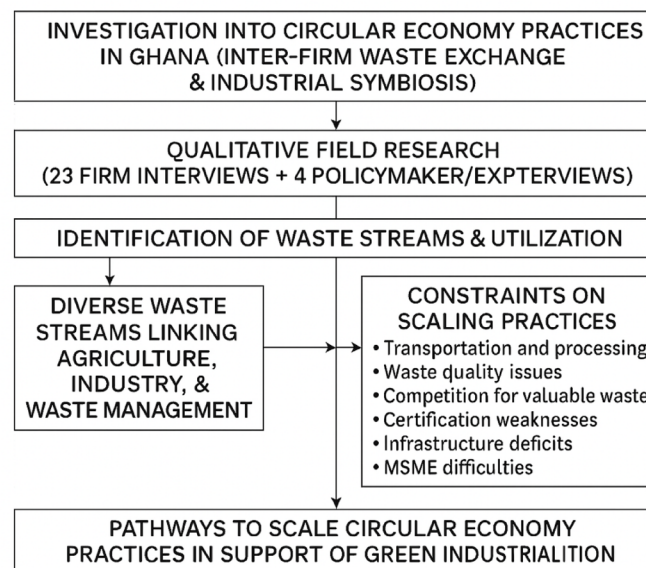
- Implementation of circular economy (CE) practices in Ghana faces major challenges including poor waste quality, high processing costs, weak infrastructure, outdated systems, and inadequate regulations.
- Cultural barriers, such as low public participation in waste segregation, further impede progress.



- Despite these constraints, CE presents strong opportunities for job creation, economic growth, cost reduction, and environmental benefits like reduced emissions and landfill waste.
- Key growth areas include organic waste recycling, textile recycling, and waste-to-energy technologies, especially benefiting agriculture and the textile industry.
- Government initiatives like the National Plastic Management Policy show progress, but stronger enforcement, regulation, and Extended Producer Responsibility (EPR) schemes are needed.
- Public-private collaboration (e.g., ACARP, SSGL, UPPR) is essential to expand CE nationwide.
- Future research should focus on:
 - Developing efficient sorting technologies for diverse waste types.
 - Enhancing public engagement in waste segregation.
 - Assessing the economic feasibility of modernizing waste infrastructure in urban and rural areas.
 - Adapting global best practices for regulation and EPR enforcement.
 - Exploring sector-specific opportunities in textiles, organics, and plastics to strengthen sustainability and economic impact.

Keywords Circular Economy, Industrial Symbiosis, Waste Utilization, Green Industrialization, Sub-Saharan Africa, Ghana

Graphical abstract



1 Introduction

This paper examines how and why circular economy (CE) practices, particularly inter-firm waste exchange, are emerging yet constrained in Ghana, and identifies policy and practical pathways to scale industrial symbiosis (IS) in support of sustainable and green industrialization. As Sub-Saharan Africa (SSA) is projected to undergo profound demographic and economic transformations, with its population expected to significantly increase in the coming decades [1], rapid urbanization and rising demand for goods, services, and infrastructure are anticipated to also increase resource consumption and waste generation, with municipal solid waste in the region forecast to nearly triple by

2050 [2]. Additionally, Hoornweg et al. [3] project that by the end of the century, Sub-Saharan Africa will produce the largest amount of waste in absolute terms. Despite this, the region currently lags behind in waste management practices compared to other ones.

The rapid industrialization and consumption processes in SSA have resulted in notable economic growth. Furthermore, more than half of SSA countries have adopted formal industrial policy documents since 2008 [4]. However, this growth comes with challenges, as SSA is also highly vulnerable to the impacts of climate change, exacerbating environmental concerns [5–7]. Unless the rising population and consumption trends are coupled with increased productivity, particularly in manufacturing and services, SSA is unlikely to manage the environmental, economic, and social pressures effectively. A solution that balances productivity growth with environmental protection through resource efficiency is crucial. Circular economy (CE) principles present a promising approach to addressing these interconnected challenges.

Ghana aims to implement transition to a circular economy [8]. The country has been actively advancing CE and green industrialization initiatives to promote sustainable development, mitigate environmental impact, and foster economic growth. Key research projects and policies underscore the country's commitment to transitioning to a green economy. For instance, the National Green Jobs Strategy (2021–2025) emphasizes job creation through green practices, preparing the workforce to adapt to sustainable industries [9]. The Green Jobs Assessment Model Ghana provides insights into industrial production patterns, aiming to foster green industrialization [10]. Additionally, UNDP's work in establishing a CE framework in Ghana's plastics sector targets reducing plastic waste through recycling and reuse [11].

Ghana has made significant strides in implementing CE practices across various sectors. Footprints Africa's [12] report identified 70 CE initiatives in Africa, with nearly a quarter based in Ghana, showcasing the country's highlighted position on the continent in this regard. Moreover, Ghana's participation in regional programs like Switch Africa Green, supported by the EU, UNEP, UNDP, and UNOPS, has facilitated industrial symbiosis and involved 13 Ghanaian companies [13, 14]. The Revival project fosters upcycling in Ghana's creative sector, supporting both sustainable design and waste reduction [15]. Policies such as the National Plastic Policy and Extended Producer Responsibility (EPR) reflect Ghana's commitment to sustainability [10]. However, challenges like limited financing and infrastructure for recycling hinder progress, particularly in waste management. Research could address these gaps, facilitating the scaling of CE practices in agriculture, housing, and construction, sectors central to Ghana's economy. Furthermore, digitization, urbanization, and tourism can serve as enablers of CE, providing opportunities for innovative solutions and sustainable consumption [16].

Hence, despite growing scholarship on circular economy and industrial symbiosis, there remains a significant research gap in empirically grounded, country-level analyses in Sub-Saharan Africa, in this case in Ghana, that examine how inter-industry waste exchange operates in practice, what economic and institutional barriers constrain it across multiple sectors, and which policy mechanisms can effectively enable its scaling within green industrialization pathways. Based on the above and previous research (see the literature review below), the research puzzle centers around *how and why the implementation of circular economy practices, namely, the utilization of waste materials, is hindered and/or has potential in Ghana.*

Thus, based on semi-structured interviews with local production and recycling companies and structured discussions with policy makers and experts, this paper aims to answer the following research questions:

RQ1 How specific waste materials and by-products are or could be exchanged among industries to promote circular economy in practice?

RQ2 How and why is the adoption of waste exchange and utilization hindered?

RQ3 How can the waste exchange and utilization be facilitated and the given challenges be effectively addressed through policy and practice?

The results show that companies in Ghana already exchange, or have strong potential to exchange, diverse waste streams across industries, supporting circular economy practices. Organic waste from agriculture and food processing is reused for compost and biofuel production, while plastics, paper, textiles, metals, and sewage sludge are recycled into secondary raw materials, fertilizers, biochar, or irrigation water. These exchanges link agriculture, manufacturing and waste management.

