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THE CHALLENGES AND POTENTIALS OF CIRCULAR ECONOMY IN SUB-SAHARAN AFRICA

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THE CHALLENGES AND POTENTIALS OF CIRCULAR ECONOMY IN SUB-SAHARAN AFRICA

ANALYSIS OF DRIVERS AND BARRIERS FOR WASTE EXCHANGE AND UTILIZATION BASED ON FIVE CASE STUDIES

DOCTORAL DISSERTATION

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CHAPTER 1: INTRODUCTION

The aim of this dissertation is to contribute to the research and understanding of sustainable development and green industrialization in Sub-Saharan Africa (SSA) by focusing on the issue of waste utilization through the concept of circular economy (CE). As presented below, consumption and waste generation trends are concerning in the region. However, waste management research is underrepresented in this area, especially in fundamental research. There is little primary data available that could provide a basis for specific solutions and policy interventions related to local conditions and problems (e.g. waste types, technology, regulation, social perceptions and behavior). Consequently, the issue resembles a blind spot for research and for policy, as well. Therefore, the motivation of this thesis work is to explore this domain and provide primary data and develop a research toolkit which can be used in following research activities. Moreover, it is of highlighted importance to inform policymaking with the research findings in the form of policy recommendations.

Accordingly, the nature of this dissertation is based on exploratory and fundamental research as well as grounded theory. Beyond, as emphasized below, the inspiration for the research derives from the waste generation trends and projections in Sub-Saharan Africa. This means that the work focuses on materials generated and used locally, not the ones imported (legally or illegally) to the continent.

The research puzzle in this context centres around the challenges and opportunities of the exchange and utilization of waste and by-product materials. The dissertation clarifies this puzzle through five case studies, based on field research activities in Uganda, Zambia and Ghana. By the qualitative and quantitative data in the case studies, the research answers the following research question (RQ), and three sub-questions (SQ):

RQ: How and why does the utilization of waste and by-product materials have potential and face challenges in Sub-Saharan Africa?

> *SQ1: How are specific waste materials and by-products exchanged, or could be exchanged, between industries to promote circular economy practices?*

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

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

In the following part of the introduction, first, the justification for the research is explained, then the dissertation's structure is presented.

Population in Sub-Saharan Africa is projected to be around 2.5 times more in 2050 by the World Population Prospects of the United Nations Population Division (2019). The World Bank's "What a waste 2.0" report (Kazat et al., 2018) expects the amount of municipal solid waste to nearly triple in Sub-Saharan Africa by 2050. Hornweeg et al. (2013) projects that at the end of the century Sub-Saharan Africa will produce the largest amount of waste in absolute terms (see Figure 1). In 2016, 44% of the waste was collected in the region, while Europe and Central Asia and North America collected at least 90% of waste. To mention some aspects of rapid industrialization and consumption processes in Sub-Saharan Africa, according to the World Bank's World Development Indicators (2020), industry output (including construction) was five times higher in 2019 compared to 2001, final consumption expenditure was four and a half times higher in 2018 than in 2001. Since 2008, more than half of the African countries have adopted formal industrial policy documents (UNCTAD, 2018; p.128). These facts together outline a tendency towards increasing waste generation in the region.

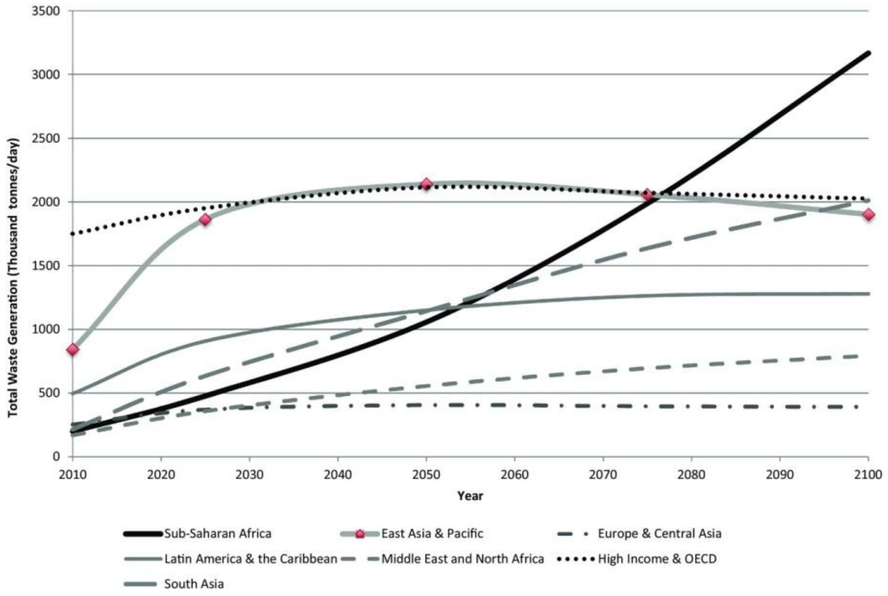

Figure 1. Waste generation by region, 2010–2100 under SSP2 (thousand tonnes/day); Source: Hoornweg et al. 2013

Furthermore, SSA is exposed and vulnerable to climate change (Collier et al., 2008; Tadesse, 2010; Abidoye and Odusola, 2015; Baarsch et al., 2020). The Climate Change Vulnerability Index 2017 (Reliefweb, 2020) evaluates the vulnerability of human populations to extreme climate events and changes in climate over the next 30 years. It combines exposure to climate extremes and changes with the current human sensitivity to those climate stressors and the capacity of the country to adapt to the impacts of climate change. As the map of Figure 2 shows, most high and extreme risk areas (orange and red) are in Sub-Saharan Africa.

Population growth and urbanization processes are the fastest in this region globally and typical consumption patterns in the region are changing and moving toward more packaged products and electronics (Kazat et al., 2018). Thus, a comprehensive rethinking and reconceptualization of waste management and utilization, product life-cycles and prevailing business models are needed to prevent serious environmental damage and deterioration of living-conditions.

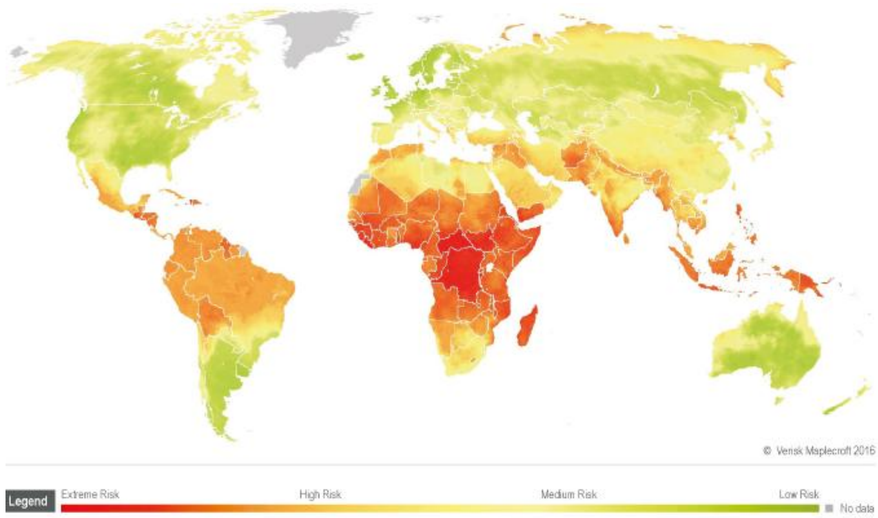

Figure 2. Climate Change Vulnerability Index 2017, Source: Reliefweb, 2020

Parallel to these tendencies, another big problem in SSA is the missing productivity increase. McMillan, Dani Rodrik and Claudia Sepulveda (2017) point out that the region has experienced a strange phenomenon of structural change between 1990 and 2010. This means that employees migrated from the traditionally low-productivity agricultural sector not to the higher-productivity manufacturing/industry sector but to the lower productivity service sector. For example, in Nigeria, productivity growth in manufacturing between 1996 and 2009 was negative relative to agriculture. In Ghana, between 1992 and 2010, manufacturing's total contribution to productivity increase was zero. In Zambia, labour productivity grew by only 0.31% between 1991 and 2010, still half of the population is employed in low-productivity agriculture (McMillan et al., 2017).

Since productivity is the base for economic growth, this stagnating, or sometimes even decreasing level of productivity is seriously curbing the chances of African countries to achieve convergence with the developed economies. Consequently, as long as the above-mentioned tendencies of population and consumption growth are not coupled with productivity growth, the economic, social, and consequently, environmental situation will be unlikely to improve. Therefore, a solution is needed that, on the one hand, ensures the increase of productivity by filling the gap of the missing manufacturing sector or increase the productivity in the service sector, and curbs environmental damage via resource efficiency.

For tackling this combined challenge, the concept of circular economy promises potential solutions. Moreover, as one of the co-founders of the African Circular Economy Network (Lemille, 2020) pointed out, Africa has an advantage when it comes to the transition to circular economy solutions. First, circular economy is a labour-intensive approach, and Africa has the youngest population with many unemployed or employed in the informal sector. Second, due to the relatively low level of development, African countries are less locked-in in linear models of production and consumption, compared to more technologically-economically advanced economies. Third, collaborative practices (traditional or new) and culture are widespread in Africa to manage scarcity, which represent a feasible starting point for circular economy.

Therefore, the research focuses on the drivers and barriers for the implementation of circular economy, more specifically one of its business models, industrial symbiosis (IS), namely the exchange and utilization of waste and by-product materials, and explores its potential in Sub-Saharan Africa.

The dissertation is structured as follows.

Chapter 2 summarizes the relevant literature, including the main concepts used in the research work such as the green and blue economy, green industrial policy, circular economy, industrial symbiosis and the level of their presence in research and practice in Sub-Saharan Africa. Chapter 3 presents the methodology and limitations for the research. Chapter 4 describes the research context in the three countries, including the state of the economy, industrialization and sustainable development, as well as summarizing the relevant policy documents for the research topic.

The central part of the dissertation is Chapter 5, consisting of five case studies representing micro, meso and macro level aspects of waste exchange and utilization, with the aim to include all relevant and important production sectors in Sub-Saharan Africa, based on 105 semi-structured interviews and discussions. This Chapter contributes new findings to the literature, as most case studies have already been or are in the process of being published as single research articles (see Table 1)[1].

[1] See publication details at each case study, as well.

Accordingly, Case study 1 presents micro-level (external) waste exchange by seven businesses and initiatives in Uganda. Case study 2 focuses on waste utilization in agriculture by presenting the case of an ecological farm and its waste suppliers in Uganda. Case study 3 takes under scrutiny the meso level by presenting the potentials and challenges of waste utilization in the Kampala Industrial and Business Park (KIBP) in Uganda. Case study 4 presents research results and conclusions regarding the utilization of copper mining waste in Zambia. Case study 5 includes micro, meso and macro level aspects of the circular economy in Ghana.

Table 1. Case studies (CS) and their data collection period (DC), respondent number (RN) and publication status; Source: author's collection

CS	Title	DC	RN	Publication status
1	Waste utilization mini case studies in Uganda	05. 2021	7	Buda, G. (2022). Seven Businesses Using Principles of Circular Economy in Sub-Saharan Africa: Results of Field Research in Uganda. Afrika Tanulmányok / Hungarian Journal of African Studies, 16(1), 5–20. https://doi.org/10.15170/AT.2022.16.1.1
2	The role of agriculture in micro-level waste exchange and utilization in Sub-Saharan-Africa. The case of Amelia Agro Ecological Farm in Uganda	05-06. 2022	9	Buda, G. (2024). Economic Determinants of Industrial Symbiosis on the Micro-level in Sub-Saharan Africa. A Case Study from Uganda. Afrika Tanulmányok / Hungarian Journal of African Studies, 17(3), 67–86. https://doi.org/10.15170/AT.2023.17.3.4
3	Potentials and challenges of waste exchange and utilization in an African industrial park. The case of the Kampala Industrial and Business Park in Uganda	01-04. 2023	43	Under review at Sustainable Futures (Elsevier)
4	Potentials and challenges of the utilization of mining waste materials. The case of copper mining waste in Zambia	04. 2023	19	Buda, G. (2025). Black Mountains and White Deserts – Why are copper mining waste materials not utilised for other products and economic diversification in Zambia? Külgazdaság, 69(1), 1–23. https://doi.org/10.47630/KULG.2025.69.eng.1

5	Waste utilization potentials and challenges on micro, meso and macro levels in Ghana	07. 2023 – 04. 2024	27	Under review at Humanities and Social Sciences Communications (Springer Nature)

Chapter 6 synthetises these two preceding blocks (existing information and new findings) and closes the dissertation with conclusions and policy recommendations.

CHAPTER 2: LITERATURE REVIEW

This Chapter summarizes the literature related to the dissertation work. First, it presents the main concepts creating the background for the research, such as the Green Economy, Blue Economy and Green Industrial Policy. Then, it turns towards the focal points and conceptualization: Circular Economy, including its roots and main stemming thoughts, limitations, advantages and disadvantages; Industrial Symbiosis, Integrated Farming Systems and Eco-Industrial Parks. The last three sub-sections of the Chapter present the relevant literature regarding the SSA region and the detected research gaps.

2.1. The concepts of Green Economy and Blue Economy

The concepts of green economy and blue economy have gained significant attention in recent decades as frameworks for achieving sustainable development while balancing environmental protection, economic growth, and social equity. Though they share a common goal of sustainability, each concept offers a distinct lens through which natural resources and economic development are managed. A growing body of literature has sought to define, differentiate, and evaluate the effectiveness of these paradigms in both global and regional contexts.

The term *green economy* came into prominence with the 1992 Rio Earth Summit and was later popularized by the United Nations Environment Programme (UNEP) during the lead-up to the 2012 Rio+20 Conference. UNEP (2018) defines a green economy as one that results in "improved human well-being and social equity, while significantly reducing environmental risks and ecological scarcities." In this sense, the green economy paradigm is deeply tied to the principles of sustainable development, integrating environmental and economic policymaking to promote low-carbon growth, efficient resource use, and social inclusivity.

Key components of the green economy include renewable energy, sustainable agriculture, green transportation, waste reduction, and ecological restoration (Barbier, 2011). Scholars emphasize that the green economy is not just an environmental initiative but also a transformative economic strategy. For example, Bowen and Fankhauser (2011) argue that the green economy involves structural changes in economic systems and investment in green infrastructure and innovation to reduce dependency on fossil fuels and resource-intensive industries.

Despite its widespread adoption, the green economy has been critiqued for its ambiguous definitions and potential for greenwashing. Brand (2012) warns that without rigorous governance and accountability mechanisms, the green economy may serve as a vehicle for neoliberal economic interests rather than genuine ecological sustainability. Similarly, Death (2014) highlights the risk of co-opting green economy rhetoric for economic growth agendas that continue to marginalize vulnerable populations.

The *blue economy* emerged as a complementary but distinct concept focused specifically on the sustainable use of ocean and marine resources. It was formally introduced during the 2012 Rio+20 Summit and later adopted into policy discourse by the World Bank, the European Union, and various small island developing states (SIDS). The World Bank (2017) defines the blue economy as "the sustainable use of ocean resources for economic growth, improved livelihoods, and jobs while preserving the health of ocean ecosystems."

Core sectors of the blue economy include fisheries, maritime transport, offshore renewable energy, aquaculture, coastal tourism, and marine biotechnology. Emphasizing the link between ocean health and economic prosperity, the blue economy encourages marine conservation, pollution control, and the protection of coastal ecosystems (Silver et al., 2015). Unlike traditional ocean-based economies, which often prioritize extraction and exploitation, the blue economy envisions the ocean as a shared global asset that must be maintained for current and future generations.

The concept is particularly important for coastal and island nations, which are heavily dependent on marine ecosystems for their economic stability. Voyer et al. (2018) point out that the blue economy holds promise in addressing poverty and food security, but only if equitable access and benefit-sharing are prioritized. However, similar to the green economy, the blue economy faces criticism for its lack of clear operational definitions and for reinforcing existing power structures. Bennett et al. (2019) caution that without inclusive governance, blue economy initiatives may exacerbate social inequities and resource conflicts in coastal communities.

The blue economy closely mirrors industrial symbiosis in its emphasis on resource efficiency, waste minimization, and circularity. Both treat waste as a valuable input - where, for example, fishery by-products in the Blue Economy are repurposed into energy or feed, just as industrial symbiosis turns one industry's waste into another's resource. Each approach relies on systems thinking and interconnected networks: the Blue Economy integrates sectors like fisheries, tourism, and marine biotech, while industrial symbiosis connects industries through shared resource flows. Both are grounded in circular economy principles and rely on innovation to optimize material use and reduce environmental impact.

They also share goals of achieving both economic growth and environmental sustainability. The blue economy emphasizes local, regenerative development - especially in coastal areas - while industrial symbiosis typically occurs in local industrial clusters. Ultimately, the Blue Economy can be seen as a marine-sector application of industrial symbiosis, adapted to the ocean context but built on the same foundation of collaborative, circular, and sustainable practices.

While both green and blue economies aim to achieve sustainability, they differ in scope and sectoral focus. The green economy encompasses the entire economic system with an emphasis on reducing environmental harm across all sectors, whereas the blue economy concentrates specifically on the marine and aquatic environment. Yet, overlaps exist: for instance, offshore wind energy, sustainable coastal tourism, and marine conservation initiatives are often discussed within both frameworks.