However, waste exchange remains constrained by major barriers, including competition for valuable waste streams, high transportation and processing costs (collection, sorting, handling), inconsistent and low-quality materials, weak certification systems, negative public perceptions, and inadequate collection and sorting infrastructure. MSMEs are particularly affected by high capital requirements, technological gaps, unreliable utilities, and limited policy support.

The findings also identify key enablers for scaling waste exchange, notably improved waste management infrastructure, integration of the informal sector, targeted financial incentives specifically targeting the labor-intensive elements of waste utilization like collection, sorting and handling, clear quality standards, and supportive regulatory frameworks. Public–private collaboration, awareness-raising, and dedicated waste exchange platforms are also essential to strengthen industrial symbiosis and advance the circular economy.

The added-value and novelty of the paper are morefold. Unlike broader or Global North-focused studies, it provides a grounded, national perspective on CE initiatives, including policy efforts and sector-specific practices in different industries. Moreover, the study uniquely integrates waste management, employment, and innovation, positioning waste as both a challenge and economic opportunity. Policy-wise, the paper identifies key barriers (e.g., processing costs, financing, infrastructure, regulation) and enabling factors, linking local initiatives with global sustainability goals. Overall, the paper offers practical insights and a relevant model for sustainable industrial development in similar contexts.

Nevertheless, while the research offers valuable insights into Ghana's CE landscape and its potential role in sustainable industrialization, its limitations lie in insufficient stakeholder representation and a need for more rigorous economic and environmental assessment frameworks. Future research could address these gaps through mixed-methods approaches, product-firm-sector-specific examinations, deeper impact evaluations, and comparative analyses with other countries.

The paper is structured as follows. First, a literature review summarizes the concept and principles of circular economy and industrial symbiosis in general, and their Africa-specific implementation potentials and barriers. Then, the methodology, research design and ways of data collection are described in the subsequent section. These are followed by the presentation of research results including the answers to the three research questions. In the subsequent section, a discussion of the findings reflects the relevant literature. Finally, the paper closes with conclusions including policy implications and future research directions.

2 Literature review

This part shortly summarizes the relevant literature for the research in thematic subsections. After presenting a general introduction of the circular economy concept, it continues by examining industrial symbiosis and its typology. This is followed by a review of research on industrial symbiosis in Africa and, finally, a discussion of opportunities and barriers related to green industrialization in the region.

2.1 Circular economy: concept and principles

The concept of the circular economy (CE), first introduced by Stahel and Reday [17], has gained considerable prominence as a framework for sustainable development [18]. Unlike the traditional linear economy, commonly described by the “take, make, use, dispose” model [19], the circular economy seeks to minimize waste by designing systems in which the output of one process becomes the input of another. This regenerative model emphasizes maintaining the value of products, materials, and resources within the economy for as long as possible, thereby promoting sustainable resource management.

CE strategies are typically grouped into three main categories: slowing (e.g., reuse), closing (e.g., recycling), and narrowing (e.g., using fewer materials) of resource loops [19, 20]. To operate these strategies, the CE framework outlines six core actions: take, make/transform, distribute, use, recover, and industrial symbiosis (IS) [21, 22]. These provide a more actionable and systemic roadmap for sustainability than broader sustainable development paradigms [23].

The literature emphasizes the multifaceted benefits of CE, including improved resource efficiency, reduced environmental degradation, and new economic opportunities through innovative business models [18]. These benefits are particularly relevant for Sub-Saharan Africa, where many countries are pursuing industrialization as a pathway to middle-income status [24] and increasingly recognize the potential of embedding circular and green principles early in industrial policy design [25, 26]. Business strategies such as product-service systems, sharing platforms, and closed-loop supply chains are therefore increasingly framed as instruments not only for environmental sustainability but also for competitiveness in late-industrializing economies.

Blomsma and Brennan [27] trace the evolution of CE from a theoretical construct to a more practice-oriented framework, emphasizing the importance of integration into core business strategies. The Ellen MacArthur Foundation [28] has been instrumental in globalizing CE discourse by providing implementation frameworks, industry case studies, and policy guidance. Nonetheless, CE is not without limitations. Kirchherr et al. [29] highlight inconsistencies across more than 100 CE definitions, potentially constraining implementation, while Korhonen et al. [30] warn against “circular washing,” where CE

rhetoric is adopted without substantive operational change. These critiques underscore the need for standardized definitions, robust metrics, and enabling policy frameworks.

2.2 Industrial symbiosis, a core component of CE, and its types

Chertow [31] defines IS as a process in which the waste or by-product of one firm becomes the input of another, improving resource efficiency while reducing disposal costs and environmental impacts. This logic directly supports CE objectives by enabling closed-loop production systems. Lybaek et al. [32] further conceptualize IS as a collective effort among independent industries to improve environmental performance and competitiveness, emphasizing the importance of policy support and institutional coordination. IS configurations vary by scale and governance structure. Neves et al. [33] distinguish micro-, meso-, and macro-level symbiosis, while Henriques et al. [34] identify internal, external, eco-industrial park (EIP), and urban IS forms. Chertow [35] additionally differentiates between self-organized, facilitated, and planned symbiosis.

The Kalundborg Eco-Industrial Park in Denmark remains the most prominent example of planned IS, demonstrating how intentional design, proximity, and cooperation can lead to long-term resource efficiency gains [36, 37]. More recent international cases, such as Shenzhen, show how integrated planning, stakeholder engagement, and centralized coordination can further enhance resource efficiency and system performance [38]. Across contexts, however, successful IS depends not only on technical feasibility but also on trust, data-sharing, intermediary institutions, and enabling governance arrangements [39–42].

2.3 Industrial symbiosis in Africa

Africa presents a distinctive context for CE and IS adoption. Lemille [43] argues that the continent holds structural advantages, including labor-intensive economic structures, strong informal-sector linkages, and collaborative cultural practices rooted in resource scarcity. Combined with Africa's relatively low ecological footprint, these factors create opportunities to leapfrog linear development pathways and adopt circular models from the outset.

Nevertheless, empirical research on IS in Sub-Saharan Africa remains limited. Early contributions include Brent et al. [44] on eco-industrial parks in South Africa and Mbuligwe and Kaseva [45] on industrial waste recovery in Tanzania. Subsequent studies examined IS potential in Mauritius [46], Tanzania's sugar industry [47], Kenyan industrial parks [48], Ethiopian garment parks [49], and multi-country assessments of regulatory and material-flow constraints [41].

Recent scholarship indicates a gradual expansion of IS-related research in Africa, including case studies from Egypt, Nigeria, Ethiopia, Kenya, and South Africa, as well as regional reviews and policy-oriented analyses advocating stronger governmental involvement [41, 50–56]. Comparative work by Lippi, Evola and Vesce [42] synthesizes African and global experiences, highlighting the importance of intermediary organizations, digital waste-matching platforms, and park-level financing mechanisms for scaling IS in low-resource settings. These findings echo evidence that small and medium-sized enterprises can operate more sustainably when embedded in industrial parks with coordinated support structures [55].

2.4 Opportunities and barriers in green industrialization in Africa

Most Sub-Saharan African countries are actively pursuing industrialization as a pathway to economic transformation and middle-income status [24]. Since 2008, more than half of African countries have adopted formal industrial policies [4], including Ghana. These initiatives aim to promote value addition, industrial diversification, and competitiveness, while creating a strategic window to embed sustainability, CE, and green growth principles early in development trajectories [25, 26].

Africa's rapid urbanization and industrial growth, however, have historically followed resource- and carbon-intensive pathways [57, 58]. The transition to green industrialization therefore represents an opportunity for the Global South to experiment with alternative development models aligned with global climate and sustainability goals [59, 60]. Leveraging abundant renewable energy resources could generate green jobs, foster innovation, enhance climate resilience, and improve competitiveness in sustainability-oriented global markets [61–63]. This is particularly relevant for addressing high youth unemployment through employment in renewable energy, waste management, and sustainable agriculture [64].

Despite these opportunities, significant barriers remain. Access to finance for green technologies is persistently constrained [65, 66], while infrastructure deficits and unreliable electricity supply hinder cleaner production and industrial upgrading [67–69]. Macroeconomic instability and rising debt burdens further increase investment risks [70]. Policy and regulatory inconsistencies, skills shortages, and governance challenges continue to limit CE and IS adoption [71–75].

These challenges reflect the broader “holy trinity of development,” encompassing environmental protection, economic growth, and social equity [76]. As Swilling et al. [77] and Ramos-Mejía et al. [78] argue, sustainability transitions in Africa must reconcile environmental objectives with poverty reduction, social justice, and local development. Recent studies therefore emphasize context-sensitive industrial policy, blended finance, and firm-level fiscal instruments as key enablers of CE and IS implementation [26, 40, 79].

Hence, research on green industrialization, and especially, the circular economy (CE) and industrial symbiosis (IS) in Sub-Saharan Africa (SSA) remains limited, with most studies concentrated in a few countries like South Africa, Tanzania, Kenya, Nigeria and Mauritius. There is a significant gap in understanding IS opportunities across a broader range of SSA countries, particularly in smaller or emerging industries not yet linked to established symbiotic networks. Additionally, existing research tends to focus on specific sectors—such as textiles, sugar, and oil refining—leaving other industrial areas underexplored. Expanding research into countries like Nigeria, Ghana, and Uganda, and into less-studied sectors, could offer valuable insights into how waste and by-product exchange can be scaled across the region.

Beyond identifying existing practices, more research is needed to support the formation of new IS networks by examining the economic and regulatory factors that enable or hinder waste material exchange. This includes a closer look at cost components in waste supply and utilization, as well as the role of government policy, infrastructure, and financial incentives. Equally important is understanding the types, volumes, and characteristics of industrial waste streams in SSA, to better facilitate cross-industry partnerships. Long-term studies are also necessary to evaluate the economic, environmental,

and social sustainability of IS practices, including community engagement and cultural perceptions of waste-based products. Addressing these gaps will be essential for promoting broader CE adoption and ensuring its relevance and effectiveness in the SSA context.

3 Methodology

3.1 Research design and approach

Waste exchange and utilization research remains underrepresented in Sub-Saharan Africa (SSA), with a limited number of published studies and the absence of comprehensive databases. More broadly, the CE concept is still in an early stage of development in the region. Given this context, the present study addresses an underexplored research field and therefore adopts an exploratory research design, grounded in fundamental research and grounded theory [80]. The exploratory nature of the study is appropriate for generating context-sensitive insights where existing theory and empirical evidence are limited.

3.2 Case study strategy

This study applies a case study approach to investigate waste utilization and industrial symbiosis (IS) practices in Ghana. Following Gerring [81, p. 342], a case study is understood as “an intensive study of a single unit for the purpose of understanding a larger class of (similar) units.” The research combines multiple firm-level cases with expert and policymaker perspectives to capture both micro-level practices and macro-level institutional conditions related to CE, cleaner production, and green industrialization.

3.3 Data collection methods

The study draws on semi-structured interviews and structured discussions, which are particularly suitable for investigating complex and underexplored phenomena. Semi-structured interviews enable systematic comparison across respondents while allowing probing and clarification, thereby enhancing depth and construct validity [82, 83]. Structured discussions complement this approach by capturing tacit knowledge, contextual nuances, and emergent insights that rigid instruments often overlook, especially in socio-technical and institutional contexts [84]. These methods are well suited to evolving systems such as CE, where practices and inter-organizational relationships remain heterogeneous and insufficiently theorized [85].

3.4 Study area and sampling strategy

Data collection was conducted between September 2023 and April 2024 through four field research trips in the Greater Accra region, supported by a local research assistant (see Acknowledgements). The region was selected for three main reasons. First, the identification of potential respondent companies relied on recommendations from the Ghana National Cleaner Production Centre, particularly firms that participated in the Switch Africa Green program [13, 14], most of which are located in Greater Accra. Additional respondents were identified using a snowball sampling method, ensuring the inclusion of both waste-using and non-using firms from different industries. Second, national-level policy-making bodies and experts relevant to CE and IS are predominantly based in this region. Third, Greater Accra holds a leading position in industrial

output and innovation, making it a practical and cost-effective location for fieldwork due to the high density of potential respondents.

3.5 Interview process and ethical considerations

Pre-selected companies and institutions were initially contacted via phone, WhatsApp, or e-mail. Upon confirmation of availability, face-to-face interviews were arranged. Respondents received both written and verbal information about the research objectives and were informed that participation was voluntary, that they could decline to answer specific questions, and that they could terminate the interview at any time without explanation. All participants provided informed consent prior to participation. Interviews lasted approximately 30–40 min on average and were, where possible, complemented by site visits to observe production processes and waste management practices. A full list of respondents and interview dates is provided in Appendix 1.

3.6 Firm-level case studies

Semi-structured interviews were conducted with twenty-three individual production and waste recycling companies, including three highlighted mini case studies: Accra Compost and Recycling Plant, Sewerage Systems Ghana Limited, and Universal Plastic Products and Recycling Limited. These interviews were complemented by on-site observations. The interview questionnaires were informed by established industrial symbiosis literature and research [33, 86–89] and tailored to the researched context.

3.7 Analytical framework for industrial symbiosis

The interview design was guided by the IS literature on drivers and barriers. Neves et al. [33] identify key drivers such as awareness of environmental, economic, and social benefits; supportive legislation; existing IS examples; presence of facilitators; communication; geographical proximity; and stakeholder involvement. Common barriers include inadequate regulation, limited knowledge of IS practices, lack of trust, resistance to data sharing, uncertainty about profitability, high costs and risks, low virgin material prices, and economic instability. These factors informed the thematic structure of the interview questions.