Recent literature emphasizes the importance of policy coherence and integration between green and blue economic strategies. As Mulazzani and Malorgio (2017) suggest, the success of either approach depends on institutional coordination, participatory governance, and the incorporation of traditional ecological knowledge.

2.2. Green Industrial Policy

As a transition to a more circular economy might require governmental interventions and policies suited for greening the industry, in this sub-section, green industrial policy is presented briefly. Before going into details about "Green" industrial policy, it is preferable to start a short introduction to industrial policy itself. Industrial policy is a concept with different definitions but, in brief, it focuses on government interventions in the economy, and it was and still is the subject of a long-lasting debate between two camps of scholars prepared with range of arguments, both legitimized and motivated by an opposite rationality of failures (Chang, 1994; Peneder, 2017). The opposing arguments oscillate around market failures, the provision of public goods and the management of externalities, the limitation of societal coming from imperfect or incomplete markets and information asymmetries which can result in adverse selection and moral hazard (Bator, 1958). The supporters highlight government failures, regulatory capture risks and government as well as bureaucratic inability to address asymmetric information, set and achieve targets properly, among others (Krueger, 1974; Tullock, 1967).

Industrial policy was championed based on the success stories of the Asian Tigers' model of the developmental state in the 60's and 70's (Wade, 2018) and their followers like Vietnam and Cambodia in the 90's and early 2000's (McMillan et al., 2017). Until the Great Recession of 2007-2009 and, especially, the recent Covid19 pandemic, industrial policy was considered as an obsolete and pariah concept from mainstream economics in most part of the world. The last decade brought a renewed interest in the concept with numerous academic articles and policy-making debates (Aiginger and Rodrik, 2020; Bailey et al., 2015; Chang and Andreoni, 2020; Cimoli et al., 2009; Oqubay et al., 2020). Ferrannini et al. (2021) summarizes three main reasons for this 'renaissance'. First, industrial processes are crucial for economic transformations and structural changes. Second, industrial policy also plays a key role in avoiding or reducing the risks and exploit the opportunities connected to globalization developments, such as global value chains, the distribution of labour and technological trends like automatization and digitalization. And finally, referring back to the intellectual debate about the legitimacy of state intervention, the financial crisis of 2007-2009 and its consequences strongly hit the validity of the neo-classical, market-fundamentalist approach to deliver long-term and stable economic prosperity.

Rodrik (2014, p. 469) defines green growth - one of the keys elements of sustainable development - “as a trajectory of economic development that is based on sustainable use of non-renewable resources and that fully internalizes environmental costs, including most critically those related to climate change”. He further argues that green growth needs green technologies, such as “’production techniques that economize on exhaustible resources and emit fewer greenhouse gases”. Accordingly, primary attributes of industrial policy for sustainable development are policies targeting decreased CO2 emissions and/or increased resource efficiency by the industry.

One very important characteristic of green, or any other new technologies highlighted by Rodrik is the uncertainty about their success and the trial-error dynamics along the marketization process, due to scientific and technological developments, potentially unpredictable prices or other commercial trends. This, on the one hand provides a justification for governmental support, and, on the other hand, calls for making industrial policy designed and fabricated for the acceptance of failures in the way of financing a larger group of projects. Rodrik supports this argument with the report of the US National Research Council in which several projects funded between 1978 and 2000, of which many projects failed but the net benefits for the overall US economy had been positive. Furthermore, shooting on more projects can avoid the failure of wrongly “picking winners” and help stop backing evident losers.

Another important criterion deriving from Rodrik’s argumentation is that green industrial policies (or those for sustainable development) should keep the focus on one specific environmental or technical target (in his case on emission target) and it should not include multiple goals, such as job creation, profitability, competitiveness or other commercial aspects. As he describes, “the greater the multiplicity of goals and the hazier their definition, the less the ability to recognize failure, remove support, and change course” (Rodrik, 2014, p. 486).

Finally, rather subsidize than restrict the market from new technologies by tariff barriers. The former can still support local actors to keep staying in or enter global supply chains and markets, while the latter one risks the deprivation of internal actors from new, useful technologies.

The wide range of financial tools for an industrial policy for sustainable development includes research and development grants, government procurement, subsidized loans and loan guarantees as well as direct subsidies. Among non-financial tools are special national programmes awareness-raising, dissemination and capacity-building actions, the provision of digital tools or platforms and support in company matchmaking (especially in the case of industrial symbiosis – the dissertation author), cap-and-trade policies and mandated energy efficiency or emission standards, mechanisms helping markets perform better for buyers or sellers (Rodrik, 2014; World Bank, 2021).

2.3. Circular economy: roots and current concepts

The current concept of circular economy roots in the works of Stahel and Reday (1977) and gained particular attention among academia and policymakers during the last two decades, as one of the theoretical concepts for sustainable development (Geissdorfer et al., 2017). Shortly, circular economy takes nature as an example, where there is no waste, each output is an input for another process. Thus, the circular approach contrasts with the "take-make-use-dispose" logic of the conventional "linear economy" and argues for a nature-like circularity in the economic system (Erkman, 1997; Korhonen, 2004; Nielsen, 2007; Bakker et al., 2014; Homrich et al., 2018). This means that the value of products, materials and resources are maintained in the economy as long as possible, resulting in a minimized amount of waste and a sustainable management of resources. In other words, the transition to a circular economy depends on the detection of and breaking down "lock-ins" of the linear economy (Sopjani et al., 2020). In the circular economy mind-set, wealth is unrelated to resource use and waste is converted into economic benefit (Ellen MacArthur Foundation, 2013). By improving design for reuse and recycling, switching to services and renewable products in place of non-renewable ones, and using existing materials, value is created (Ellen MacArthur Foundation, 2015).

According to Nobre and Tavares (2021), the circular economy is an economic system that aims to be free of waste and pollution during the entire life cycle of materials, from extraction through industrial processing to final consumers, and applies to all stakeholders in the ecosystem. At the end of their useful life, the materials are returned to industrial processes or, in the case of treated organic waste, safely to the environment, as in a natural regeneration cycle. The circular economic model creates added value at the macro, meso and micro levels and exploits the embedded concept of sustainability to the fullest extent. The energy sources used in the model are clean and renewable. The use of resources is efficient.

Similarly, Awan et al. (2020) defines the model of the circular economy as a set of activities and processes aimed at reducing the amount of materials and resources used during production and consumption. Its purpose is to create resilience, closed loops during material and resource flows, and to maximize the sustainability of the ecological system.

One of the main characteristics and, at the same time, a great strength of the circular economic model is that it represents a holistic approach to the renewal of the economic and production sectors, and, accordingly, it considers sustainable local economic development, close, stable and long-term cooperation between market players to be absolutely essential, as well as the efficient use of local resources. Another extremely important aspect is that the circular economic model separates economic growth and the enhancement of production/output, i.e. it does not regard one concept as a necessary condition for the other (Fogarassy et al., 2017), as it is presented through the schools of thoughts affecting the concept in the followings.

2.3.1. Thoughts behind the concept

Kovacic et al. (2020) provide a detailed review of the schools of thought that inform research on the circular economy and on the ideas and debates that have led to the emergence of the concept. Their approach starts with the academic thinking connected to the questions of scarcity and the role of innovation in economic growth and depression cycles (starting from Thomas Malthus, 1798 and Henry George, 1898). According to Giampietro et al. (2012), on one side of the debate are the ones arguing that resource scarcity and biophysical limits would put an end to economic growth, the so-called “Prophets of Doom”. On the other side, the “Cornucopians” argue that environmental constraints could be overcome through technological progress and human ingenuity.

Hence, the greatest novelty circular economy brings as a concept is to dissolve the contrast between these two sides and blend them together. On the road to this conclusion, two emerging trends in the intellectual landscape were setting the ground for the appearance of circular economy: systems thinking and social metabolism. The former has influenced the understanding of the economy as a system, embedded in a higher-level ecosystem, and composed of parts that interact with each other (Von Bertalanffy, 1972). One of the ideas of the circular economy deriving from this is to promote industrial symbiosis, exploiting the interactions between the parts of the system via feedback and loops, rather than just optimising individual behaviour (Odum, 1996). The latter one describes the economy similar to a larger organism (Murray et al., 2017) which depends on an embedding ecosystem for its inputs and which discharges waste into this ecosystem, rather than just a set of independent inputs and outputs. Consequently, social metabolism (alongside with industrial ecology) investigates the material and energy throughput that is needed for a society to reproduce itself. The circular economy blends these two components to make the economic system more circular: reducing throughput and transforming waste into an input.

Another important feature of circular economy is the restorative approach, rooted in the appearance of the planetary perspective based on Kenneth Boulding's essay "The economics of the Coming Spaceship Earth (1966) and the Club of Rome's report "The Limits to Growth" (Meadows et al.,1972). The main addition of this to the evolution of the circularity concept was to present the economy, in parallel with a planet, as a closed system and implied a steady-state economy to maintain its size and not exceed the carrying capacity of nature (Daly, 2005). Thus, nature-like restorative processes need to be internalised in the economic system via closing the loop between inputs and outputs: reducing the economic growth from resource consumption and re-inserting outputs into the economic cycle as inputs. Therefore, circular economy focuses on innovation through eco-design and improvement of social corporate responsibility.

2.3.2. Critiques, limitations, advantages and disadvantages of CE

The concept of the circular economy (CE) has emerged as a promising response to the longstanding tension between economic growth and environmental sustainability. Rather than viewing these objectives as mutually exclusive, CE seeks to align them by reconfiguring production and consumption systems to minimize waste, extend the lifespan of materials, and reduce dependence on virgin resources. This transformative model advocates for closing material loops and optimizing resource use across entire product life cycles. Geng et al. (2013) note that CE is increasingly seen as a way to mitigate environmental damage while sustaining economic activity. However, this apparent alliance between growth and environmental preservation is built on fragile foundations, with several theoretical and practical limitations that must be acknowledged.

One of the most fundamental challenges concerns the treatment of energy and food within the CE paradigm. While certain materials such as metals, paper, cardboard, and plastics can be reprocessed - albeit with some loss in quality or quantity - the same cannot be said for energy and food. Once fuels are burned, their energy is dissipated and cannot be recycled. Similarly, once food is ingested and metabolized, it exits the economic process in a degraded form that is no longer usable in production. Georgescu-Roegen (1971) emphasized this issue by introducing the concept of entropy into economic thinking, arguing that all economic processes are subject to the second law of thermodynamics. According to his view, economic activity inevitably degrades high-quality energy and material resources into waste and heat, a process that is irreversible. This implies that, from a biophysical standpoint, the economic process is fundamentally linear, and any attempt to model it as circular must contend with the inescapable reality of energy dissipation and material degradation.

Despite this thermodynamic constraint, proponents of CE continue to explore strategies for reducing the linearity of current systems. Merli et al. (2018) define CE as a model that seeks to preserve the value of materials in the economy for as long as possible, primarily through reuse, remanufacturing, and recycling. However, the status of energy within circular systems remains debated. Some scholars argue that energy flows should be excluded from circular accounting due to their inherently non-recyclable nature (Kovacic et al., 2020). Others, however, contend that the use of renewable energy - such as solar, wind, and hydro - can approximate circularity by providing continuous inputs without depleting finite reserves. Nonetheless, even in renewable systems, energy once used cannot be regained, and additional energy inputs are required for any transformation or recycling process.

Another contested aspect of CE relates to the role of waste-to-energy conversion. While turning waste into energy might seem to close the loop, this strategy poses significant paradoxes. First, if energy production depends on waste availability, the system may create a perverse incentive to generate more waste. Second, the process of converting waste into energy often demands further energy inputs, raising questions about net gains in efficiency or sustainability (Kovacic et al., 2020). These issues reflect a broader concern highlighted by the Club of Rome, which argued that resource consumption tends to grow exponentially, while technological innovation typically produces only linear gains in efficiency (Meadows et al., 1972). Consequently, relying on technological solutions alone is insufficient to offset the escalating pressures of resource use.

The theoretical ideal of a fully closed material loop is further undermined by physical and ecological realities. Many essential resources, including food and freshwater, are not amenable to circular reuse. Most of these must be extracted continuously from the environment, and even the most advanced human-controlled systems are unable to recycle them completely. Moreover, many aspects of modern economic life - such as services, labor, and financial capital - do not operate in physical loops and thus do not fit easily into circular models. While material goods can be repurposed to a limited extent, most consumer products are discarded or degraded, with only a small portion re-entering production cycles. In this regard, economic processes are fundamentally dissipative, operating at the expense of natural inputs and environmental services (Georgescu-Roegen, 1971). Chemical and mechanical processes inevitably produce heat and waste, which cannot be reused without additional energy, further entrenching the linearity of economic systems.

Despite these limitations, the CE model is not without substantial advantages. Numerous studies highlight the potential of CE to reduce environmental degradation, improve resource efficiency, and foster economic innovation. For example, Geissdoerfer et al. (2017) argue that CE represents a new sustainability paradigm that promotes eco-innovation, green product design, and circular business models. Similarly, Kirchherr et al. (2018) find that CE implementation can create jobs in recycling, remanufacturing, and repair sectors while reducing dependency on volatile international resource markets. Additional benefits include cost savings through improved material efficiency, reduced landfill use, and new market opportunities for sustainable goods and services. These advantages are particularly significant for regions heavily dependent on imported raw materials, where circular strategies can enhance economic resilience and self-sufficiency (Qazi and Appolloni, 2022).

Nevertheless, the CE model also comes with important disadvantages and trade-offs. One among these is the potential for economic deceleration. As Kovacic et al. (2020) argue, internalizing ecological cycles into production systems often slows economic activity, since biological and material recovery processes are inherently slower than linear extraction and manufacturing. In a circular economy, the pace of production would no longer be determined solely by technological capacity or market demand but would depend on the rate at which primary inputs - such as recyclable materials - become available. This shift could lead to bottlenecks, especially in sectors where materials degrade over time or are not easily recovered. Furthermore, reallocating labor and resources from primary production to recycling introduces opportunity costs, potentially reducing the overall productivity of the economy (Kovacic et al., 2020). These inefficiencies are further exacerbated by the rebound effect, in which gains from efficiency lead to increased consumption elsewhere, undermining net environmental benefits (Thiesen et al., 2008).

Implementing CE also faces several institutional and structural barriers. Among the most significant ones are regulatory fragmentation, lack of standardized metrics, and inadequate financial incentives. Kirchherr et al. (2018) found that despite growing interest, many businesses lack clarity on how to operationalize circular principles due to inconsistent policies and the absence of supportive legal frameworks. Small and medium-sized enterprises (SMEs), in particular, face high upfront costs for transitioning to circular practices and often lack access to the technological expertise or capital needed for redesigning products or processes (Eikelenboom and de Jong, 2021). Consumer resistance also plays a role; many consumers continue to favor new products over refurbished or recycled alternatives, limiting market uptake of circular goods.

Nevertheless, several factors have been shown to facilitate CE implementation. Key enablers include supportive public policies, such as extended producer responsibility (EPR), green public procurement, and circular design mandates. Financial incentives - such as subsidies, tax credits, and innovation grants - can help offset the high initial costs of circular transitions (Qazi and Appolloni, 2022). Technological advancements also play a critical role: tools like digital product passports, blockchain tracking, and artificial intelligence in sorting and waste management improve transparency and material recovery rates (Pichlak and Szromek, 2021). Furthermore, the availability of green skills and dedicated environmental roles within organizations is positively correlated with CE adoption, particularly in the manufacturing sector (Bassi and Guidolin, 2021). Cross-sector collaboration, supply chain integration, and consumer education are also essential for scaling CE initiatives.

In conclusion, while the circular economy represents a compelling vision for aligning economic and environmental goals, it must be approached with pragmatic realism. Its theoretical foundation is challenged by thermodynamic laws and the limits of material and energy recovery. Its practical implementation is constrained by economic trade-offs, technical limitations, and institutional inertia. Nonetheless, when applied selectively and strategically, CE can serve as an important complement to broader sustainability efforts - supporting resource conservation, fostering innovation, and guiding economies toward more resilient and less wasteful models of development.

2.4. Industrial Symbiosis and its research status in SSA

This section of the literature review centers on the core phenomenon that forms the conceptual basis for research on waste exchange and utilization: industrial symbiosis (IS) and its various implementation levels and forms. The framework typically distinguishes between three levels of IS engagement: micro, meso, and macro (see more details in 3.2.2.). The micro level refers to in-house circularity within a single company or bilateral material exchanges between two companies. The meso level encompasses relationships among geographically proximate companies, often within (eco-)industrial parks. The macro level concerns activities implemented on regional or national scales. This foundational structure informs the review of existing literature, followed by an examination of how these concepts have been studied in Sub-Saharan Africa (SSA), a step that will support the identification of subsequent research gaps.

According to Bocken et al. (2016) and Bakker et al. (2014), the circular economy (CE) can be defined through strategies aimed at slowing (e.g., reuse), closing (e.g., recycling), and narrowing (e.g., using fewer materials in production) resource loops. Park et al. (2010) and Stahel (2016) further elaborate on CE, identifying six fields of action: take, make/transform, distribute, use, recover, and *industrial symbiosis*. While the broad concept of sustainable development has often been critiqued for its lack of operational clarity, CE is recognized for adopting a more systemic approach to the design, planning, and management of production and consumption systems (Salomone et al., 2020). Table 2 summarizes the business models of circular economy.