Additionally, cost–benefit models developed by Boons et al. [89] and Bertani et al. [87] were used to conceptualize the economic conditions under which firms engage in IS. For suppliers, participation depends on whether the net cost of selling waste—comprising storage costs (c_{st}) and pre-processing or handling costs (c_p), minus the waste selling price (p_w)—is lower than the cost of landfill disposal, including landfill taxes (l) and transportation costs (c_{trl}).¹ For buyers, IS remains viable as long as the combined cost of acquiring waste materials ($p_w + c_{trw}$) does not exceed the cost of purchasing and transporting virgin materials ($p_v + c_{trv}$).² Subsidies may further influence this balance by incentivizing waste-based inputs. These cost considerations formed a core component of the firm-level questionnaires, supplemented by additional items such as sorting, treatment, labor, and certification costs. Following HAEE [86], the questionnaire comprised four main sections, distinguishing between waste users and non-users, as well as waste suppliers and non-suppliers.

¹ This condition is expressed as: $c_{st} + c_p - p_w \leq l + c_{trl}$.

² This condition is expressed as: $p_w + c_{trw} \leq p_v + c_{trv}$.

3.8 Expert and policymaker interviews

Structured discussions were also conducted with four experts and policymakers representing the Ministry of Environment, Science, Technology and Innovation (MESTI), Africa Environmental Sanitation Consult, the Association of Ghana Industries, and the Ghana National Cleaner Production Centre. These discussions focused on five thematic areas: green industrial policy, cleaner production, resource efficiency, circular economy, and waste management.

3.9 Data analysis

All interviews were audio-recorded, transcribed, and securely stored, with recordings deleted after transcription. Data analysis followed a thematic coding approach using an inductive–deductive strategy [90]. Initial coding categories were derived deductively from the literature—such as barriers to industrial symbiosis, waste valorization practices, and collaboration mechanisms—while additional themes were generated inductively based on recurrent patterns, unexpected insights, and context-specific dynamics emerging from the interviews.

3.9.1 Data and sample

Most data were received in verbal text formats, as they referred to views, impressions, experiences and practices. This way, a descriptive analysis of qualitative aspects hindering or fostering waste exchange was possible. In some cases, respondents were asked to put in ascending order certain cost items and reasons for waste (not-)using and waste (not-)selling. As the sensitivity of financial information from companies usually constrains the reception of accurate data within the framework of academic research, and in most cases it is hard even for the respondents themselves to exactly differentiate among certain aspects, this way of data gathering enabled the analysis to show priority orders and highlights among decisive factors of waste exchange.

The sample of 23 companies is divided into four categories: Waste Users, Waste not Users, Waste Suppliers, and Waste not Suppliers. A company can fall in one or two of these categories, as in both cases of waste usage or supply the position is binary: yes or no. Beyond this, their operation can be relevant for multiple waste materials. Therefore, a company can be a respondent for different categories and materials. To further complicate the case, some companies answered as waste users in the case of certain materials, and as waste suppliers in the case of other materials, and vice versa. Not all companies answered the questionnaire parts to all categories relevant for their situation and not all of them responded to each question. This way the 23 companies represent 33 respondents in the study (see Table 1).

Among the respondents, 17 are Waste Users, who utilize a variety of waste materials, including organic (5), plastics (4), paper (2), wood (1), metals (1), textiles (1), and

Table 1 The categorization of companies as respondents according to waste exchange role and industry (materials)

	Organic	Wood	Plastics	Metals	Paper	Textiles	Waste management	
<i>23 companies in 33 respondent roles</i>								
Waste User	5	1	4	1	2	1	3	17
Waste not User	3		2	1	1			6
Waste Supplier	2			1	3		1	6
Waste not Supplier	1		2			1		4

waste management services (3). The 6 Waste not Users mainly work with organic waste (3), plastics (2), and metals (1) and paper (1). On the other hand, the 6 Waste Suppliers primarily supply paper (3), organic waste (2), metals (1), and materials falling in each of these above categories after waste sorting and treatment (1). Finally, 4 respondents fall into the Waste not Supplier category, mostly supplying plastics (2), along with textiles (1) and organic materials (1).

4 Results

In this part, the results of the research are shortly summarized, starting with the company interviews. Then, three local waste recycling firms and their challenges and potentials are presented. Finally, the learnings from the four expert and policy maker interviews are described. These are followed by the answers to the research questions and a table summarizing the potentials and challenges of the circular economy in Ghana.

4.1 Company interviews

A variety of waste materials, including wood pallets, paper, plastics (PET, PS, LDP, PP, HD), textiles, food waste, metals, and organic by-products like coconut and cocoa, are recycled into paper, biofuel, compost, and repurposed plastic products. Sewage is also treated for energy recovery, supporting circular economy goals. These materials come from diverse sources such as Tema Port, industrial areas, packaging firms, schools, vendors, households, and informal collectors. Despite a broad supply chain, rising demand and inconsistent material quality challenge businesses, making it hard to standardize operations. The cost of acquiring, transporting, and processing waste is increasing, especially with competition and logistical hurdles. Pre-treatment and handling costs further complicate operations.

Motivations for using waste include cost savings, reduced environmental impact, lower carbon emissions, and landfill diversion. Many companies also see recycling as a business opportunity and a way to create jobs, support communities, and contribute to sustainability.

The cost structure for businesses using waste materials is influenced by various factors (see Fig. 1). Transportation is the highest cost in waste management, as materials must be moved from collection points to processing sites. Additional key expenses include the varying cost of waste based on type and quality, as well as costs for pre-processing, treatment, and handling. Sorting, storage, and electricity for machinery add further operational burdens. Though smaller, quality control remains important to ensure materials meet recycling standards.

To support the effective use of waste materials, businesses request VAT reductions, tax relief on machinery, and subsidies for organic fertilizers to promote sustainability over chemical alternatives. High costs of imported materials, driven by taxes and fuel prices, make waste materials more competitive, highlighting the need for financial incentives to improve cost-effectiveness. Risks of using waste materials include potential business failure due to poor-quality inputs, which can cause production issues. There are also concerns about food contamination and environmental pollution if waste isn't properly processed, requiring careful management. Despite these challenges, using waste materials offers significant benefits, such as access to alternative energy, reduced production costs, and environmental impact.

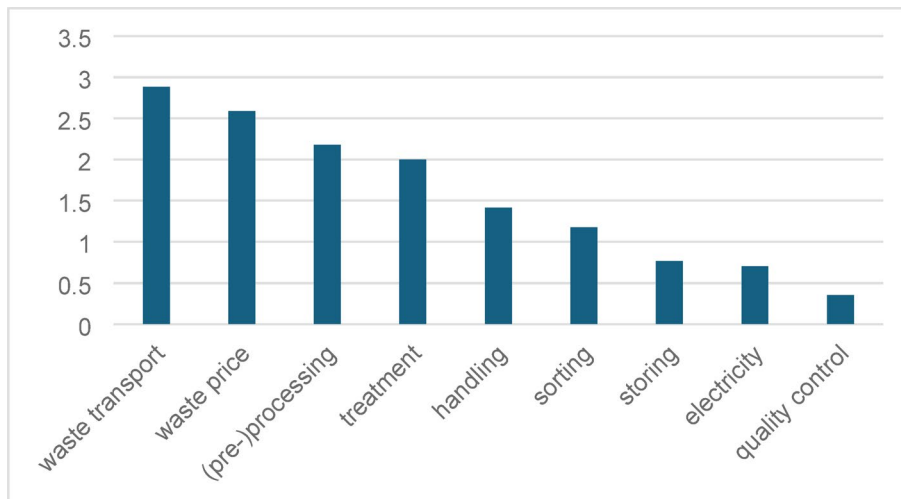


Fig. 1 Relative significance of cost items in waste usage (based on the weighted average of 16 Waste User respondents' answers, where 5 is the most significant and 1 is the least significant). *Source:* Author's construction

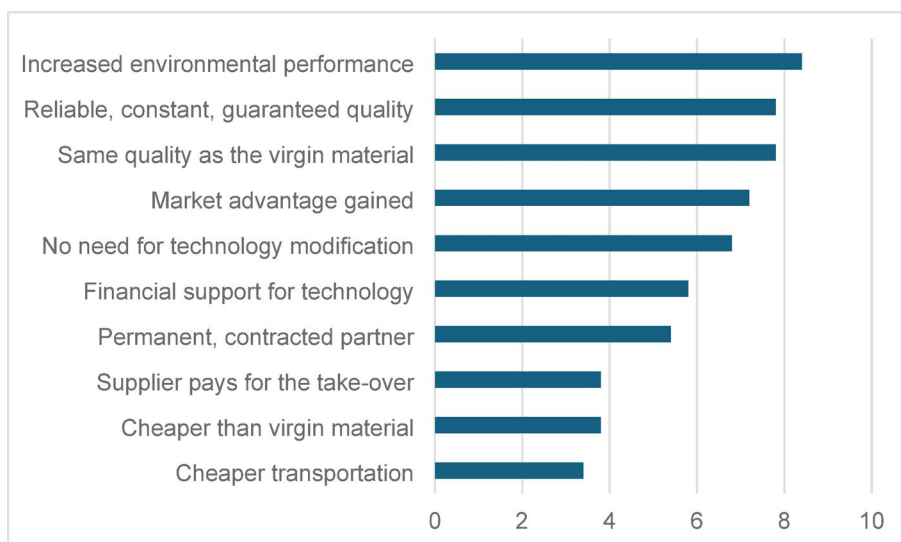


Fig. 2 Conditions for starting to use waste materials (based on the weighted average of 5 Waste not Users' answers, where 10 is the most significant and 1 is the least significant condition). *Source:* Author's construction

For businesses not using waste, responses regarding potential costs for an imaginary case of starting to use waste materials vary, with some seeing increases and others seeing no change, indicating a largely unstable cost environment that requires further industry support. For the successful inclusion of waste materials in production, companies have outlined several key conditions (see Fig. 2). Waste materials must meet reliable, consistent quality standards, ideally matching or exceeding the quality of primary materials they replace. Companies are more inclined to use waste if it offers a competitive advantage and requires minimal technological changes. If modifications are needed, financial support is essential. Companies also prefer when suppliers cover processing costs and waste materials are cheaper than primary materials. Lower transportation costs would further encourage waste usage.

For businesses not yet using waste materials, key needs include free waste treatment, tax relief, sustainability incentives, and local standards for recycled products. Ensuring recycled materials meet quality standards is crucial, and higher taxes on imported virgin materials could motivate businesses to adopt waste materials.

Waste suppliers, including those providing plastics, paper, and materials from dairy or culinary industries, are driven by income generation, cost savings, and environmental goals. Recycling helps reduce waste and avoid landfills. Businesses benefit from cost savings by avoiding landfill fees and lowering transportation costs, with transport and sorting being the highest expenses in the waste supply chain. Storing costs, while necessary, tend to be the least significant (see Fig. 3).

In conclusion, while using waste materials offers environmental and economic benefits, businesses face challenges in logistics, quality control, and financial costs. Support measures, such as tax reliefs, financial incentives, and improved waste processing infrastructure, are crucial to facilitating the wider adoption of waste materials and advancing sustainability efforts.

4.2 Waste recycling companies

According to Oteng-Ababio's [91] recent study on Accra's solid waste management, the capital city generates about 2,800 metric tons of solid waste daily, of which only 70% is collected, with informal providers handling over half of waste collection; the waste stream is dominated by organic materials (about 54%, or 69% excluding soil and dust), followed by plastics and paper, and per capita waste generation is highest in high-income areas and lowest in low-income areas.

The three waste recycling companies included in this study, ACARP, SSGL, and UPPR, each contribute uniquely to waste management and environmental sustainability in Ghana, more particularly in Accra, tackling different aspects of waste treatment and recycling, as shortly presented in the following.

The Accra Compost and Recycling Plant (ACARP), located in Adjen Kotoku, is West Africa's first advanced waste sorting and composting facility. Designed to tackle Accra's

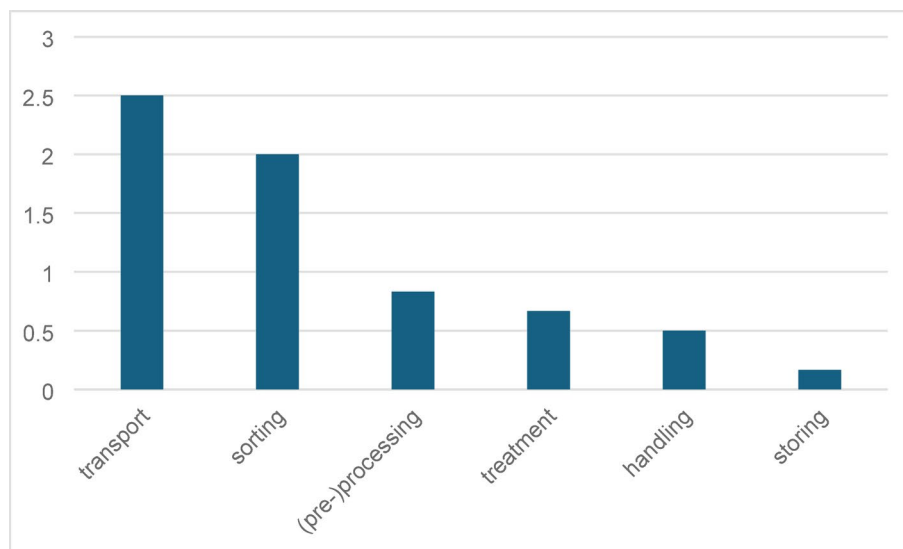


Fig. 3 Relative significance of cost items in waste supply (based on the weighted average of 6 Waste Suppliers' answers, where 5 is the most significant and 1 is the least significant), *Source:* Author's construction

growing waste management challenges, ACARP processes 600 tons of municipal solid waste (MSW) daily (of the 2,800 metric tons overall in Accra, see above). Using a combination of manual sorting, Chinese-German technology, and mechanical systems, the plant separates organic from inorganic materials. Organic waste is then composted to produce nutrient-rich compost for agriculture, while recyclables are recovered for reuse. ACARP also produces Refuse Derived Fuel (RDF) from non-degradable waste for use in energy-intensive industries. The facility's goal is to reduce landfill reliance, cut pollution, and support recycling practices in Accra and beyond.