Table 2. Circular economy business models, Source: Bocken et al. (2016)

Business model	**Description**
Access and performance	Satisfying users' needs without owning physical products
Extended product value	Free-of-charge retake and remanufacturing of the products by the manufacturer
Long-life	Durable design and a guaranteed repair service
Encourage sufficiency	Producers or resellers build their brand on telling the costumer not to buy certain products
Extending resource value	Collection or sourcing of otherwise wasted materials and resources to turn these into new forms of value by finding another useful function.
Industrial symbiosis (IS)	End-products, by-products or waste-products of one industrial activity can be an important input of another one

Within both academic and policymaking circles, industrial symbiosis is acknowledged as a cornerstone of circular economy implementation (Salomone et al., 2020). In general, industrial symbiosis (IS) can be described as a collective strategy in which the waste or by-products of one company become inputs for another (Neves et al., 2019). In its essence, IS seeks to close pre-consumer resource loops by redirecting industrial residues for reuse, as originally emphasized by Chertow (2000).

Understanding IS involves two essential distinctions. First, unlike conventional waste recycling, which primarily addresses post-consumer municipal waste, IS focuses on pre-consumer industrial by-products. Second, industrial symbiosis has inherently a nature of business-to-business (B2B), relying on direct synergies between companies. The academic and policy interest in IS over the past two to three decades stems from its potential to create mutual benefits for participating firms. As Neves et al. (2019) observe, businesses implementing these synergies can save costs (e.g. avoidance of transportation and landfilling costs as well as access to cheaper alternative raw materials) and generate additional revenue when selling the waste materials. Lybaek et al. (2020, p.1) echo this sentiment by defining IS as "the connection of traditionally separate industries in a collective effort to simultaneously increase competitive advantage and reduce environmental impacts by means of by-product exchange and shared infrastructure.” This broader conceptualization includes not only material exchanges but also shared infrastructure and services, especially for waste and water management (Neves et al., 2019).

Starting at the micro level, a conventional example of in-house circularity can be found in Integrated Farming Systems (IFS). These systems treat smallholder farms as interconnected units, integrating multiple agricultural practices to boost productivity (Simmonds, 1985). IFS typically involves the recycling of crop waste, animal manure, and fish waste to enhance production efficiency and ensure environmental sustainability (Mukhlis et al., 2018). According to the FAO (2001), integrated systems represent a more resource-efficient alternative to diversified models with separate, non-interactive livestock and crop components. Chan (1985) also emphasized IFS's role in addressing food security in the "Third World," particularly in response to rising costs of fuel, feed, and fertilizers.

IFS falls within the internal exchange category of IS as it operates entirely within a single system. This internal looping of resources exemplifies the CE principles of reducing external inputs and reusing waste streams, making it a fitting representation of micro-level IS.

At the meso level, the concept of Eco-Industrial Parks (EIPs) has become a tangible application of IS. EIPs aim to foster sustainable industrial ecosystems by encouraging the exchange and reuse of materials, energy, and water among co-located businesses (The World Bank, 2021). The idea gained momentum following Frosch and Gallopoulos’s (1989) publication of "Strategies for Manufacturing," with the Kalundborg Symbiosis in Denmark serving as a pioneering example where firms successfully exchanged steam, water, and waste (Ehrenfeld and Gertler, 1997). Similarly, the Shenzhen EIP in China showcased improvements in resource efficiency through stakeholder collaboration and integrated planning (Gao et al., 2019).

EIPs promote CE practices by reducing operational costs and environmental footprints while relying on collaboration among firms, local governments, and communities. Benefits include reduced greenhouse gas emissions, lower energy consumption, and minimized waste generation (Chertow, 2000; Gibbs and Deutz, 2007). Firms located in EIPs often experience cost savings and enhanced competitiveness (Gibbs and Deutz, 2007; Lo et al., 2023). However, challenges such as high startup costs, long payback periods (Behera et al., 2012), and complex regulatory environments (Tseng et al., 2021) can limit the scalability and attractiveness of EIPs.

Despite the theoretical appeal of IS and CE strategies, their research and application in Sub-Saharan Africa remain underdeveloped. Only a limited number of studies have explored IS at any level in this context. Brent et al. (2008) reported seven eco-industrial park cases in South Africa. Oguntoye et al. (2019) examined the Gauteng Industrial Symbiosis Programme initiated in 2014. The Ellen MacArthur Foundation (2020) cited the Western Cape Industrial Symbiosis Programme as the first of its kind on the continent. Mbuligwe and Kaseva (2006) studied waste management and resource recovery in Tanzania, while Alfaro and Miller (2013) assessed IS and IFS opportunities in a smallholding farm in Liberia.

Oliyade (2015) identified sixteen success factors for industrial ecology in SSA, and Mauthoor (2017) explored IS potentials in slaughterhouses, edible oil refineries, and scrap metal recycling in Mauritius. Rweyendela and Mwegoha (2020) presented a case of IS in Tanzania's sugar industry, highlighting material exchanges such as bagasse, molasses, and boiler ash among co-located units. In Kenya, Khisa and Onyuka (2018) advocated for the greening of special economic zones through IS practices, and Jensen (2020) documented eco-industrial park cases in Ethiopia's garment sector. Oni et al. (2022) conducted a comprehensive analysis of IS challenges and opportunities across Africa, focusing on waste material availability, regulatory landscapes, and existing IS networks.

In terms of Integrated Farming Systems, although the approach is widely recognized, empirical research in SSA is limited. Dessie (1997) investigated poultry integration in Ethiopian farms, and Harris (2002) studied manure and residue usage in the Sahel. Agbonlahor et al. (2003) showed that poultry-based IFS models enhance soil fertility in Southern Nigeria. Ruddle and Prein (2006) developed impact assessment methods for aquaculture-agriculture systems in Ghana, while FAO (2009) reported on crop-livestock integration in Burkina Faso. Singbo and Lansink (2010) demonstrated production efficiency improvements using IFS in Benin. Obi (2013) and Ezeaku et al. (2015) provided evidence of soil and food productivity benefits from IFS in South Africa and Nigeria, respectively. Agosson et al. (2016) discussed the model of Songhai Farm in Benin, showcasing an integrated farming approach.

Lastly, scholarly literature on eco-industrial parks and green industrialization in Africa remains scarce. Sakr et al. (2011) examined the situation in Egypt, Greenberg and Rogerson (2014) in South Africa, and Okereke et al. (2019) in Ethiopia. Ronoh (2020) discussed the KenGen Green Energy Park in Kenya, while Bilyaminu et al. (2024) recently highlighted industrial symbiosis opportunities in an industrial park in Nigeria.

2.5. Research gaps

The adoption of circular economy (CE) and industrial symbiosis (IS) approaches offers significant potential for sustainable development in Sub-Saharan Africa (SSA), especially as the region faces increasing resource pressure, rapid urbanization, and escalating waste generation. However, as seen above, existing research in these areas remains limited, fragmented, and largely exploratory. Despite emerging interest from both policymakers and scholars, critical gaps persist that hinder the widespread implementation of CE and IS practices across the region (see Table 2).

A major research gap lies in the contextual adaptation of CE frameworks. Much of the academic literature on CE originates from developed countries and assumes the existence of mature infrastructure, institutional coherence, and formalized production systems. These assumptions often do not hold in SSA, where informal economies, fragmented governance, and limited technological capacity dominate (Desmond and Asamba, 2019). As a result, circular strategies like product life extension, eco-design, or material recirculation are often not directly transferable. Many studies in SSA are conceptual or policy-oriented, with few empirically grounded investigations that examine how CE principles can be practically applied in local contexts, especially among small-scale and informal actors (Koc et al., 2024).

The field of industrial symbiosis (IS) remains significantly underexplored in SSA. While isolated IS case studies exist in countries like South Africa, Tanzania, Kenya, and Mauritius (see above), there is a scarcity of research across the broader region (Boom-Cárcamo and Peñabaena-Niebles, 2022). Existing studies tend to focus on well-established industries such as textiles in Ethiopia, sugar processing in Tanzania, and oil refining in Mauritius, while neglecting emerging sectors in other countries. Further empirical studies are needed to map out underutilized waste streams and explore untapped IS opportunities, particularly among smaller and less-integrated firms.

Additionally, there is considerable potential for developing new IS networks. While some industrial linkages have been established, many waste materials remain unexploited due to a lack of information on their availability, quality, and economic viability. Research should investigate how to facilitate the development of new symbiotic relationships, with attention to cost structures, supply chain logistics, and targeted incentive mechanisms. The role of regulatory frameworks, government infrastructure, and policy incentives also warrants deeper examination, as these factors critically shape the enabling environment for IS adoption (Kuri-Sarpong et al., 2016).

Another neglected area involves the characterization of waste streams generated by industries across SSA. Without robust data on the types, quantities, and physical/chemical properties of industrial waste, it is difficult to identify feasible symbiosis pathways or material substitution opportunities (Nkulu et al., 2018). There is a need for comprehensive mapping of waste availability at national and regional levels, integrated with spatial data and industry cluster analysis.

Social and behavioral dimensions also remain under-researched. Public perception of waste-based products, social acceptance, and cultural attitudes toward reuse and recycling are key factors influencing the uptake of CE and IS models. Yet, studies rarely examine these socio-cultural elements, which are crucial for mainstreaming CE practices at the community and household levels. Furthermore, informal waste workers, who contribute significantly to material recovery and reuse, are often excluded from CE and IS planning, despite their potential role in building circular systems (Bennett et al., 2019).

Lastly, the sustainability and long-term impact of CE and IS initiatives in SSA remain poorly evaluated. Most existing research focuses on short-term outputs rather than life-cycle assessments, economic feasibility studies, or social equity analyses. There is a pressing need for longitudinal studies that assess environmental, economic, and social outcomes of circular practices to inform policy and investment decisions.

By the five case studies the dissertation aims to address most of the above research gaps in circular economy and waste material utilization in Sub-Saharan Africa (SSA). All case studies touch on aspects of the CE framework, policy and regulation as well as waste characterization in SSA. Table 2 demonstrates what (other) research gaps are covered by the different case studies.

Sub-chapter 5.1 explores micro-level waste exchange in Uganda through seven mini-case studies, highlighting the economic, environmental, and social benefits of waste reuse and the challenges of scaling these activities. It addresses gaps in small-scale industrial symbiosis and emphasizes the need for better waste characterization and supportive policies.

Sub-chapter 5.2 focuses on agricultural waste exchange and how industrial waste can be used in agriculture in Uganda, presenting a case of an ecological farm utilizing internal and external waste exchanges. It tackles gaps in Integrated Farming Systems (IFS), showing how agricultural waste can enhance productivity and industrial waste can be used as input in agriculture, while reducing environmental impact, but also identifies barriers such as limited market access for recycled materials.

Sub-chapter 5.3 shifts to the meso level with an analysis of waste utilization in the Kampala Industrial and Business Park. It addresses industrial symbiosis at the park level, showing the potential for resource sharing between industries, while highlighting challenges related to infrastructure and coordination in formal IS networks. Therefore, this case study mostly aims to fill research gaps in sectoral coverage, network development, waste characterization, the engagement of the informal sector (especially for waste collection and sorting), and regulatory aspects.

Sub-chapter 5.4 presents a macro-level case on copper mining waste in Zambia, a major sector in SSA. It highlights the potential for recycling mining waste but also discusses economic, technological, knowledge and regulatory challenges in repurposing mining by-products, contributing to the understanding of waste utilization in extractive industries. This case study mostly addresses gaps in sectoral coverage, social acceptance, waste characterization, long-term impact as well as policy and regulation.

Finally, Sub-chapter 5.5 provides a comprehensive look at waste utilization in Ghana, covering micro, meso, and macro perspectives. By interviewing companies and policymakers, it addresses waste recycling at different scales, showing how businesses, experts, and policies can work together to promote a circular economy and green industrialization. Consequently, this final case study touches on gaps related to the CE framework, IS, sectoral coverage, policy and regulation, waste characterization, informal sector, social acceptance and long-term impact.

Table 3. Research Gaps: Circular Economy and Industrial Symbiosis in SSA

Research Area	**Identified Gaps**	**Case Studies**				
		1	**2**	**3**	**4**	**5**
CE Framework	Poor contextual adaptation of CE principles to SSA's informal, low-infrastructure environments	x	x	x	x	x
Geographic Focus	Concentration on urban areas; neglect of rural and peri-urban contexts		x		x	
Industrial Symbiosis (IS)	Sparse research on IS across most SSA countries and sectors		x	x	x	x
Sectoral Coverage	Limited studies beyond traditional industries (e.g., sugar, oil, textiles)			x	x	x
Network Development	Lack of understanding on how to establish new IS relationships			x		
Policy & Regulation	Insufficient analysis of local policies, incentives, and regulatory environments	x	x	x	x	x
Waste Characterization	Limited data on industrial waste types, quantities, and usability	x	x	x	x	x
Informal Sector	Exclusion of informal actors from CE and IS frameworks			x		x
Social Acceptance	Lack of research on cultural attitudes and public perception of waste-based products	x		x	x	x
Long-Term Impact	Few studies assess life-cycle, environmental, or socio-economic impacts of CE and IS initiatives		x		x	x

CHAPTER 3: RESEARCH QUESTIONS, DESIGN, METHODOLOGZ AND LIMITATIONS

3.1. Research Questions

The aim of this dissertation is to explore the challenges and opportunities of circular economy in Sub-Saharan Africa. As argued before, this is executed through the concept of industrial symbiosis, namely, the utilization of economic actors', production companies' waste and by-product materials by other actors. Therefore, the main research question of the research is the following:

> ***RQ: How and why does the utilization of waste and by-product materials have potential and face challenges in Sub-Saharan Africa?***

To answer this comprehensive question, it is broken down into three sub-questions (SQ). First, since industrial symbiosis and the circular economy focus on physical materials, to understand the drivers and potentials of waste exchange it is crucial to see the available waste and by-product materials. Accordingly, the first sub-question is:

> ***SQ1: How are specific waste materials and by-products exchanged, or could be exchanged, between industries to promote circular economy practices?***

Second, after seeing the list of these materials, one needs to scrutinize if these materials are already used or if not, why they are not used. Consequently, the next sub-question aims to explore the level and way of waste material usage and the barriers for those not used in the following format.

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

After this, the remaining part of the puzzle focuses on the materials not used and the potential drivers of how they could be utilized, as follows.

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

The aim of this last sub-question is to provide potential solutions, and policy recommendations for the facilitation of waste exchange among companies and industrial symbiosis in the region.

3.2. Methodology and Research design

To answer the research question and the related sub-questions, the dissertation employs case studies based on 105 semi-structured interviews via field research. In this part, first, the research design, then, theoretical framework and conceptualization are explained which served input to the interview questionnaires. Then, country selection is described. Finally, case study selection and data collection methods are presented.

3.2.1. Research design: Grounded theory, exploratory and fundamental research

As stated above, waste exchange and utilization research is relatively underrepresented in SSA. The number of relevant published research articles is limited and databases are absent. In general, the whole concept of circular economy is in its initial phase in the region. Consequently, the research project aims to explore an undiscovered field. This makes its nature exploratory based on fundamental research and grounded theory. These creat the theoretical framework of the dissertation, as explained below.

Grounded Theory (GT), exploratory research, and fundamental research each play distinctive but complementary roles in building theoretical and empirical knowledge, particularly in the social, environmental, and business sciences. While GT provides a methodological framework for inductively generating theory from data (Glaser and Strauss, 2017), exploratory research focuses on the investigation of poorly understood phenomena without predefined hypotheses. Fundamental research, on the other hand, is concerned with expanding fundamental knowledge and understanding of concepts and relationships, often independent of immediate application. Together, these approaches contribute to the discovery, refinement, and development of new theories in emerging or complex domains.

In the social sciences, exploratory and GT-based approaches are frequently combined to study lived experiences and hidden social processes. For instance, Hussein et al. (2020) used GT to explore how cultural memory shapes psychosocial well-being in historic urban settings. Their exploratory study, grounded in field interviews, uncovered deeply embedded cultural narratives not addressed by existing theory. Likewise, Soliman et al. (2022) employed GT within an exploratory framework to investigate sustainability values in informal settlements, a domain where traditional theory-building has been limited. These examples show how GT and exploratory research can synergize in contexts where formal theory is underdeveloped and social dynamics are complex.

Environmental education research has also benefited from GT's alignment with exploratory goals. Smith-Sebasto and Walker (2010) conducted an exploratory case study using GT to derive a model of student learning in a residential environmental education program. Their work exemplifies how exploratory qualitative inquiry - using participant narratives and experiential data - can lead to new theoretical insights. Bowers and Creamer (2020), in a systematic review, synthesized findings from numerous exploratory studies in environmental education using GT coding principles, underscoring the method's strength in identifying emergent themes across cases.

In business and management research, GT is commonly positioned as both exploratory and theory-generative, particularly where researchers seek to investigate under-theorized phenomena. Geiger and Turley (2003) explored the nature of client relationships in sales through an open-ended GT approach, revealing the nuanced, co-constructed nature of trust and persuasion. Binder and Edwards (2010) conducted an exploratory GT study in the automotive industry to examine governance mechanisms in inter-firm relationships, providing a conceptual framework that emerged directly from qualitative interviews. Goyal et al. (2022) similarly adopted an exploratory GT lens to examine gender-based pay disparity in organizational contexts, uncovering structural and cultural patterns that perpetuate inequity.