ACARP aims to expand its operations with plans for new plants focusing on plastic processing, medical waste treatment, and fecal sludge management, while also extending its reach to Kumasi, the second biggest city of Ghana. However, challenges remain, particularly in changing public attitudes toward waste disposal, as a significant portion of waste is still improperly disposed of, exacerbating pollution and health risks. ACARP's operational costs are largely driven by sorting waste materials into different categories, as it requires significant labor and resources. Pre-processing, which includes cleaning, shredding, and preparing waste for further recycling, also incurs substantial costs. Additionally, in-house transportation adds to the operational expenses as waste materials need to be moved within the facility. The physical handling of materials, such as loading and unloading, is another contributor to costs.

Sewerage Systems Ghana Limited (SSGL), established in 2012, focuses on providing efficient liquid waste treatment solutions. The company has built two fecal treatment plants and rehabilitated a third, contributing significantly to the country's sewage treatment capacity. SSGL experiments in transforming sewage into four main products: fish food, biochar, organic fertilizer, and irrigation water. Biochar, despite its potential, faces challenges due to public perception and technical complexities in its production, including the careful management of carbonization processes. Organic fertilizer, especially after the surge in demand triggered by rising chemical fertilizer prices, is considered the company's most promising product, although scaling production requires larger facilities and certification. SSGL is also exploring the use of biogas in biochar production to reduce reliance on traditional energy sources.

Irrigation water, another promising byproduct, faces logistical challenges in transportation to farms. The company is also testing fish food, formulated from palm kernel cake and soybeans, for use in aquaculture. Despite challenges in production and certification, SSGL's commitment to turning sewage into valuable products makes it a leader in sustainable waste management solutions. The company plans to expand further across Africa, replicating its success in Ghana to improve sewage treatment and waste management on the continent.

Universal Plastic Products and Recycling Limited (UPPR), a subsidiary of the Jospong Group of Companies, was founded in 2013. The company processes the waste plastics and convert them to final useful products, such as plastic bins, chairs and other tools, and it also serves other plastic production companies with recycled raw materials, such as pellets. UPPR operates several recycling plants across Ghana, with a focus on reducing plastic pollution by collecting used waste bins, sachets, and other plastic items for recycling.

However, UPPR faces challenges with the quality of received waste materials, as much of it is mixed or contaminated, complicating the recycling process. Production costs are

also affected by fluctuations in exchange rates, rising fuel prices, and taxes. Despite these obstacles, UPPR continues to improve its recycling efficiency and work towards sustainable plastic waste management. Its ongoing efforts to reduce plastic pollution, create jobs, and promote environmental sustainability are helping to mitigate the environmental impact of plastic waste in Ghana and West Africa.

Together, these companies are making significant strides in improving waste management in Ghana through innovative recycling and treatment technologies, while navigating the challenges of cost, public behavior, and resource limitations.

4.3 Expert interviews

Expert interviews on Ghana's green transition highlight key challenges and opportunities in sectors such as plastics, textiles, waste management, industrialization, and cleaner production. Plastic waste is a major concern, with Ghana generating 1 million tons annually, of which only 6% is recycled, as stated by one of the interviewed experts. The government's National Plastic Management Policy and the Extended Producer Responsibility scheme aim to address this, supported by initiatives like the UNIDO-led pilot project.

Textile waste is another challenge, with Ghana importing USD 420 million worth of second-hand textiles, 45% of which ends up in landfills, as one of the respondents highlighted. Funding from the African Development Bank and the Development Bank of Ghana is supporting infrastructure improvements, including a large sorting center and potential fiber-to-fiber recycling.

The food system holds untapped potential for sustainability, but waste management remains underfunded, particularly in the informal sector, which is crucial for waste collection. Private sector involvement is vital to meet demand in waste management. Ghana's 2010 Sanitation Policy introduced circular economy principles, yet less than 10% of waste is recycled, and many materials, such as organic waste, remain underutilized. Investment in infrastructure and regulatory reforms, like the removal of fossil fuel subsidies, are necessary for better waste management.

Ghana faces industrialization hurdles such as high interest rates, limited infrastructure, and unreliable utilities. However, initiatives like the "1 District, 1 Factory" (1D1F) program and digitalization policies present opportunities. The lack of a comprehensive carbon tax and clear green industrial policies remains a barrier.

MSMEs face challenges adopting cleaner production, with resistance to change and lack of funding. However, improving locally fabricated equipment and offering incentives like tax relief could support this transition. Waste management in plastics and textiles holds potential, but challenges like infrastructure, financial viability, and enforcement remain. To address these, stronger support, incentives, and technical capacity building are essential for Ghana's shift toward a circular economy.

4.4 Answers to the research questions

RQ1 How specific waste materials and by-products are or could be exchanged among industries to promote circular economy in practice?

To promote a circular economy, various waste materials are exchanged among industries to reduce environmental impact. Organic waste, such as coconut waste, bamboo, cocoa by-products, and food scraps like cereals and fruits, are recycled into compost or

used for biofuel production. These materials are sourced from farms, food industries, and vendors. Plastics, including PET, PS, and HD, are repurposed into new products, sourced from packaging companies, waste collectors, and plastic industries. Waste paper from offices and schools is recycled into new paper products, reducing waste and promoting reuse.

Textiles, from second-hand shops and clothing industries, are recycled or repurposed into new fabrics. Metals, collected from scrap and industrial waste, are recycled for industrial use or construction projects. Food waste, such as fruits and vegetables, is converted into compost or biofuel, supporting agricultural sustainability. Liquid waste, like sewage, is treated and transformed into biochar, organic fertilizers, or irrigation water, contributing to energy recovery and sustainable waste treatment.

SQ2 How and why is the adoption of waste exchange and utilization hindered?

Several barriers hinder the adoption of waste exchange and utilization. One major challenge is resource competition, as industries vie for the same waste materials, driving up prices and limiting availability. Transportation issues also complicate sourcing and delivery. Cost remains a significant barrier, especially for recycling and waste management companies, with rising material, treatment, fuel, and tax costs.

Another challenge is the quality of waste, particularly mixed or low-quality materials, which complicate recycling processes and increase environmental risks. The lack of certification for products like biochar and negative public perception further limits adoption. Inadequate infrastructure for collection, sorting, and recycling, coupled with underfunded informal waste management, hampers progress. There is also a lack of regulatory frameworks and financial incentives to support recycling networks, despite calls for tax reliefs and subsidized fertilizers.

High capital costs, technological gaps, and unreliable utilities pose barriers for MSMEs, which also face resistance to change and the use of inefficient equipment. Overcoming these barriers requires incentives, technical training, better infrastructure, and stronger market demand for recycled products.

SQ3 How can the waste exchange and utilization be facilitated and the given challenges be effectively addressed through policy and practice?

To promote waste exchanges, several mechanisms can be implemented. Improving waste collection, sorting, and infrastructure, especially within the informal sector, is key. The government should invest in better waste management and integrate informal workers into formal systems by providing funding, tools, and training.

Financial incentives like tax relief, subsidized fertilizers, and local standards for recycled products can support businesses engaging in recycling or circular economy practices. Low-interest loans and grants can help offset high costs for adopting cleaner technologies.

Public awareness campaigns can address the negative perception of waste-derived products like biochar, promoting the environmental benefits of recycling. Clear regulatory frameworks, such as mandatory recycling quotas or incentives for using recycled materials, should be introduced. Expanding policies, like the National Plastic Management Policy, can guide waste disposal and recycling.

Table 2 Summary of the research results as challenges and opportunities for CE in Ghana

Resp.	Challenges	Opportunities
<i>Production company interviews</i>		
Waste users	Resource competition and pricing issues; Transportation and sorting difficulties; Challenges integrating waste materials into production processes	Adoption of sustainable practices and reduced environmental impact; Financial incentives (e.g., tax relief, subsidies for recycled products); Cost reduction for labor
Waste not users	Low quality of recycled-material products; Environmental pollution from unmanaged waste; Rising material and treatment costs	Competitive advantages through quality assurance and sustainability; Financial incentives and cost-saving initiatives linked to recycled products
Waste suppliers	Unstable pricing of waste materials; High logistics and transportation costs; Market competition for waste streams	Income generation from waste supply; Reduced disposal costs; Contribution to environmental protection by diverting waste from landfills
Waste not suppliers	Lack of consistent waste material supply; High processing and logistical costs; Environmental concerns related to waste disposal	Potential for structured waste sourcing systems; Improved logistics coordination; Environmental benefits through better waste management
<i>Recycling company mini-case studies</i>		
ACARP	Limited public engagement in waste separation and recycling; Logistical and infrastructure constraints	Promotion of sustainable agriculture through composting; Reduced landfill dependency
SSGL	Negative public perception of by-products (e.g., biochar); Product certification challenges; Experiments to marketable scale;	Production of organic fertilizers; Biochar as a cleaner energy source; Potential expansion across Ghana and beyond
UPPR	Mixed waste quality complicating recycling processes; Financial pressures from exchange rate volatility, fuel costs, and taxes	Large-scale plastic recycling capacity; Streamlined operations via multiple recycling facilities; Promotion of plastic waste reduction
<i>Expert interviews</i>		
Gov. & Experts	Inadequate funding for waste collection and sorting infrastructure; Poor waste separation in the informal sector; High costs and limited investment in recycling technologies	Green transition and circular economy potential; Access to international funding (e.g., World Bank, AfCFTA); Expanded market access for recycled products
Industrial Sector & MSMEs	High capital costs for green transition; Technological gaps and unreliable utilities; Resistance to change and limited access to finance	Creation of demand for recycled products; Adoption of renewable energy solutions; Incentives, technical training, and improved waste infrastructure to support MSMEs

Collaboration between the government and the private sector is crucial to advancing recycling technologies and supporting renewable energy use in recycling operations. Establishing local standards for recycled goods and utilizing initiatives like the African Continental Free Trade Area (AfCFTA) can drive market demand.

Creating platforms for waste material exchange, supported by public–private partnerships, can facilitate business negotiations and scaling up recycling infrastructure. Training and technical support for businesses, particularly MSMEs, can help them adopt cleaner production techniques and use waste materials efficiently.

Table 2 highlights the key challenges and opportunities of waste utilization identified from the company interviews, recycling company case studies, and expert interviews, organized by their respective respondent categories.

5 Discussion

5.1 Circular economy principles and their operationalization in Ghana

Ghana's growing implementation of CE principles is evident in efforts to repurpose diverse waste streams into products such as biofuels, compost, and recycled materials. These practices closely align with the foundational CE logic articulated by Stahel and Reday [17], which emphasizes value retention through reuse and recovery, and with later conceptualizations that frame CE as a regenerative and systemic alternative to linear production models [18, 20, 28].

In practice, the interviewed Ghanaian firms operationalize CE primarily through closing resource loops, particularly recycling and recovery, rather than through higher-order strategies such as product-life extension or product-service systems. This mirrors broader patterns observed in late-industrializing contexts, where CE adoption often begins with waste valorization due to immediate economic and environmental pressures [27]. As noted in the literature, CE's promise lies not only in environmental gains but also in competitiveness and resource security: dimensions that are particularly salient in Sub-Saharan Africa's industrialization agenda [24–26].

However, consistent with critiques by Kirchherr et al. [29] and Korhonen et al. [30], CE implementation in Ghana remains uneven and fragmented. While firms increasingly adopt circular practices, these are often constrained by weak standardization, limited metrics, and insufficient policy alignment. As a result, CE risks remaining a collection of isolated initiatives rather than a fully embedded industrial paradigm, reinforcing concerns about “circular washing” without systemic transformation. To address this fragmentation, the establishment of a dedicated waste management system operator in Ghana, resembling Di Foggia and Beccarello's [92] proposal from lessons in the energy industry, would be critical, as such an entity could coordinate reporting of environmental outcomes, ensure universal service provision, plan and monitor circularity targets, and support local authorities, thereby reducing institutional complexity and enabling the transition from isolated circular practices toward a more coherent and system-wide circular economy.

5.2 Industrial symbiosis as an emerging but constrained practice

Applying IS typologies from the literature, Ghana's current practices largely correspond to micro- and meso-level symbiosis [33], characterized by bilateral or small-network exchanges rather than fully integrated eco-industrial parks. They also resemble self-organized or semi-facilitated symbiosis rather than planned IS, as conceptualized by Chertow [35]. This is consistent with findings from other low- and middle-income contexts, where IS often emerges opportunistically in response to waste disposal costs and regulatory pressure rather than deliberate spatial planning [32, 39].