Exploratory research is particularly important when entering a domain where variables and relationships are not yet well-defined. As Douglas (2003) noted, grounded theory is inherently exploratory and serves as a bridge to basic theory development by capturing patterns in behavior and decision-making that may otherwise remain invisible. O'Reilly et al. (2012) further emphasized this by clarifying how GT can serve as a methodological pathway to abstract theoretical development in business disciplines, especially when researchers begin with open-ended questions rather than testable hypotheses.

From a fundamental research perspective, grounded theory supports the foundational work of building generalizable concepts and theoretical models. Unlike applied research, which aims to solve practical problems, fundamental research often begins with open exploration, seeking to enhance disciplinary knowledge. For instance, Bowers and Creamer's (2020) GT-based synthesis contributed to the basic theory of environmental learning by identifying cross-cutting dimensions of student engagement. Likewise, Goyal et al.'s (2022) work offers a contribution to basic understanding of organizational inequality structures, providing a foundation for further empirical and policy-oriented investigations.

These methodological intersections demonstrate the epistemological value of GT within both exploratory and fundamental research paradigms. GT offers a structured pathway for inductive theory building, aligning with the open-ended, hypothesis-free nature of exploratory research while contributing to the theoretical rigor demanded by fundamental research. In disciplines characterized by social complexity, rapid change, or insufficient prior theory, GT remains a particularly powerful approach for discovering novel insights and initiating new lines of inquiry.

3.2.2. Theoretical framework and conceptualization

The concept and business model of Industrial Symbiosis is employed to conceptualize the research, as it focuses on the exchange and utilization of waste and by-product materials. Understanding IS in details is crucial to determine main topics and factors which can be used as inputs for the questionnaires of the data collection. Thus, this sub-section presents the typology of IS, main drivers and barriers, enhancing policies and the economic modelling of IS.

Typology of Industrial Symbiosis relationships

One of the most commonly used differentiation among IS cases, also applied by Neves et al. (2019), is the level of implementation, referred to the boundaries at which IS partnerships develop. The micro level is related to the company level; meso level describes the relationship between companies with geographic proximity, such as (eco-)industrial parks; and the macro level refers to activities that are carried-out on regional or national level. Henriques et al. (2021) apply another but similar typology, focusing more on the „exchange" aspect of IS, which, as mentioned above, has highlighted importance for the research project, following Chertow's (2000) definition. They differentiate four different levels:

1. **Internal exchange**, which refers to the development of synergies within one certain organization. The main advantage of implementing internal IS is realized in the added value through lower virgin input purchase, and thus production costs, and additional revenues.
2. **External exchange**, which refers to two or more companies who can send or receive wastes to/from other companies, which will use them in their production processes. In this model, the value is captured in two perspectives: the sender (or supplier) through the sale of the waste that is used by other companies (or at least to avoid the cost associated to waste disposal) and the receiver through lower production cost.
3. **Eco Industrial Park,** where the local companies cooperate with each other in order to reduce the waste and pollution trough the symbiotic exchanges. The main goal of this collaboration is to reduce economic costs and engage in sustainable production practices. In this approach, a central authority may design and manage the stream exchanges that will take place in the EIP. The value is captured through material exchanges (by-products, wastes, resources or real-value products), operational cost reduction and non-direct revenues like stakeholder contributions and tax benefits.
4. **Urban Industrial Symbiosis** is described as a network of community and industrial actors bridging local needs to improve resource utilization, by exploring synergies in urban and industrial areas, namely by using municipal solid waste into industrial companies, and meanwhile, applying industries as

providers for living resources. In this approach, the government usually facilitates the wastes exchanges and interaction between companies and community, and, therefore, this approach is characterized by a high level of centralization.

For a sectoral analysis and typology, our starting point is Neves et al. (2019) synthesizing the results of 103 articles and studies on potential industrial symbiosis. In their sample, manufacturing accounts for 63% of the total occurrences, and other sectors, such as agriculture, forestry and fishing, electricity and water, and waste management and recycling are also among the most common cases.

Regarding the types of waste exchanged, organic waste is the absolute leading material (food and food processing wastes, biomass, livestock and fisheries wastes), followed by rubber, wood, metallic, non-metallic (such as glass, waste from construction and demolition, lime-based waste), paper, waste heat and steam, ash, water and wastewater, chemicals, sludge, waste oil and others (such as textile waste).

Drivers and barriers of Industrial Symbiosis

In the literature of industrial symbiosis, one of the central topics of analysis is the factors that facilitate or hinder the establishment and success of this synergetic relationship, respectively its "drivers" (or enablers elsewhere) and "barriers". In this issue, again, Neves et al. (2019) provide the most thorough and comprehensive article summary available by the time being and highlight the following.

The most frequent Drivers are:

- Knowledge of environmental, economic and social benefits (Neves et al., 2019),
- Legislation, plans and policies (Mouzakitis et al., 2019; Wang et al., 2015; Behera et al., 2015; Carpenter and Gardner, 2008; Ometto et al., 2007)
- Concern for environmental issues (Mathews and Tan, 2011; Liu et al., 2018),
- Existence of cases of industrial symbiosis implemented (Pakarinen et al., 2010),

- Presence of cases of self-organized symbiosis networks (Domenech et al., 2019; Pakarinen et al., 2010; Patricio et al., 2018; Daddi et al., 2015; Wolf and Petersson, 2007),
- Existence of facilitators (Simboli et al., 2014, 2015 and 2017),
- Good communication routes (Simboli et al., 2014, 2015 and 2017)
- Good geographical position (Simboli et al., 2014, 2015 and 2017),
- Stakeholder involvement (Simboli et al., 2014, 2015 and 2017),
- Predominance of some types of industry (Hara et al., 2011; Simboli et al., 2015; Zhu et al, 2019)
- Diversity of industries (Mathews and Tan, 2011),
- Existence of companies or industries anchor tenant (Jensen et al., 2012),
- Geographic proximity (Simboli et al., 2017).

The most frequent Barriers are:

- Lack of appropriate legislation and policies (Simboli et al., 2015),
- Lack of knowledge of industrial symbiosis practice (Bacudio et al., 2016),
- Lack of knowledge of companies with potential to receive or provide waste (Wolf et al., 2005),
- Lack of trust (Bacudio et al., 2016),
- Resistance to providing process and generated waste data (Mauthoor, 2017),
- Uncertainty of the profitability of the symbiosis network (Afshari et al., 2018),
- Associated costs and risks (Mouzakitis et al., 2019),
- Fear of dependence on the continuity of waste flow in sufficient quantity and quality (Wolf et al., 2005),
- Low virgin material prices and economic value of waste (Dong et al., 2017),
- Limited willingness of stakeholders to collaborate (Bacudio et al., 2016),
- Initial cost associated with infrastructure and some equipment (Kim et al., 2018),
- Lack of technology availability (Bacudio et al., 2016),
- Social and economic instability of a country (Neves et al., 2019).

Policies enhancing Industrial Symbiosis

Another frequent topic in the literature refers to the policies national or local governments can apply to facilitate industrial symbiosis in their countries, regions or municipalities. To overcome the above-mentioned barriers of IS, Neves et al. (2019) also collected strategies, that lead us further to the certain policies:

- Changes the regulations and policies to facilitate the use of waste,
- Provision of economic incentives,
- Provision of dissemination actions,
- Provision of trainings,
- Introducing facilitating entities,
- Using digital programs and platforms,
- Greater investment in research and development of technological innovations.

Lybaek et al. (2020) differentiate between top-down and bottom-up as well as direct and indirect IS policies. They define top-down policies as policies formulated by central governments and international or supra-national organizations (in their case, the EU), whereas bottom-up policies are understood as more local incentives, support and initiatives, etc. taken by local stakeholders and governments at the municipal and regional level.

Under direct policies they understand policies which are formulated by a governmental agency (on national, regional or local level of governance) that are designed explicitly and specifically to support, promote or legally enforce industrial symbiosis. Best examples for direct policies are the National Industrial Symbiosis Programme of the UK, or the sub-programmes of the EU-UNEP-run Switch Africa Green Programme (UNEP, 2021) in Sub-Saharan African context.

On the other hand, indirect policies are policies that are not explicitly designed for industrial symbiosis but influence industrial symbiosis systems anyway. They cover a very broad range of general framework conditions such as infrastructure policies, general tax and tariff policies (such as landfilling tax), waste policies and general policies that regulate market conditions for resources, products or services, among others.

The participants in the symbiosis have to realize the economic benefits from this activity. As mentioned by Neves et al. (2019), the economic component (regulations, policies and incentives) has been referred to by various authors as being essential in inducing companies to take the initiative to establish an industrial symbiosis relationship.

Moreover, Lybaek et al. (2020) concluded in their analysis on IS-policies that incentives-based policy support at the local level regarding land-use regulation and planning are important for Industrial symbiosis to develop, and that indirect waste policies are more valuable for industries than direct policies targeting Industrial symbiosis. They also refer to Kim (2007) who finds that governments should focus on local incentives rather than top-down regulation.

If the economic value of raw materials is very close to that of waste, there is no incentive for companies to use waste in their production processes. The main aim of using economic instruments in the waste sector is typically to reduce waste generation or divert waste away from landfill towards recycling and recovery (Nahman et a., 2012). Moreover, the price that companies are willing to pay for waste may not be economically advantageous for the company producing such waste. In this case, there is no incentive for companies to divert waste from landfills and start a symbiosis relationship.

Based on Boons et al. (2011) and Bertani et al. (2019), the costs and benefits for supplier and buyer companies in IS can be modelled by two fitness condition equations. For simplicity, there are two assumptions: 1. suppliers carry out necessary treatments of waste and bear related costs, and 2. The transportation of input materials generates cost for the buyers. Thus, economic factors for suppliers and buyers are different, which needs to be considered explicitly.

Hence, the IS fitness condition for a supplier company is as follows:

$$c_{st} + c_p - p_w \leq l + c_{trl} \qquad (1)$$

where

- c_p is the pre-processing and/or handling cost of waste;

- c_{st} is the storage cost of waste;
- p_w is the waste selling price;
- l is landfill tax;
- c_{trl} is the transportation cost to the nearest landfill location.

In other words, it means that supplier companies will establish or stay in industrial symbiosis relationships as long as the cost related to the waste selling (pre-processing costs – waste selling price) will be lower than its cost related to landfilling (landfilling tax + transportation cost). Thus, if landfilling taxes are increased, supplier companies will be more motivated to sell their waste materials than to landfill them.

For a buyer company, the IS fitness condition can be described as follows:

$$p_w + c_{trw} \leq p_v + c_{trv} \qquad (2)$$

where

- p_w is the waste selling price;
- c_{trw} is the transportation cost of waste;
- p_v is the price of virgin material;
- c_{trv} is the virgin material transportation cost.

This means that a receiver company will establish or stay in industrial symbiosis relationships as long as its costs related to using waste materials are lower than its costs related to using virgin materials. Subsidies have the role in holding this difference. If subsidies are increased, the receiver companies will be more motivated to keep using or switch to waste or secondary materials.

These cost items presented here serve as the basis for the interview questionnaire used in the case studies, completed with other relevant items such as sorting and treatment, in some cases labour, utilities and certification costs.

3.2.3. Country selection

For country selection, two factors were taken into consideration. First, the existing circular economy and industrial symbiosis cases already revealed in literature. Second, as the dissertation is based on field research activities, personal and professional connections as well as previous field experience played a crucial role. Additionally, the author masters English language for high quality data collection, against French or Portuguese, thus, anglophonic countries were preferred.

Image 1. Location of the three research countries within Africa; Source: Crowdfunder, 2025

Regarding the first factor, a report from the NGO Footprints Africa (2021) identified most businesses and initiatives applying circular economic models in five countries of the continent: Ghana, Kenya, Tanzania, South Africa and Uganda. Moreover, the common project of the EU, UNEP, UNDP and UNOPS “Switch Africa Green” focused on six countries (Burkina Faso, Ghana, Uganda, Kenya, Mauritius and South Africa) with one of the programs dedicated to the facilitation of industrial symbiosis in 2020 (UNEP, 2020 and 2021). These reports helped narrow down the number of potential countries.

From this list, Uganda was selected due to a private trip to the country in May 2021 which enabled the researcher to visit some of the initiatives mentioned in these reports and get in contact and discussion with local experts and professional bodies, such as the Uganda Cleaner Production Centre and the National Planning Authority. These activities were also supported by other professional contacts gained before the trip through other work activities. The exploration of further local cases was based on a snow-ball method, through the recommendation of interview respondents and local professionals.

Chronologically, Ghana has been determined as another country for the research, based on the high number of cases detected by Footprints Africa (their HQ is also in Ghana), the previous work and field experience of the researcher gained in the country in 2015, and a research grant by the Institute for Advance Study of the Central European University Foundation in Budapest. Additionally, the author participated in a conference in Accra, Ghana in 2022, during which an initial meeting with the Ghana Cleaner Production Centre drafted the starting sample of companies and experts for the research.

Zambia was selected also due to the above-mentioned Ghanaian conference, where the researcher met two colleagues from the Copperbelt University of Zambia (CBU), who focused on copper mining. As the dissertation research was still missing to touch on one important sector in Africa, mining, this personal connection offered a great opportunity to include the issue of Zambian copper mining waste in the research. The local knowledge and connections of the CBU colleagues enabled the research to meet mining experts, mining companies and other local researchers at CBU and other institutes working on the utilization of copper mining waste materials.

3.2.4. Case study selection and data collection

Gerring (2004. p. 342) defines the case study as "an intensive study of a single unit for the purpose of understanding a larger class of (similar) units". The case study selection motivation is two-fold. First, it aims to touch on each scale of waste exchange, as mentioned in Chapter 2, micro, meso and macro levels (see Table 4).

Table 4. Case studies according to waste exchange level, categorization by Henriques et al. (2021); Source: author's constrcution

Level	Form of exchange	Actors	Sub-chapters
Micro	Internal exchange	One single company	5.2., 5.5.
	External exchange	Two or more companies	5.1., 5.2., 5.5.
Meso	(Eco) Industrial park	Companies in the industrial park and park management authority	5.3.
	Urban industrial symbiosis	Local community (authority) and companies	5.5.

Macro	Nation-wide industrial symbiosis	Economic sectors	5.4., 5.5.

Second, as the research aimed to draw conclusions for the whole SSA region, the case studies touch on most industrial and production sectors dominant in Sub-Saharan Africa. Therefore, the dissertation also applies the comparison of most-different cases design, as it aims to provide a strong basis for generalization (Seawright and Gerring, 2008). Each case study is based on field research activities for data collection through semi-structured interviews between May 2021 and March 2024. This method of data collection was chosen against other ones, such as anonymous online surveying, because informants may require guidance and explanation at certain questions, and additional information and further observations can be gained, as well.

Along with the logic of exploratory research and grounded theory, the depth of research and the development of interview questionnaires evolved chronologically. This means that not the same questionnaires and respondent guiding techniques were used for all case studies. Experiences and feedback from each step resulted in modification and changes of questions, the questionnaire structure and asking methods to increase the precision and efficiency of data collection and to be suited to the given case, industry or company. As the case studies are presented in chronological order, this evolution is also reflected in the depth of analysis.

The questionnaires for semi-structured interviews were mostly inspired by previous research papers related to industrial symbiosis (HAEE, 2021; Neves et al., 2019; Bertani et al., 2019; Gibb and Deutz, 2007; Boons et al., 2011) and completed by other relevant questions for the given case. They were designed in four different sections dedicated to the respondents' waste exchange role (waste users, waste not users, waste suppliers, and waste not suppliers) and the questions focused on different aspects to understand the drivers and barriers of waste exchange, such as attitudes, knowledge, economic costs and benefits, technology, and regulation. Further information regarding each case study is presented in the following.

Case study 1

Sub-chapter 5.1 presents micro-level (external) waste exchange by seven mini case studies of businesses and entrepreneurs applying circular economy models in Uganda. The organizations were visited and interviewed within the framework of field research in the country in May 2021. These samples were selected from Footprint Africa's Circular Economy Case study report (2021) and based on the recommendation of experts at the Uganda Cleaner Production Centre and the Uganda National Planning Authority. The examples touch on plastic recycling, agriculture, carpentry, textile, paper and packaging industries. Beside introducing their core activities, the research focused on highlighting the economic, environmental and social benefits created by these businesses, while competitor products and main challenges are also discussed.

Case study 2

Still remaining at the micro level of waste exchange, Sub-chapter 5.2. focuses on agriculture, one of the main economic sectors in Sub-Saharan Africa, by presenting the further economic utilization of different non-hazardous and non-infectious waste materials (hereafter industrial waste) by using the models of IS and integrated farming systems (IFS). For analysis, the paper applies schematic modelling of IS fitness conditions for companies, revealing the actors' organizational motivations and financial gains. Data collection was carried out through two field visits in May 2021 and June 2022, which included participant observation and twelve qualitative interviews with existing and potential partners.