Despite the presence of key IS drivers, such as environmental awareness, landfill avoidance, and rising disposal costs, several barriers identified by Neves et al. [33] persist in Ghana. These include limited knowledge of IS practices, weak trust among actors, insufficient institutional coordination, and uncertainty regarding profitability. The absence of reliable data-sharing mechanisms and intermediary organizations further constrains scaling, echoing the broader literature emphasizing trust, governance, and facilitation as critical enablers of IS [34, 40, 41].

5.3 Economic feasibility, waste quality, and firm-level decision-making

Economic feasibility remains central to firm participation in IS networks. Analytical frameworks proposed by Boons et al. [89] and Bertani et al. [87] are particularly useful for interpreting Ghanaian firms' behavior. In urban areas such as Accra, high landfill levies and fuel costs incentivize waste generators to divert materials to recycling facilities like ACARP, rather than bearing full disposal costs. This dynamic illustrates how IS conditions can be met even in low-capital settings when relative cost advantages exist.

However, these advantages are fragile. As observed by Costa et al. [93] and Takacs et al. [94], inconsistent waste quality, rising collection and sorting costs, and lack of standardized supply chains undermine production efficiency and limit scalability: challenges that are especially acute for Ghanaian SMEs. When virgin material prices are kept artificially low through subsidies or imports, or when certification and processing costs for recycled materials are high, IS exchanges become economically unattractive. These constraints mentioned by several respondents in this study reinforce findings by Gokul [95], who highlights quality uncertainty and lack of certification as key inhibitors of market confidence in recycled products.

In this aspect, one should see a major characteristic of waste materials which differentiates them from virgin materials, in quality, quantity and cost, as well. Labor-intensive waste processing activities, particularly collection, sorting, and handling, are central to the economic feasibility of waste utilization because sorting is the single most cost-intensive step after transportation, as evidenced by ACARP and mentioned by other companies (see Fig. 3). Operational costs are largely driven by manual, labor-heavy sorting and pre-processing of waste materials. This reflects Pluskal et al.'s [96] work showing the importance of separation and sorting in the economic feasibility of waste management. Since waste quality is a critical barrier to IS and can only be addressed through effective sorting, targeted tax reductions or exemptions for labor-intensive processing stages would directly lower waste utilization costs while simultaneously formalizing and supporting informal workers. Such measures would not only improve material quality and reduce operational expenses, but also expand employment, strengthen waste supply chains, and facilitate more reliable inter-industry waste exchanges.

5.4 Sectoral dynamics: plastics, textiles, agriculture, and industry

Ghana's CE progress varies significantly across sectors. The plastics sector remains particularly challenged. While policy instruments such as the National Plastic Management Policy and Extended Producer Responsibility (EPR) schemes represent important steps, their impact remains limited. Similar to observations in other African contexts, expanding public–private partnerships and improving collection infrastructure are essential for scaling recycling [41, 97].

In the textile sector, the influx of second-hand clothing creates substantial waste streams. As Davis Sumo [98] argues, the absence of effective sorting and recycling systems results in significant environmental leakage. Recent initiatives supported by the African Development Bank and the Development Bank of Ghana suggest emerging institutional responses, echoing calls in the literature for sector-specific IS interventions [55].

Agriculture represents one of the most promising frontiers for CE and IS in Ghana, given its substantial organic waste streams. Consistent with Ivukina and Skvortsova [99], agricultural waste recycling has the potential to enhance food security while advancing

environmental objectives. Yet, insufficient sorting infrastructure, limited rural collection systems, and weak private-sector engagement constrain progress. These barriers are commonly identified in SSA-wide studies [41, 54].

At the industrial level, Ghana's "1 District, 1 Factory" initiative reflects strong ambitions for local industrialization and diversification. However, high production costs, limited access to finance, and outdated infrastructure hinder the integration of CE principles into manufacturing. As Shayganmehr et al. [100] note, CE can reduce material and disposal costs, but these benefits are difficult to realize without complementary investments in clean technologies and reliable energy systems.

5.5 Policy, institutions, and the political economy of CE transition

Government intervention emerges as a decisive factor in overcoming Ghana's CE and IS barriers. Firms consistently call for fiscal and regulatory measures, such as VAT reductions, import duty exemptions for recycling equipment, and subsidies for organic fertilizers, mirroring international recommendations on CE-enabling policy frameworks [28, 32].

Institutional actors such as ACARP, SSGL, and UPPR illustrate both the potential and fragility of Ghana's CE ecosystem. While their operations deliver environmental benefits, including reduced greenhouse gas emissions and improved soil health [101], they remain constrained by financial instability, supply-chain inefficiencies, and limited access to advanced technologies and, consequently, less space for experimenting with new CE-based products or maneuver for marketable scaling up. This reflects broader challenges identified in African green industrialization literature, including infrastructure deficits, financing constraints, and governance weaknesses [65, 71, 72].

6 Conclusions

This paper analyzed the emergence of circular economy (CE) and industrial symbiosis (IS) practices in Ghana, with particular attention to cost structures, economic feasibility, and policy implications. The findings show that while CE principles are increasingly operationalized through waste recovery and recycling across agriculture, plastics, textiles, and industry, their scalability is primarily constrained by cost-related factors rather than technical feasibility. Waste-based production remains highly sensitive to fluctuations in waste quality, supply reliability, and processing costs, especially when competing with low-priced virgin materials.

A key result is that labor-intensive waste processing activities, most notably collection, sorting, and handling, constitute the dominant cost components in recycling and IS networks, second only to transportation. Evidence from ACARP and other firms shows that manual sorting and pre-processing largely determine operational costs, while inadequate upstream sorting exacerbates quality risks and limits inter-industry exchange. These characteristics distinguish waste from conventional inputs and explain why many IS arrangements remain small-scale and opportunistic.

The policy implications are therefore highly specific. Rather than broad subsidies, targeted fiscal measures should focus on reducing the cost burden of labor-intensive waste processing. Tax reductions or exemptions for collection, sorting, and pre-processing activities would directly improve economic viability, enhance waste quality, and strengthen supply chains, while simultaneously supporting employment creation and

the formalization of informal waste workers, which are all highly important in a developing country context. Complementary measures, including quality standards and certification for recycled products, improved collection infrastructure, and institutional intermediaries for waste exchange, are essential to reduce uncertainty and transaction costs.

Future research should prioritize firm- and sector-level cost analyses to quantify the economic thresholds at which waste exchange becomes viable, as well as comparative studies across African contexts to assess how policy instruments affect sorting intensity, employment, and IS formation. Longitudinal research is also needed to evaluate how cost structures and policy incentives shape the durability and scaling of CE and IS networks over time.

Supplementary Information

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Supplementary Material 1

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Data availability

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

All human participants in the study provided informed consent prior to participation. The research was approved by the Research Ethics Committee of Corvinus University of Budapest, Hungary (protocol code KRH/234/2022; 28 October 2022) and was conducted in accordance with the Declaration of Helsinki.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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