Amelia Agro Africa Ltd. is a small-scale organic farm in Jinja, Uganda. They grow several varieties of plants, raise animals (chicken, fish, pigs, cows, goats, rabbits) and produce organic fertilizer (compost) for the local market. The farm uses several waste materials for composting, feeding animals and plant protection due to a great number of waste exchange relationships both internally and externally. This makes it perfect for a case study to: a) present a variety of waste and by-product materials suitable for further economic utilization in SSA, and b) enable the research to examine the economic factors, gains and costs of the farm's IS partners, and thus inform the conceptualization of a local incentive policy. This latter element is even more significant, as the farm's IS clientel represents nearly one-third of the Ugandan manufacturing sector's portfolio[2] (MTIC, 2021, p.5).

Amelia Agro was first visited in May 2021 (see Chapter 5.1. and Buda, 2022) based on the recommendations of experts at the Uganda Cleaner Production Centre and National Planning Authority. Then, the farm's operation was observed and studied and the IS and IFS aspects were discussed with the farm's managing director. This also included identifying supplier companies for further company visits and interviews. The description of different material utilization practices, presented below. Following this first field work, the waste materials utilized and practices applied through IS by the farm were researched via literature review.

A second field research trip was carried out in June 2022, through which data was gathered from the farm's suppliers. Nine companies, whose waste materials are utilized by the farm, were visited and interviewed. These nine informants represented more than two-thirds of the farm's suppliers and were selected based on their availability and willingness to respond. Furthermore, the researcher also visited two other companies as potential future suppliers and one agro-waste distributor company selling materials to the farm. In accordance with the IS fitness condition (1) for suppliers, the semi-structured interviews focused on the following aspects:

1. supplier's primary motivation to participate in the IS relationship;
2. landfilling costs saved;
3. transportation costs to landfill saved;
4. storing costs realized;
5. handling or pre-processing costs realized;
6. whether Amelia Agro pays for the received material;
7. whether Amelia Agro pays for the transportation of waste received;
8. the value of these cost items relative to each other.

[2] According to the Ugandan Green Manufacturing Strategy, the local manufacturing sector comprises mainly manufacture of food products, beverages, tobacco products, textiles and clothing apparel, leather and eather products, wood and wood products, paper and paper products, chemicals and chemical products, pharmaceuticals, medicinal chemicals and botanical products, rubber and plastics products, basic metals and fabricated metal products, cement and bricks. The presented IS relationships in this paper cover nearly one-third of this portfolio.

In line with the above-mentioned logic, the case study applies the model of IS and equations (1) and (2) as its theoretical framework (see 3.2.). The results presented in the following section should be seen as snapshots from the two field visits in May 2021 and June 2022. Amelia Agro is continuously experimenting with the utilization of new industrial materials to broaden its supplier portfolio, improve economies of scale and elaborate best practices. Based on the low sample number, these results are not representative and not statistically significant, yet they serve the deeper understanding of the research topic.

Case study 3

In Sub-chapter 5.3., the Kampala Industrial and Business Park (KIBP) in Uganda is used as a case study to explore the potential and challenges of waste exchange and utilization on the meso level. KIBP is located in Namanve, the suburb of Kampala, Uganda's capital city. It is the country's oldest and largest industrial area, playing a highlighted role and example for local industrial expansion, with tenants of various categories, stretching from large local or multi-national companies with decades of operation to newly established firms and SMEs. The park management is under the Uganda Investment Authority with sector specific support from the Government of Uganda agencies such as the National Environment Management Authority (NEMA) which handles the environment-related aspects of the enterprises within the park from design to operational phases, the Uganda National Bureau of Standards (UNBS), among others. KIBP was selected for a case study based on its importance in the local industrialization progress, the large number of tenant companies, and the openness of the park management, as of the availability of peer support, to collaborate in the research process.

The analysis is based on information obtained from companies operating in the park and the park management authority. In the following when writing about respondent companies, I interchangeably use companies, firms, enterprises in the text. Each of these expressions refer to economic organizations operating in the park under an official tenancy agreement.

Accordingly, semi-structured interviews were conducted and complemented by site-visits to enterprises wherever possible allowed the researcher to probe further on aspects such as cost items occurring when using or selling waste materials (see Boons et al. Bertanini et al.); attitude towards and/or awareness on waste usage or selling as practice; barriers to engaging in industrial symbiosis approaches and the support needs. Inspired by HAEE (2021), the questionnaire comprised four main sections, separately for waste material receivers and non-receivers, as well as waste material suppliers and non-suppliers.

Data was collected between 24th January and 12th April 2023. Respondents to the research were selected with the support of the industrial park management. At the time of data collection, slightly over 100 companies are registered and /or operational in the KIBP. The first selection criterion focused on producing companies that generate physical waste materials and have the potential to use those, as well. A second criterion focused on bigger companies which might have advantages in economies of scale and organizational capacities to implement industrial symbiosis practices. Third, companies known for recycling activities were also included. Accordingly, a list received from the park management contained 78 enterprises.

First, all the 78 companies were contacted and invited to partake the research. In response, some indicated that they were not operational yet while others turned down the invitation. Consequently, only enterprises that were operational and open to partake in the research were engaged. Respondents were informed about the research objectives in written and verbal format. Further, the researchers emphasized to the respondents that participation in the study was at free will and that respondents were also at liberty to decide which questions to answer and stop the interview at any time without explanation. In cases where audio recording was required, written consent was obtained from respondents. All recordings were deleted after transcription and analysis. Following the first interviews and a preliminary examination of the answers, some companies were contacted again physically, on phone or WhatsApp to respond to follow-up and supplementary questions missed or unclearly answered during the first interviews.

From the list of 78 companies, 42 interviews were conducted and one in-depth discussion with the park management authority. In terms of business size, based on Ugandan business categorization (MTIC, 2015), 18 firms count as small, 9 as medium and 15 as large business entities. Regarding business activity, most of the respondents were chemicals, cosmetics, plastics (most common) and foam producers. These were followed by those from agricultural, food and beverages processing companies. These are followed by a smaller number of metal processing and electronics producers, and a few ones in other sectors, such as carpentry, timber and paper, construction and materials producers and a tobacco factory (see Figure 3).

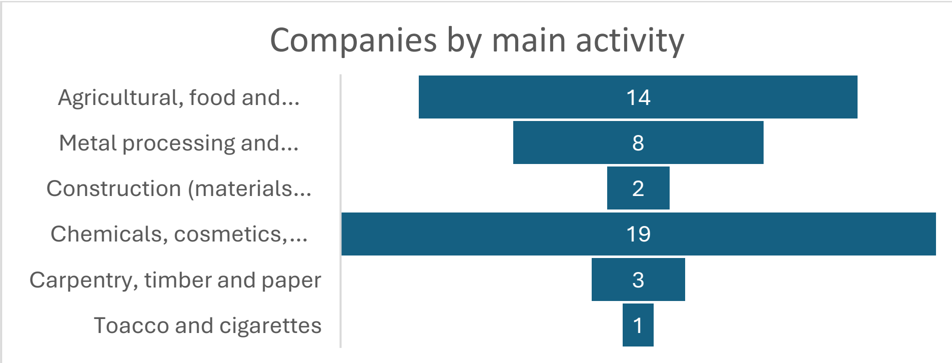

Figure 3. The 42 interviewed companies in KIBP, categorized by production activity, Source: author's construction

Beside the companies, the park management was also interviewed. The questions focused on the role of the park management in facilitating industrial symbiosis and greening the industrial park. The questionnaire for this in-depth discussion was partly adapted from the Framework for Eco-Industrial Parks (World Bank, 2021, pp. 42-43.) and Gibbs and Deutz (2007).

Case study 4

Sub-chapter 5.4. analyses the factors that facilitate and hinder the utilization of copper mining waste in Zambia, particularly in the Copperbelt Province. The topic is highly relevant both in Africa and globally. Although the mining sector is economically vital for the region, it produces enormous amounts of waste materials with hazardous characteristics for both humans and the natural environment. Copper mining slag is piled-up in the form of huge mountains (named "black mountains" locally), while mining tailings occupy hectares of lands resembling post-apocalyptic wastelands. Thus, new knowledge and research on the economic utilization of mining waste is of great interest and can contribute to job creation, the diversification of the economy and the achievement of sustainable development, the mitigation of negative environmental impacts, among other important goals.

According to Lebre et al. (2017) and Khorami et al. (2019), the mining sector is a significant producer of waste and is to blame for the quick depletion of non-renewable mineral resources. Inextricably connected to population expansion, economic development, and technological improvement is the depletion of mineral resources. As a result, it is anticipated that during the coming decades, both primary resource extraction and concurrent waste generation would significantly grow (UNEP, 2013 and 2016; UNEP-ISWA, 2015; Kuiper et al., 2018). With an average annual production of 17 million tons and a corresponding rise in the yearly production of copper slag waste of 37.7 million tons, copper is one of the metals that has seen high production rates globally (Phiri et al., 2021). According to advancements in the knowledge of the environmental consequences caused by anthropogenic activity, extensive mineral resource exploitation has a negative impact on the environment (Gorai et al., 2003; Roy et al., 2015; Potysz et al., 2015; Kuiper et al., 2018).

Metalliferous mine tailings and heaped overburden offer major environmental risks to the environment, to human health, and to agriculture in addition to changing the natural landscape. Tailings dams are frequently constructed close to populated areas in places where contaminated groundwater could endanger farming communities, such as in the Zambian Copperbelt region (von der Heyden and New, 2004). Moreover, both urban and national economies become extremely dependent on and exposed to the fluctuation of copper prices, as local communities also had to learn to live with pollution surrounding them (Pesa, 2022).

The circular economy might be applied to the mining sector by recycling waste streams like tailings and water, utilising recovered metals in products for an extended period of time, and lowering waste production through sophisticated sorting. It is important to examine the potential for a transition to a circular economy in various industrial sectors. Despite the tremendous economic potential in recycling waste into useable resources, very few efforts have been put into running the circular economy concept in mining rather than the existing linear economy approach (Lebre et al., 2017).

The circular economy can be implemented in mining in a variety of ways, starting at the organizational level where materials can be recycled or applied, moving up to the mine area level, and finally reaching the value chain and systemic levels where other businesses and industries can utilize the side streams (Zhao et al., 2012; Balanay and Halog, 2016).

Mine wastes usually include waste rock, overburden, slag, and tailings on land surfaces (Festi net al., 2018). Waste rock contains mineral concentrations too small to be of interest for extraction of minerals or metals. Overburden includes soil and rock that are removed to gain access to ore deposits. Copper slag is a by-product of copper extraction by smelting. During smelting, impurities become slag which floats on the molten metal. Tailings consists of sand-resembling materials. After the extraction and beneficiation of the minerals, the residuals and mill rejects are combined into a form of slurry and disposed into lagoons.

Lottermoser (2010, 2011) provides definitions to remining, reuse, recycling, reprocessing and treatment in mining. Remining refers to the recovery of minerals from previously mined areas/materials (incl. Storing for future remining). Reuse means using the materials without considerations of the mineral value and without reprocessing, typically for backfilling. Recycling is the conversion of waste into new valuable products with physical, thermal, biological or chemical methods. Reprocessing refers to using waste materials as a feedstock for producing valuable products when the used treatment reduces the toxicity or volume of the mine waste.

Regarding copper mining waste materials, or by-products, the research project specifically focused on copper smelter slag and mine tailings. As the utilization of other mining by-products is already in economic practice to a certain extent (such as waste rock for construction and copper slag for re-processing to extract remaining valuable minerals), this research work aimed to investigate the remaining materials of slag and tailings (after re-processing), as they may represent significant unused economic potential.

Based on Gorai et al. (2003) and Phiri at al. (2021), nine potential products have been identified to which copper mining waste materials can be used as production inputs. The study calls these as “destination products” which are the followings: blended cement, cement clinker, road pavement, abrasives, concrete, tiles, glass, cutting tools, roofing granules.

Neves et al. (2019) collected the drivers and barriers of this synergetic phenomenon. Based on their work, the interview questions and later findings are categorized into four aspects: knowledge, technological, economic and legal ones.

Under knowledge aspect, all factors were collected related to the lack of information, lack of circular economy mindset, general knowledge of using the waste materials for other purposes, and issues related to organizational knowledge or competence. The technological aspect refers to challenges in physical, mechanical, chemical processes and equipment to turn the given mining waste materials into a suitable form for the production of other products. The third aspect, economic, derives from the previous one and includes the general cost factors of industrial symbiosis (based on Boons et al. (2011) and Bertani et al. (2019), such as: pre-processing, treatment, handling, storing, transportation and material price. Finally, legal aspects refer to prevailing regulation and governmental will related to the management and utilization of copper mining waste materials.

Thus, to answer the research question, the research aimed to explore the role of these four aspects between the place of material generation (supplier) and the producer of these nine destination products (buyer). This framework is presented in Figure 4 below.

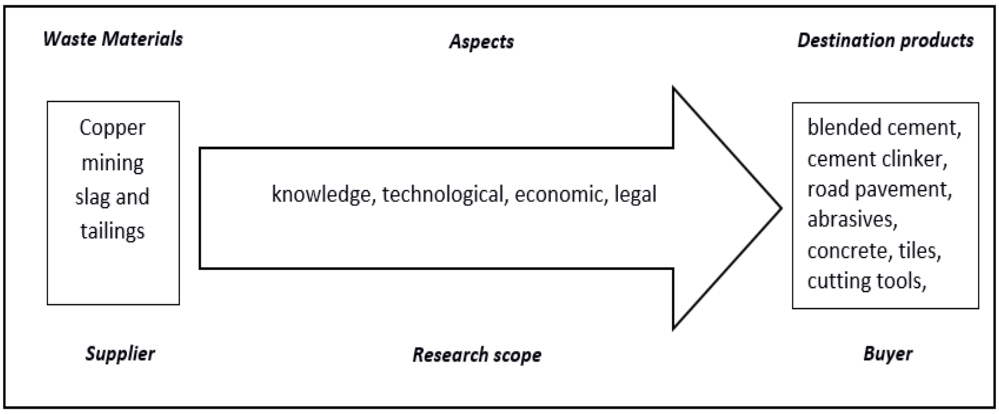

Figure 4. Conceptualization of the research for Case study 4.; Source: author's construction

Data collection was carried-out in the Copperbelt Province of Zambia (Kitwe, Mufulira and other smaller municipalities and facilities) between 12th and 26th April 2023, including nineteen interviews. Seven of these were with local experts, lecturers and researchers in the form of an unstructured discussion about the research interest. For mining or re-mining companies and destination companies, a questionnaire was developed for semi-structured interviews. Ten respondents representing the mining industry, working presently or formerly for mining companies were met and asked. Additionally, two concrete producer firms were also interviewed, as potential destination companies. The sample allows for exploration of views, but it is not representative. However, in the applied understanding it does not influence the main results and arguments, as seen below. All respondents were informed in verbal and written format about the research goal, the liberty in answering any of the questions or stopping the interview any time without explanation and they were also asked for written consent. The interview discussions were voice recorded, transcribed and then deleted.

Case study 5

Sub-chapter 5.5. includes micro, meso and macro level aspects of waste exchange and utilization based on interviewing twenty-three individual companies, highlighting three mini case studies of waste recycling companies, and discussing with four local experts and policy-makers related to waste utilization and the broader perspective of the circular economy and green industrialization in Ghana.

Data collection was carried out between September 2023 and April 2024 through four field research trips in the Greater Accra region of the country and with the help of a local research assistant. Semi-structured interviews with the individual production and the waste recycling companies (Accra Compost and Recycling Plant, Sewerage Systems Ghana Limited, Universal Plastic Products and Recycling Limited) were based on the same questionnaire used in Chapter 5.3. (waste users, waste not users, waste suppliers, waste not suppliers). The structured expert and policy maker discussions centered around five main topics: (green) industrial policy, cleaner production, resource efficiency, circular economy and waste management. Respondents represented the Ministry of Environment, Science, Technology and Innovation (MESTI), Africa Environmental Sanitation Consult, Association of Ghana Industries and the Ghana National Cleaner Production Centre.

At the end of each sub-chapter, the three sub-questions are answered.

3.3. Limitations

The research work for the dissertation met the following limitations.

First, the distance to the research countries made field research trips expensive and limited in time frames. Thus, the data collected was constrained by the availability of respondents during the visit to the field. However, thanks to modern technology, data collection was also possible online and by employing local research assistants. Nevertheless, the quality of data gained through personal visits was far better than of those gathered by different methods.

Furthermore, the research work aimed to draw generalizable conclusions for Sub-Saharan African. Even though, neither financial, time and research scope conditions could not make it possible to collect representative data from all 49 countries in the region. Hence, the research results are rather indicative than representative or statistically significant.

Another important limitation aspect is that the key informants in the research are representatives of companies or authorities. Therefore, the research and its conclusions are based on the answers of the respondents, independent from the truth these answers cover.

Finally, it is difficult to gain information about the exact cost items or other financial aspects in waste exchange and utilization. First, because of their sensitivity, second, because of the complexity of work activities. In many cases it is difficult to separate cost items from each other and exactly determine their weight. Consequently, to overcome these barriers, questions on cost items and financial aspects were designed for estimation and priority orders. This enabled the analysis to indicate the relevance and weight of different factors.

CHAPTER 4: RESEARCH CONTEXT

This Chapter briefly summarizes the contexts of each country involved in the research work. First, economic, industrial and sustainability status is taken under scrutiny. Then, the dissertation also touches on the relevant policy frameworks.

4.1. State of the economy, industrialization and sustainability in the research countries

4.1.1. Uganda

Nestled in the heart of East Africa, Uganda spans approximately 241,038 square kilometers and is bordered by Kenya, South Sudan, the Democratic Republic of Congo, Rwanda, and Tanzania (WorldAtlas, 2025). As of 2023, this landlocked nation is home to a vibrant population of about 50 million (Worldometer, 2025), earning its nickname as the "Pearl of Africa" for its breathtaking landscapes and rich biodiversity. Since gaining independence from British colonial rule in 1962, Uganda has endured tumultuous periods marked by dictatorship and civil strife. Nevertheless, recent decades have witnessed a resurgence of political stability and economic growth, leading to notable advancements in living standards.

Economic Structure (2000-2023)

Between 2000 and 2023, Uganda's economy has demonstrated remarkable resilience and transformation, encompassing three primary sectors: agriculture, industry, and services.

Share of Sectors (World Bank Group, 2025a):

- Agriculture: Once the bedrock of the economy, agriculture contributed around 34.79% of GDP in 2000. Although this share has decreased over time, with contributions declining from 5.82% growth in 2000 to 4.78% in 2023, the sector remains vital, employing approximately 70% of the population and accounting for 23.77% of GDP.

- Industry: The industrial sector has shown promising growth, increasing its GDP contribution from 21.44% in 2000 to 25.96% in 2023, driven primarily by construction, mining, and manufacturing. However, its growth rate has slowed from 10.18% in 2000 to 3.50% in 2023.
- Services: Expanding significantly, the services sector now contributes around 42.38% to GDP, up from 37.82% in 2000, with key subsectors including trade, transportation, telecommunications, and financial services.

In 2023, Uganda's economy grew by 4.6%, a slight decline from 6.3% in 2022. Inflation rates decreased from 7.2% to 5.5%, a result of the Bank of Uganda's stringent monetary policies, including a maintained policy rate of 10.25%. Overall, inflation has risen from 3.52% in 2000 to about 5.35% in 2023. The unemployment rate has also increased, from 2.83% in 2000 to 3.45% (World Bank Group, 2025a; AFDB, 2024)

Historically, Uganda's exports have been dominated by agricultural products. In the early 2000s, coffee was the leading foreign exchange earner, alongside tea, tobacco, fish, and cotton. By 2022, Uganda's exports had shifted, comprising gold ($1.92B), coffee ($753M), fish ($69.5M), raw sugar ($61.7M), and cocoa beans ($60M), with major export destinations including the United Arab Emirates, India, Hong Kong, Kenya, and Italy (OEC, 2025).

Conversely, Uganda's imports primarily consist of packaged medicaments ($230M), cars ($139M), motorcycles ($115M), and broadcasting equipment ($112M), mainly sourced from China, Kenya, India, the United Arab Emirates, and Tanzania (OEC, 2025). The East African Community (EAC) and the Common Market for Eastern and Southern Africa (COMESA) play crucial roles in Uganda's trade, enhancing regional integration and economic collaboration (EAC, 2025).

State of Industrialization

Uganda is at a pivotal stage in its industrialization journey, marked by the emergence of new industries and concerted efforts to bolster manufacturing. The National Industrial Policy (MTIC, 2020) aims to transition Uganda from a primarily agrarian economy to a modern industrialized one. Key infrastructure developments are underway, particularly in hydroelectric power production, to address energy shortages hindering industrial growth. Improved transportation networks are essential for facilitating efficient goods movement. However, Uganda faces challenges in its industrialization efforts, including limited financing for small and medium enterprises (SMEs), a shortage of skilled labor, and high production costs due to energy inefficiencies (AFDB, 2025)

Main Challenges to Sustainable Development and Industrialization

Uganda has made significant strides in its development since 2000, marked by robust economic growth, poverty reduction, and improvements in key social indicators. The challenges facing Uganda in sustaining economic growth and reducing poverty are compounded by increased shocks and a slower pace of policy reform. High population growth keeps a significant portion of the population in poverty, exacerbated by deficits in human capital and infrastructure that constrain growth and social welfare improvements (World Bank Group, 2025b). Uganda also faces challenges in achieving sustained economic growth and diversifying its economy beyond agriculture and raw commodity exports (UNIDO, 2024). Uganda faces significant challenges in providing adequate infrastructure and services, including transportation, healthcare, and education, which are essential for sustainable development (UNDP, 2022).

Industrialization in Uganda is at a developmental stage, with the country striving to transition from an agrarian-based economy to one driven by manufacturing and industrial activities. The industrial sector contributes approximately 36.07% to the GDP, with manufacturing alone accounting for about 16% (World Bank Group, 2025a). However, Uganda's industrial growth is constrained by challenges such as inadequate infrastructure, limited access to finance, and a shortage of skilled labor (UNDP, 2022). The major issue facing the Ugandan government to create a more conducive environment for industrial growth, emphasizing infrastructure development, improving vocational training, and enhancing regulatory frameworks. Uganda's industrial sector is underdeveloped, with limited capacity for adding value to agricultural products and raw materials and this limits industrial growth and economic diversification (UNIDO, 2024).

Uganda ranks 142 out of 166 countries on the sustainable development goals dashboard and has achieved about 56.13% in 2024 (Sachs et al., 2024). Uganda has significant potential for renewable energy, particularly hydroelectric power, but harnessing this potential effectively remains a challenge due to financial and technical constraints (UNDP, 2024). Economic sustainability is hindered by a reliance on natural resource-intensive sectors, coupled with limited technological advancements and infrastructure deficits.

In sum, Uganda's journey reflects a narrative of resilience and potential. Addressing infrastructure, educational, and technological challenges is paramount for fostering sustainable development and industrialization. Strategic investments and comprehensive policy reforms will be instrumental in realizing Uganda’s ambitious economic aspirations, paving the way for a brighter, more sustainable future.

4.1.2. Zambia

Zambia, a landlocked country in Southern Africa, is bordered by eight nations: the Democratic Republic of the Congo to the north, Tanzania to the northeast, Malawi to the east, Mozambique to the southeast, Zimbabwe and Botswana to the south, Namibia to the southwest, and Angola to the west. Spanning approximately 752,618 square kilometres (WorldAtlas, 2025), Zambia is home to a vibrant population of about 21 million as of 2024 (Worldometer, 2025).

Since gaining independence from British colonial rule in 1964, Zambia has carved out a reputation for its abundant mineral resources, particularly copper, which remains pivotal to its economy. The capital city, Lusaka, serves as the economic and political heart of the nation. Historically, Zambia's reliance on copper mining has profoundly shaped its economic landscape.

Economic Structure (2000-2023)

From 2000 to 2023, Zambia's economy has navigated a landscape of significant fluctuations, heavily influenced by global commodity prices, especially those of copper. While the mining sector remains dominant, substantial efforts have been made to diversify the economy with varying levels of success.

Share of Sectors (World Bank Group, 2025a)

- Agriculture: Contributing approximately 16.15% to GDP in 2000, this sector has faced a dramatic decline, accounting for only 2.79% by 2023. Key agricultural products include maize, soybeans, tobacco, cotton, and sugar. The GDP growth rate for agriculture has plummeted from 0.16% in 2000 to an alarming -15.86% in 2023.

- Industry: Comprising mining, manufacturing, and construction, the industrial sector has seen growth from 23.24% of GDP in 2000 to 36.07% in 2023. Mining and quarrying dominate this sector, contributing approximately 7.5% to GDP, with copper mining alone accounting for about 70% of export earnings.
- Services: The services sector has flourished, expanding from 48.96% of GDP in 2000 to around 54.9% in 2023. This growth is driven by retail, banking, telecommunications, and tourism, with a GDP growth rate soaring from 5.28% in 2000 to 9.90% in 2023.

In 2023, Zambia's GDP growth rose to 5.8%, up from 5.2% in 2022, with wholesale and retail commerce, agriculture, and mining fueling this expansion (AFDB, 2024). However, GDP growth has declined from 3.90% in 2000 to 5.83% in 2023. Inflation rates, while decreasing, remain high, having fallen from 26.03% in 2000 to 10.88% in 2023 (World Bank Group, 2025a). The fiscal deficit improved from 8.2% in 2022 to 6.6% in 2023, bolstered by increased mining revenues, while the current account deficit shifted from 3.8% to 1.1% in the same period. As of 2021, the unemployment rate stood at 13.8% (ZamStats, 2025).

Regarding exports (OEC, 2025), copper reigns supreme in Zambia's export landscape, constituting over 70% of total export revenue. The top exports include raw copper ($6.6B), refined copper ($2.78B), gold ($955M), and precious stones ($403M). Major export destinations encompass Switzerland ($4.5B), China ($2.6B), the Democratic Republic of the Congo ($1.51B), the Pitcairn Islands ($1.49B), and the United Arab Emirates ($1B). In 2022, Zambia emerged as the world's largest exporter of raw copper.

In the case of imports (OEC, 2025), Zambia's primary imports include refined petroleum ($519M), nitrogenous fertilizers ($391M), delivery trucks ($380M), copper ore ($372M), and packaged medicaments ($343M), sourced mainly from South Africa ($2.69B), Equatorial Guinea ($1.84B), China ($1.38B), the United Arab Emirates ($761M), and the Democratic Republic of the Congo ($656M).

Zambia actively engages in trade with fellow Southern African Development Community (SADC) countries, benefiting from various trading agreements, including membership in the Common Market for Eastern and Southern Africa (COMESA) and the African Continental Free Trade Area (AfCFTA).

State of Industrialization

Zambia's industrialization has progressed slowly, with mining as the main focus. While manufacturing has grown modestly, it remains underdeveloped compared to mining, fluctuating between 4.20% in 2001 and 4.40% in 2010. From 2000 to 2023, Zambia's industrialization was heavily reliant on copper, with efforts to diversify the economy moving slowly. The early 2000s saw significant dependence on copper, which fueled economic growth but left the country vulnerable to global price fluctuations (ZamStats, 2025).

In the 2010s, Zambia sought to diversify its economy by promoting agriculture, manufacturing, and services, with strong economic growth supported by Chinese investments (CFR, 2017) in mining and infrastructure. However, external shocks like fluctuating copper prices and global downturns affected stability. Although infrastructure and policy initiatives for industrialization improved, challenges like high debt, fiscal deficits, and political transitions continued to affect economic growth. Manufacturing contributes around 8% of GDP, including sectors like food processing, textiles, and beverages (ZDA, 2025).

Main Challenges in Sustainable Development and Industrialization

Zambia is advancing its sustainable development agenda, focusing on biodiversity conservation, combating desertification, and promoting sustainable forest use. However, critical challenges, such as insufficient infrastructure in transport and energy, hinder economic activities, especially in rural areas, limiting market access and growth. The economy's dependence on copper mining makes it vulnerable to global price fluctuations, and infrastructure gaps in transport, energy, and telecommunications further impede progress (UNDP, 2022). Governance challenges, including corruption (TI, 2025), weak institutions, and setbacks in education and health, also limit development, though new policies and investments show promise, with support from the UN and development partners (AFDB, 2024).

Industrialization faces obstacles like poor infrastructure, lack of skilled labor, and reliance on raw commodity exports with little local processing, limiting growth (UNIDO, 2024). Regulatory hurdles and limited financing for small businesses further impede industrial development. Zambia also ranks 147th out of 166 countries in achieving Sustainable Development Goals (Sachs et al., 2024). Environmental challenges, including deforestation, soil erosion, and climate change impacts like droughts and floods, exacerbate the situation (UNDP, 2022). The lack of locally produced equipment for renewable energy limits green industrialization (UNIDO, 2024).

In conclusion, Zambia's economic potential lies in its mineral resources, but addressing infrastructure gaps and diversifying the economy is crucial for sustainable development. Strategic investments and policy reforms are needed to build a resilient and inclusive economy.

4.1.3. Ghana

Ghana, located in West Africa, has a population of approximately 34.12 million as of 2023 (Worldometer, 2025). It is bordered by Côte d'Ivoire to the west, Burkina Faso to the north, Togo to the east, and the Gulf of Guinea and Atlantic Ocean to the south, covering about 238,533 square kilometers (WorldAtlas, 2025). Ghana was the first sub-Saharan African country to gain independence in 1957.

As a lower middle-income country (World Bank Blogs, 2024), Ghana's official language is English. It is divided into 16 administrative regions, with the capital city, Accra, serving as a commercial and industrial hub. Accra hosts multinational corporations and vibrant markets, reflecting the country's dynamic growth. Known for its political stability, Ghana experienced an 8.1% GDP growth rate in 2017 (Statsbank Ghana, 2025), positioning it as one of Africa's fastest-growing economies.

Economic Structure (2000-2023)

From 2000 to 2023, Ghana's economy has undergone some significant transformations. Ghana's economic structure is primarily driven by a mixed economy, which combines both state-led and market-oriented approaches. The economy is mainly driven by agriculture, mining (especially gold and bauxite), oil and gas and manufacturing. The government plays a significant role in the economy, with state-owned enterprises operating in key sectors such as energy, transportation, and communications. However, in recent years, there has been a shift towards privatization and liberalization, aimed at promoting economic growth and attracting foreign investment.

From 2000 to 2023, Ghana's economic sectors have seen shifts in their contributions to GDP (World Bank Group, 2025a). Agriculture's share decreased from 21.7% to 18.5%, while industry declined from 36.9% to 34.2%. In contrast, the service sector increased from 41.4% to 47.2% between 2013 and 2019. In 2022, the service sector led with 44.9% of GDP, growing at 5.5%, followed by agriculture at 4.2%, and industry at 0.9%.

- Agriculture: Once dominant, agriculture's GDP share declined from 35.27% in the early 2000s to 21.10% in 2023, with its employment share falling from 53.9% in 2007 to 29.8% in 2019. Cocoa, a major agricultural product, remains a key contributor, with Ghana being the second-largest cocoa producer globally.
- Industry: The industrial sector, comprising mining, manufacturing, and construction, grew significantly, particularly after oil was discovered in 2010, boosting growth from 6.95% in 2010 to 41.64% in 2011. By 2023, industry contributed 29.46% to GDP, despite a decline of -1.22% in growth.
- Services: The services sector has become the largest GDP contributor, growing steadily to 42.66% in 2023. Key subsectors include trade, transport, financial services, and public administration, with information and communication seeing a significant 46.5% growth in 2019.

Ghana's GDP growth peaked at around 14% in 2011, driven by oil production. However, growth has slowed due to the COVID-19 pandemic and other challenges, declining from 8.13% in 2017 to 3.82% in 2022, and further to 2.94% in 2023 (World Bank Group, 2025a).

Inflation has been a long-standing challenge, averaging 10% over the past decade. It rose from 25.1% in 2000 to 37.5% in 2023, driven by food prices and currency depreciation. Despite this, exchange rate depreciation slowed from 60% to 17% due to macroeconomic adjustments (AFDB, 2024).

The unemployment rate decreased from 10.46% in 2000 to 3.08% in 2023 (World Bank Group, 2025a), but youth unemployment remains high at 7.16%, with women facing higher rates (36.7%) than men (29.3%). Poverty has decreased from over 50% in the early 2000s to around 24%. The fiscal deficit narrowed from 11.8% to 4.5% of GDP, while public debt decreased from 92.4% to 84.9% of GDP, partly due to the Domestic Debt Exchange Program (AFDB, 2024).

Regarding exports (OEC, 2025), between 2000 to 2022, the export products have been the same throughout the period between gold, cocoa beans and the addition of the exploitation of oil production in 2010 had crude petroleum having a higher percentage of export. In 2022, Ghana had its top exports being Gold ($9.53B), Crude Petroleum ($5.21B) and Cocoa Beans 16. However, the main export countries with higher contribution remain the same, with the United Arab Emirates, Switzerland and the United States being the highest export partners.

In terms of imports, the main import products to Ghana have been the same over the span of 2000-2022 refined petroleum and crude products and other machinery like cars, plane and helicopters. The top imports of Ghana are Refined Petroleum ($1.79B), Coated Flat-Rolled Iron ($410M) and Cars ($358M) mostly importing from China ($7.91B), Netherlands ($1.26B), India ($1.01B) and United States ($938M). Due to the lack of oil refinery machinery in Ghana, a huge amount of crude petroleum is export and import in and out of the country (OEC, 2025).

Ghana has had a lot of trade agreement with other countries, notably the Intra-African trade is also significant, bolstered by Ghana's active participation in the African Continental Free Trade Area (AfCFTA). Ghana has some bilateral Economic Partnership Agreement (EPA) with the European Union and an Interim Trade Partnership Agreement with the United Kingdom and Northern Ireland.

State of Industrialization

From 2000 to 2023, Ghana's industrialization has seen mixed success, driven by key government policies. Transitioning to a private sector-led development strategy, the country focused on value-added processing of natural resources. Notable initiatives include the Ghana Industrial Policy and the "One District, One Factory" (1D1F) program, launched in 2017, which led to the establishment of over 150 factories by 2022 (One District One Factory, 2025).

Ghana's manufacturing sector grew significantly during this period, with its contribution to GDP rising from around 7% in 2000 to about 10% in 2022, driven by investments in food processing, beverages, and textiles. Heavy industries such as mining, construction, and energy also expanded, with Ghana becoming a major producer of gold, oil, and natural gas. Oil production increased from 7,081 barrels per day in 2009 to over 173,000 barrels per day in 2020 (Statista, 2025). The automotive sector also flourished, with major international companies like Volkswagen, Nissan, and Toyota establishing assembly plants in the country (GIPC, 2025).

Challenges in Sustainable Development and Industrialization

Ghana has made notable progress in sustainable development, particularly in addressing plastic pollution through the National Plastic Action Partnership (NPAP) to promote a circular economy for plastics (UNDP, 2022). Despite these advances, the country faces significant challenges, including economic instability with fluctuating growth rates, inflation, and dependence on cocoa and gold exports. Corruption, bribery, and nepotism hinder resource allocation and development (TI, 2025). Ghana also struggles with achieving economic growth and providing sufficient employment (UNIDO, 2024).

From 2000 to 2023, Ghana's industrial growth faced key challenges, including ineffective industrial policies and slow adoption of modern technologies, limiting advancements in manufacturing and other sectors (UNDP, 2022). Bureaucratic inefficiencies and inadequate infrastructure—such as roads, ports, and telecommunications—further hindered industrial expansion (UNIDO, 2024). The sector's vulnerability to global crises, such as the COVID-19 pandemic and the

Ukraine-Russia war, led to significant declines in manufacturing's contribution to GDP (UNDP, 2022).

In 2024, Ghana ranks 117 out of 166 countries with a score of 63% on the SDGs (Sachs et al., 2024). The country faces challenges in environmental degradation, waste management, and resource exploitation, with limited investment in clean energy and sustainable industrial processes (UNIDO, 2024). Additionally, reliance on gold mining and logging contributes to unsustainable practices and ecosystem damage.

In summary, while Ghana has seen economic growth and poverty reduction, addressing infrastructure, energy, education, and technology gaps is crucial for achieving sustainable development and industrialization. Strategic investments and reforms are needed to ensure inclusive growth for all.

4.2. Summary of the relevant policy frameworks of the researched countries

4.2.1. Uganda

National Environment (Waste Management) Regulations

Uganda's National Environment (Waste Management) Regulations (NEMA, 2020a) establish a comprehensive framework aimed at enhancing waste management practices across the country. These regulations are pivotal in promoting effective waste handling and environmental sustainability.

Regulations and Policies

Under the National Environment Waste Management Regulations, any entity intending to manage waste must obtain a license from the relevant authority. This licensing process includes several critical requirements, such as conducting environmental impact assessments, ensuring facility fitness, meeting personnel qualifications, and demonstrating financial security (Page 4190). Moreover, the Authority, in collaboration with appropriate lead agencies, is empowered to create detailed guidelines for various waste management practices, including landfill operations, waste incineration, and the management of plastic waste (Page 4259).

Incentives for Compliance

Entities that comply with these regulations and secure the necessary licenses gain legal recognition, enabling them to operate within the waste management sector. This compliance can lead to business opportunities, partnerships, and enhanced credibility in the marketplace (Page 4248).

Opportunities for Innovation

The focus on effective waste management paves the way for the adoption of innovative technologies. By implementing advanced recycling methods, waste sorting technologies, and data management systems, efficiency in waste handling can be significantly improved. This shift not only enhances operational effectiveness but also presents opportunities for tech startups and innovators to enter the waste management sector (Page 4250).

National Environment (Environmental and Social Assessment) Regulations, 2020

Complementing the waste management regulations, the National Environment (Environmental and Social Assessment) Regulations (NEMA, 2020b), provide a framework for conducting strategic environmental assessments (SEAs) for policies, plans, and programs. These assessments are essential for integrating environmental sustainability and social considerations into decision-making processes (Page 4399).

Regulations and Policies

The SEAs emphasize the evaluation of environmental, health, and social impacts, particularly concerning mining activities and other policies (Page 4338). This structured approach ensures that potential negative impacts are identified and mitigated effectively.

Simplifying Compliance

The regulations also offer guidelines and a structured framework for conducting SEAs, making it easier for ministries and agencies to comply with environmental standards (Page 4412). This streamlined process promotes greater adherence to sustainable practices.

Long-Term Benefits and Collaboration

By aligning policies with national and international sustainable development goals, SEAs contribute to long-term benefits for society and the environment (Page 4404). Furthermore, the regulations encourage collaboration among various government agencies, fostering more comprehensive and coordinated environmental management efforts (Page 4400).

In summary, Uganda's National Environment Regulations, particularly in waste management and strategic environmental assessments, provide a robust framework for promoting sustainability and innovation. By establishing clear guidelines and incentives for compliance, these regulations not only enhance environmental protection but also open doors for economic opportunities in the growing waste management sector. Through effective implementation, Uganda can achieve significant progress toward its environmental goals, benefiting both the economy and society as a whole.

4.2.2. Zambia

Environmental Management Act, 2011

Zambia's Environmental Management Act, 2011, provides a comprehensive framework for managing and protecting the environment. It includes strategies for sustainable development and conservation, such as the Environmental Management Strategies and the National Environmental Action Plan, which guide environmental action at both national and local levels (Parliament of Zambia, 2011). The Act emphasizes biological diversity conservation, environmental impact assessments (EIAs), and the establishment of Environmentally Protected Areas (EPAs) and Strategic Environmental Assessments (SEAs) to safeguard critical ecosystems (Pages 113-120).

Incentives within the Act encourage the adoption of sustainable practices, balancing conservation with economic growth. The Act also provides guidelines for industries, including mining, to promote cleaner production and reduce environmental impact, particularly in the management of natural resources, air, water, and land (Pages 104, 126-127). Specific regulations are set for mining, such as overseeing activities related to radioactive ores (Page 145). The Act also regulates invasive species and ensures sustainable forestry practices (Page 147).

Despite these positive elements, challenges like insufficient funding hinder effective implementation of the regulations (Page 118). However, the Act promotes public participation, allowing citizens to engage in environmental decision-making (Page 153), and highlights opportunities for sustainable development near protected areas (Page 119). Overall, the Act provides a strong legal framework for Zambia's sustainable development, balancing environmental protection with economic needs.

Environmental Management Licensing Regulations, 2013

The Environmental Management Licensing Regulations of 2013 (ZEMA, 2013) provide a comprehensive framework for managing environmental activities in Zambia, focusing on regulating pollution and waste. These regulations establish licensing requirements for emission activities, waste management, hazardous waste handling, and the use of pesticides and toxic substances, including the Emission License, Waste Management License, Hazardous Waste License, and Pesticide and Toxic Substance License (Pages 749; 751; 754; 758).

The regulations emphasize monitoring and minimizing contamination, requiring operators to assess groundwater contamination if effluents are found to cause harm (Page 750). They also encourage the recovery, re-use, or recycling of waste to promote a circular economy, with companies urged to reduce waste generation and implement Integrated Waste Management Plans (Page 752; 753).

For mining waste, the regulations set standards for the safe handling and disposal of pollutants to prevent environmental degradation (Page 749). Overall, these regulations aim to mitigate environmental risks from various industries, ensuring effective waste management, effluent control, and pollution prevention to protect Zambia's natural environment.

The Mines and Minerals Development Act, 2015

The Mines and Minerals Development Act of 2015 (Parliament of Zambia, 2015) is a key piece of legislation governing the mining sector in Zambia, providing a framework for licensing and regulating mining activities. It establishes a single licensing system for mining operations, in alignment with the Business Regulatory Act of 2014. Under this Act, holders of mining rights are required to maintain registered offices within Zambia and display their mining or non-mining rights in prominent locations, ensuring transparency and accountability (Page 207).

Additionally, the Environment Management Act No.12 of 2011 plays a critical role in shaping mining practices in Zambia. It mandates that all exploration, mining, or mineral processing activities must receive prior written approval from the Zambia Environmental Management Agency (ZEMA) through an environmental impact assessment. This regulatory requirement ensures that the environmental consequences of mining operations are carefully considered before any activities begin (Page 178).

The Act also includes provisions for financial incentives to stimulate investment in the mining sector. These incentives include exemptions on mineral royalties and charges under specific conditions, as well as tax rebates and reductions for mining companies. These measures are designed to encourage more companies to invest in Zambia’s mining sector, fostering economic growth and development (Page 228; 242).

In terms of environmental protection, the Mines and Minerals Development Act outlines comprehensive regulations that address mining waste and promote sustainable mining practices. The Act requires the avoidance of wasteful mining practices and mandates the development of mine closure plans, which include decommissioning and rehabilitating mine sites to mitigate environmental impacts (Page 223; 238). Furthermore, mining waste must be properly managed to prevent contamination of soil and water resources, ensuring that mining activities do not harm the surrounding environment (Page 225).

Despite the positive strides in regulation, challenges persist, particularly in ensuring compliance among mining companies, especially smaller ones with limited resources. Enforcing these extensive regulations can be difficult, and some mining operations may face delays due to adverse economic conditions or technological limitations, which may be temporary in nature (Page 192).

However, there are significant opportunities for the mining sector in Zambia. The development of mineral resources can be carried out in a way that contributes to the country's socio-economic development and aligns with international conventions to which Zambia is a signatory (Page 172). The mining sector also offers substantial potential for creating employment opportunities, thereby benefiting local communities and boosting the national economy (Page 182). By implementing sustainable mining practices and adhering to environmental regulations, mining companies can enhance their reputation, attract more investment, and ensure long-term success (Page 173).

In sum, Zambia's environmental management framework, guided by the Environmental Management Act, 2011, and the Mines and Minerals Development Act, 2015, reflects a commitment to sustainable development. While challenges such as funding limitations and compliance issues exist, the potential for public participation, technological innovation, and sustainable mining practices offers a pathway toward a more environmentally responsible future. By fostering collaboration between government, industry, and communities, Zambia can navigate its environmental challenges and harness its natural resources for socio-economic development.

4.2.3. Ghana

National Solid Waste Management Strategy for Ghana (MSWR, 2020)

The National Solid Waste Management Strategy for Ghana is a comprehensive framework aimed at improving the country's waste management practices. Led by the Ministry of Sanitation and Water Resources (MSWR), the strategy consolidates existing legislation into a cohesive document that defines roles, responsibilities, and enforcement mechanisms, thus enhancing accountability and service delivery in the waste management sector. The framework aligns with modern waste management practices, addressing regulatory and policy issues for effective waste management across the country.

A significant component of the strategy is the Draft National Plastics Management Policy (2018), which introduces an extended producer responsibility scheme for the plastic industry, encouraging producers to take responsibility for the entire lifecycle of their products to reduce plastic waste (Page 5). Another key initiative is the National Environmental Sanitation Strategy and Action Plan (NESSAP), which introduces the concept of Materials in Transition (MINT), promoting waste as a resource for recycling and sustainable management (Page 14).

The Local Government Act supports waste management by enabling joint development boards for managing waste infrastructure across districts. It also mandates the creation of a regulatory body to oversee service delivery and enforce environmental compliance (Page 7). Additionally, incentives such as VAT exemptions and lower licensing fees are being introduced to encourage private sector participation in waste management (Page 19). The government is also exploring a dedicated fund to support recycling facilities and waste valorization projects (Page 29).

In mining waste management, Ghana's Environmental Protection Agency (EPA) regulates mining activities to mitigate environmental impacts, requiring mining companies to implement waste management plans for safe disposal (Page 3).

Despite these efforts, Ghana faces challenges, including inadequate waste management infrastructure in urban areas like Accra, Kumasi, and Takoradi, and fragmented regulatory frameworks that hinder effective service delivery (Page 3, 13). There is also a significant lack of public awareness about proper waste disposal practices, and enforcement of regulations remains weak, exacerbating waste management issues (Page 3).

In conclusion, while the National Solid Waste Management Strategy for Ghana outlines crucial policies, frameworks, and incentives, it highlights the need for improved infrastructure, better regulatory clarity, and increased public awareness to achieve long-term success in waste management.

A Roadmap for Radical Reduction of Plastic Pollution in Ghana (GNPAP, 2021)

The Roadmap for Radical Reduction of Plastic Pollution in Ghana offers a strategic approach to tackling the growing issue of plastic waste, emphasizing sustainability and circular economy principles. Central to this effort is the revised National Plastics Management Policy (NPMP), updated in March 2020. The policy focuses on four key areas: encouraging behavioral change, promoting strategic planning and cross-sectoral collaboration, mobilizing resources for a circular economy, and fostering good governance with shared accountability. These principles align with international standards, emphasizing waste reduction, reuse, recycling, energy recovery, and proper disposal (Page 14, 26).

Another important regulatory measure is the Environmental Tax Act 863, also known as the Plastic Wastes Management Environmental Tax. This initiative, aimed at generating funds for improving plastic waste management infrastructure, raised about $40 million by the end of 2019, supporting future waste management efforts (Page 14, 26). The Environmental Sanitation Policy also promotes waste segregation and proper disposal, supported by the National Environmental Sanitation Strategy and Action Plan, which focuses on enhancing infrastructure and public education to foster better waste management practices (Page 12, 26-27).

The roadmap incorporates financial incentives to encourage businesses to adopt circular economy models and reduce plastic pollution. It proposes industry-friendly financing with low interest rates and long repayment periods to make investments in recycling more attractive (Page 79). It also suggests creating incentives for companies to use recycled content in products, such as setting recycling targets, offering tax breaks, and ensuring the profitability of recycled materials (Page 79). Additionally, the roadmap includes the introduction of Extended Producer Responsibility (EPR) schemes, which will fund waste collection, recycling infrastructure, and research into new materials (Page 10, 13).

In mining waste management, the Policy for Safe Waste Disposal outlines the importance of securing proper waste disposal sites and enforcing laws against unsafe dumping. It also includes provisions for training, monitoring, and enforcing best practices among waste pickers and workers, with the goal of improving sanitary conditions at dumpsites (Page 12).

Despite these efforts, the implementation of the National Plastics Management Policy faces several challenges. One significant issue is the lack of effective financial models and the high interest rates, which deter investment in waste management initiatives (Page 14). Furthermore, low compliance with waste segregation practices points to a broader attitudinal problem that requires robust public education to address (Page 14).

However, there are opportunities to overcome these challenges. A key opportunity lies in developing a viable market for recycled materials, which would create a profitable and reliable sector for recyclables, thereby addressing the poor business outcomes faced by recyclers (Page 14). Initiatives like the UNDP-Ghana Waste Recovery Innovation Challenge provide technical and financial support for innovative waste recovery projects, raising awareness and promoting better waste management practices (Page 6).

In conclusion, Ghana’s roadmap for reducing plastic pollution outlines a thorough strategy with policy reforms, financial incentives, and new regulations aimed at enhancing waste management practices and supporting the circular economy. While challenges remain, including financial barriers and low compliance, the opportunities for innovation and development in the recycling sector provide a pathway to a cleaner, more sustainable future.

CHAPTER 5: RESULTS

This Chapter represents the main added value of the research to literature and knowledge about the status, challenges and opportunities of the circular economy in Sub-Saharan Africa. Where applicable, the author also refers to other studies and research results relevant for the given topic. Via 5 case studies, it touches on most relevant production sectors on the continent and on the micro, meso and macro levels of waste exchange and utilization. As mentioned above, due to the exploratory character of the research work, the sophistication of data collection and the depth of analysis evolved with the advancement of the research activities. This is also reflected in the presentation of the case studies in chronological order. While Case study 5.1. is based on short visits and rather unstructured discussions with seven businesses employing circular economic models in Uganda, Case study 5.2. already focuses on an ecological farm and its relationship with waste suppliers and in-house circularity of waste materials, based on a more accurate questionnaire for semi-structured interviews. These experiences were channelled into an even more challenging field of data collection, Case study 5.3. In this case, the dissertation starts to touch on the meso level of waste exchange and utilization by 42 companies interviewed in the Kampala Industrial and Business Park in Uganda, with an already cleaner concept and refined version of the questionnaire structured into four main sections suited for waste users and not-users, as well as waste suppliers and not-suppliers. From then on, this four-part logic and structure uniformly characterized the questionnaires used for data collection and the analytical approach. Case study 5.4. applied the same logic when taking under scrutiny the utilization of copper mining waste in Zambia: mining companies were characterized as suppliers/not-suppliers, and companies with a hypothetic potential to use the waste materials based on the literature were characterized as users/not-users. With this case study focusing on an important industry for many economies in the region, the dissertation starts to touch on the macro level aspects of waste utilization. The last sub-section, Case study 5.5. concludes on micro, meso and macro aspects, as well, since it builds on information gained from production and recycling companies as well as policy experts and professionals in Ghana.

Each case study first presents the research results, then, based on them, it answers the three research sub-questions.

5.1. Waste utilization mini case studies in Uganda[3]

This sub-chapter presents micro-level (external) waste exchange by seven mini case studies in Uganda, and touches on the economic, environmental and social benefits of these activities, as well as the main challenges they face. The map of Image 2 shows the locations where data was collected for this case study. Pictures from the field research are presented in Appendix 1.

Image 2. Data collection locations in Uganda for Case study 1; author's construction based on Mappr.co, 2025

[3] Case study 5.1. has been reformatted into a research artical and published as Buda, G. (2022). Seven businesses using principles of circular economy in Sub-Saharan Africa: Results of field research in Uganda. *Hungarian Journal of African Studies, 16*(1), 5–20. https://doi.org/10.15170/AT.2022.16.1.1
Some of the minin case studies were also mentioned and used as indicative cases in the following artcile: Buda, G., and Ricz, J. (2023). Industrial symbiosis and industrial policy for sustainable development in Uganda. Review of Evolutionary Political Economy, 4(1), 165–189. https://doi.org/10.1007/s43253-023-00097-8

5.1.1. Research Results

Hya Bioplastics is a young organization, started as a pilot project of students at the Makerere University in Kampala in 2018. They focus on the replacement of plastic with research and development on the productive utilization of water hyacinth, an invasive plant growing in Lake Victoria and other freshwaters causing serious problems for the fishery industry. Water hyacinth is usually harvested by fishermen to clear up fishing areas and dumped as waste or used as animal feed. Hya Bioplastics pilot products are trays, packaging tools, coasters and name tags from biodegradable "plastic" based on the mixture of dried water hyacinth, sawdust and casava starch. The customized products are sold mostly to restaurants and bars. As the plastic replacement business is still in the initial phase, Hya Bioplastics also started to produce sawdust-based briquettes sold to poultry farms or households as a replacement of more polluting and less efficient charcoal. Briquette selling provides the company with additional revenue to invest in further research and development of the production of alternatives to plastic. Sawdust is supplied free of charge by a carpenter company, Motiv Creations to whom the disposal of this by-product was costly and problematic before.

Economic benefits: As the most important economic benefits of Hya Biplastics, one can mention the cheaper production of its products based on low-cost or even free input prices, the additional revenues due to easier fish production, improved production efficiency of poultry farmers with more durable and more efficient sawdust briquettes and the saved landfilling costs of Motiv Creations.
Environmetnal benefits: Among environmental benefits are the followings: reduced or avoided landfill of sawdust, less polluting poultry raising, the reduced usage of plastic and the contribution to the maintenance of natural fishing areas and biodiversity.

Social benefits: The contribution to additional revenues and even the creation or conservation of jobs for casava farmers and fishers is an important social benefit.

Main challenges: Naturally, the young initiative faces several challenges. On the one hand, the lacking water resistance of the packaging products require large investments in technological research and development. On the other hand, cheap imported plastic products pose a serious competition. The combination of these two factors limits the increase of market share and economical production.

Amelia Agro Ltd. is an organic farm on 8 acres in Jinja, 100kms to the East from Kampala, the capital. The farm grows several varieties of plants and raises animals (chicken, fish, pigs, cows, goats, rabbits). The organization is an excellent example for making use of other companies' waste or by-products as compost, animal feed or organic pesticide. Bagasse (the left-over of crushing sugar cane) is received from sugar companies. Slaughterhouses supply them with blood, intestines and flesh off-cuts, as other flesh remaining is also supplied by fishers, fish processors and tannery companies. From paper companies, the carbon-rich boiler ash is a valuable source for keeping the soil fertile, while floating barley and husk from breweries are being fed by the pigs and also used as compost component. Water hyacinth comes from the Jinja Sailing Club and is used as pig and chicken feed. Finally, effluent from spirit producers is also used for composting. The farm's products are sold on the local market and to restaurants. Another supply of organic waste comes back from restaurants' peels and left-overs. Beside the in-coming organic waste supply, within the farm there is a circular model of materials. Everything is utilized for feeding or composting, as the animal manure and the weed or other plant residues.

Economic benefits: The competitive advantage of this farm is to make and keep the soil fertile with high nutrient content and profit from increased crop and animal production. The big advantage of the above-mentioned industrial symbiosis practices is that most of these supplies of nutrient rich ingredients are received free of charge, the only cost for the farm is transportation. Besides, supplier companies can realize serious reductions of landfilling costs.

Environmental benefits: Among the several environmental benefits created by the farm, some most important ones to mention are the avoidance of waste landfilling which results in the reduction of open-air waste decomposition and green-house gas emission. Moreover, the improved soil quality can contribute to the increase of carbon sequestration capacity which is a crucial factor in the mitigation of climate change.

Social benefits: The farm tries to avoid the use of machinery as much as possible. Therefore, it employs a relatively high ratio of human workforce and so creates jobs. Organic agriculture may contribute to better nutrition conditions.

Main challenges: In spite of these above advantages, Amelia Agro still struggles for reaching profitability, as organic agriculture is very labour-intensive, the results of soil nutrient improvement are time-consuming, and local lower demand and purchasing power for organic crops (compared to non-organic ones) does not allow significant price differentiation. Furthermore, the farm faces serious competition with imported chemical fertilizers and industrial animal feed.

ProTeen employs black soldier flies to process organic waste into fertilizer and animal feed. The organization has a strategic partnership with the Kampala Capital City Authority (KCCA) waste management department which supplies organic waste from the Central market and Nakawa market of the city. The waste of these markets is estimated to be organic in 80-90%, according to the respondent. Besides, additional organic waste is also delivered by private waste collectors and food processing companies. The organic materials are shredded and mixed, then the black soldier fly larvae eat it up within 8 days. After this, the larvae serve as the input material for three different products: a protein-rich animal feed which is mostly purchased by large chicken producers, fat-rich extracted oil which is a useful input to pigs' and other animals' feed, and a fertilizer granulate used by organic farmers, mostly coffee farmers, to "bring back" the nutrients to their farms. As industrial fertilizers, mostly imported from the Netherlands, are expensive, only a few organic fertilizers are available locally and Proteen's technology is much faster than composting, their solution has a great competitive advantage, beside contributing to waste processing with reduced greenhouse gases emissions. Moreover, other alternatives, as competitors, like silver fish-based fertilizers are more expensive with lower and unreliable quality due to the reasonability of production.

Economic benefits: Supplier companies and municipalities can save landfilling, and waste management costs. Farmers and animal keepers can obtain cheaper and better-quality organic fertilizers and animal feed, produced locally.

Environmental benefits: The organization's activities also contribute to the reduction and avoidance of waste landfilling, the reduction of ope-air waste decomposition and green-house gas emission. With returning organic nutrients, the soil quality and carbon sequestration capacity is also strengthened.

Social benefits: ProTeen creates new jobs and improves food nutrient content that indirectly contributes to better social nutrition and health conditions.

Main challenges: The biggest challenge for Proteen, as for most of the companies presented here, is to provide machinery to achieve economy of scale and ensure production with constant price and quality.

TexFad is a non-profit organization that deals with hand-woven textile products in the suburbs of Kampala. The production of carpets, table matts, scarfs and other handcrafts are based on two inputs: textile off-cuts and banana stem. Textile off-cuts and reject cotton thread (a product of misfunctioning production or defective product that is three time cheaper than the normal one) is supplied by two cotton factories: Nytil in Jina and Fine Spinners in Kampala. Banana tree stems come from local farmers (four bigger plantations and ten smaller-scale producers) and the fibre is extracted on the site of TexFad. After one banana tree raised its fruits which were harvested, it does not grow any more fruits. The 3-5 meters tree remains as waste, with an unused potential. The extracted fibre is used for carpet-weaving, and the remaining parts for the production of organic fertilizer and carbonized briquettes (like in the example of Hya Bioplastics). TexFad is investing in further research on the treatment of banana fibre so that it can replace cotton in the future. Carpets and table matts typically sold to hotels and apartments, while briquettes and fertilizer to poultry farmers, restaurants, homes and schools.

Economic benefits: The company takes advantage of lower input costs and contributes to additional revenue generation of textile producers and banana farmers. Households, catering and poultry businesses benefit from the more durable and efficient briquettes as solid energy sources. Besides, suppliers can save landfilling costs.

Environmental benefits: TexFad also contributes to the avoidance of landfilling, the reduction of green-house gas emission based on open-air waste decomposition and air pollution by using briquettes instead of charcoal for cooking, soil quality and carbon sequestration capacity improvement.

Social benefits: The organization creates additional jobs and revenues.

Main challenges: Competition with imported synthetic rugs and carpets, chemical fertilizers and charcoal producers pose the main challenges for TexFad.

TakaTaka Plastics is based in Gulu, the North of Uganda, and deals with plastic recycling. Taka means waste in the local language, Acholi. Thus, the name choice represents a mission to change the local perspective about waste, its utilization and value. The organization was founded in 2020 by freshly graduated students who won 6 different business competitions to gather funding for launching the project. They process disposed plastic bottles and bags to produce a large variety of products, such as roofing and wall tiles (their main product), construction lambers, clips, strings (used in basket weaving), face shields and glass coasters. Plastic is collected in Gulu city and the surrounding area in several ways. The company deployed plastic collection banks in 9 schools, several restaurants, bars and other public places. Hospitals supply around 70 kg plastic per week. Together with local authorities they organize monthly community waste collection actions which supply an average of 200kgs of plastic to process. In this way, 90% of the plastic comes for free (resp.), which provides the basis for a great competitive advantage against ceramic tiles, the main competitor product. Beside being cheaper, TakaTaka Plastics tiles are also more durable, and recyclable compared the conventional, ceramic ones. They plan to reach self-sustaining operation within the next 2 years in Gulu, and open additional processing stations in other cities, like Arua and Hoima. To increase collection and production efficiency and to reduce the operation carbon footprint, they envision the equipment of local collection points with shredders to enable plastic pre-processing, so improve the amount-per-transport ratio, and the extension of the recycling portfolio to aluminium cans, as well.

Economic benefits: TakaTaka's input material is very cheap, their input costs are basically reduced to transportation. Consumers can buy cheaper and more durable tiles, while municipalities can save waste collection and management costs.

Environmental benefits: The most beneficiaries of the company's activities are local communities and the nature, as plastic waste is collected and public areas are kept cleaner.

Social benefits: Beside job and additional income creation, TakaTaka's contributes to social awareness-raising and better hygienic as well as health conditions.

Main challenges: Despite this advantage, the business is still not economically sufficient, as they are in the struggle to reach economy of scale. At the time of the interview, TakaTaka processed 1 ton of plastic per month and, according to their calculation, economic sustainability would be reached on the level of 9 tons monthly production. This is also reflected in their income structure: according to the respondent, only 20% comes from the actual business, while 40% from different business grants and another 40% from donations. Beside finding funding, the most challenging factor is to provide cheap and reliable machinery, as both the import and local manufacturing of appropriate machines are costly.

Ecobrixs, a company in Masaka city, also processes plastic bottles. Their main products are plastic bricks, lambers and limbs used in construction. Besides, they also produce face shields, baseball cap inserts, book covers and black boards with frames, both from recycled plastic. These latter products are mostly purchased by local NGOs, schools and hospitals. An outstanding feature of Ecobrixs' model is the incentive system for waste collection, namely, that they pay for the collected plastic. This ensures a stable production input supply, as individuals can gain additional income by delivering plastic to Ecobrixs' 30 collection centers within a 100 kms radius from Masaka. Apart from the collection centers, the company also receives plastic waste from 28 schools. So, the organization has only to provide the transportation from the collection centers which is carried-out by their collection truck

Economic benefits: Inputs are cheap for Ecobrixs. As their construction products are much cheaper than concrete and much more durable than timber, the two competitor products, the company's market share is markedly increasing. Municipal waste management costs are also reduced.

Environmental benefits: Similarly to TakaTaka, the company contributes to the collection and plastic waste and, thus, keeping natural and public areas cleaner.

Social benefits: Ecobrixs directly provides full-time jobs for 13 employees in their process station in Masaka and 25 in the collection centers, while an average of 165 individual plastic collectors can gain additional income in the cooperation with the organization. Moreover, cleaner public and natural areas contribute to better hygienic and health conditions.

Main challenges: Machinery deficiencies and production capacity still strongly hinder to reach profitability.

The **Uganda Industrial Research Center** (UIRI) experiments on several technologies related to cleaner production and the utilization of wasted materials, such as replacing timber with bamboo, the utilization of cotton husks for mushroom growing and using glass waste in ceramic production, among others. At the research site visit, one of the most impressive and advanced initiatives was the one of Mr Samuel Nuwagaba. He works on the utilization of paper waste and agricultural waste, such as banana fibre or other plants like sisal, to produce alternative paper and packaging products. As mentioned above, banana fibre is available in huge quantities in Uganda and in broader Sub-Saharan Africa. The packaging industry is still dominated by plastic products, mostly imported from China, India and Kenya. Mr Nuwagaba invented a mixture of banana fibre and waste paper (30-70 percent ratio, respectively) which provides offices with alternative recycled paper. He also produces other paper products from banana fibre exclusively, such as bags, notebooks and boxes. These are purchased by local art craft centers, shop owners and tour and travel operators to make their products and services more attractive for tourists, and by foreign NGOs, mostly from The Netherlands, Germany and Japan., Economic benefits: Input materials come for free and local craft sellers and tour operators can increase their value proposition.

Environmental benefits: The initiative contributes to the reduction of plastic usage and virgin paper production.

Social benefits: Hard to identify, as the project is in an initial phase. In the long term, shifting paper production towards banana and other alternative input materials may create new jobs and economic sectors in Uganda and broader Sub-Saharan Africa.

Main challenges: Machinery deficiencies (regular break-down and misfunctioning) and the missing local manufacturing and repair expertise put serious obstacles to the achievement of reliable and profitable production.

5.1.2. Answers to the research sub-questions

SQ1: How are specific waste materials and by-products exchanged, or could be exchanged, between industries to promote circular economy practices?

Key materials include water hyacinth, which Hya Bioplastics uses to create biodegradable products like trays and packaging, as well as animal feed, helping to reduce plastic use. Sawdust is another important material, utilized by Hya Bioplastics to produce briquettes and by TexFad for making carbonized briquettes and compost, replacing charcoal. Bagasse, a by-product from sugar processing, is supplied to Amelia Agro Ltd. for composting and animal feed, enhancing soil fertility.

Slaughterhouse by-products, including blood and off-cuts, are also used by Amelia Agro Ltd. for composting and animal feed, turning waste into valuable resources. Carbon-rich boiler ash from paper companies is employed by Amelia Agro Ltd. to maintain soil fertility. Plastic waste is a significant resource for companies like TakaTaka Plastics and Ecobrixs, which recycle it into products such as tiles and bricks, thus reducing plastic pollution.

Banana stems are another valuable resource; TexFad extracts fiber for weaving and produces organic fertilizers and briquettes from the remaining material. ProTeen processes food waste to feed black soldier flies, which produce animal feed, oil, and fertilizer. Agricultural waste, including banana fiber and cotton husks, is used in the production of alternative paper and packaging, contributing to reducing reliance on plastic. By exchanging these materials, industries can create synergies that promote sustainability, reduce waste, and support the circular economy.

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

Limited access to affordable, reliable machinery and technology hampers the scaling of production and consistent output. Local, eco-friendly products often face stiff competition from cheaper imported alternatives, such as plastic products, which limits market opportunities. Furthermore, low consumer demand, driven by a lack of awareness, restricts revenue, especially for organic and alternative products. The high costs of research and development (R&D) make innovation difficult, particularly for small businesses that struggle to invest in growth.

Waste collection also poses a significant challenge, as organizing efficient systems is complicated by logistical issues and inadequate infrastructure. The absence of skilled local labour for manufacturing and machinery repair further hinders production capabilities. Many businesses face difficulty in achieving economic sustainability due to high costs and a heavy reliance on grants or donations. Additionally, regulatory challenges, such as unclear or insufficient government policies, can stifle the growth of waste management initiatives. These barriers make it difficult for businesses to achieve economies of scale and long-term success in the region.

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

First, affordable, durable machinery should be developed, either through local production or partnerships, to address high equipment costs. Raising awareness and educating communities about the environmental and economic benefits of waste utilization can help drive demand for sustainable products. Governments can support these efforts by providing incentives such as tax breaks, grants, and clear waste management policies. Additionally, fostering research and development through collaborations with universities and institutions can provide the technical expertise needed to innovate and improve processes.

Collaboration between businesses is also essential, as sharing resources, infrastructure, and technologies can reduce costs and enhance efficiency. Efficient waste collection systems must be established to ensure a steady supply of materials for processing. Access to finance, through micro-financing or impact investment, is crucial for scaling businesses and supporting innovation. Capacity building initiatives, such as training workers and entrepreneurs in waste processing and machinery maintenance, will also strengthen the industry. Expanding markets for waste-derived products, including potential export opportunities, will help improve financial sustainability and reduce reliance on local markets.

5.2. The role of agriculture in micro-level waste exchange and utilization in Sub-Saharan-Africa. The case of Amelia Agro Ecological Farm in Uganda[4]

This sub-chapter focuses on agriculture, one of the main economic sectors in Sub-Saharan Africa, by presenting the case of an ecological farm (Amelia Agro Africa Ltd.) and its suppliers in Uganda, and showing examples of internal and external waste exchange and utilization. Image 3 shows the location of the research area, Jinja city and its surroundings in Uganda. The questionnaire used for the data collection can be found in Appendix 2. Pictures from the field research are presented in Appendix 3.

Image 3. The location of the research area for Case study 2, Jinja city and surroundings in Uganda; Source: author's construction based on Google Earth

5.2.1. Research Results

This section first presents the in-house circularity of materials on the farm, reflecting on IFS. This is followed by the IS relationships of the farm with the nine suppliers.

[4] Case study 5.2. has been reformatted into a research article and published as:
Buda, G. (2024). Economic Determinants of Industrial Symbiosis on the Micro-level in Sub-Saharan Africa. A Case Study from Uganda. Afrika Tanulmányok / Hungarian Journal of African Studies, 17(3), 67–86. https://doi.org/10.15170/AT.2023.17.3.4

The gains and motivation of the supplier companies are then analysed, and further research observations are presented.

5.2.2.1. Integrated farming model – within-unit circularity of materials

Within the farm, there is a circular model of materials, which demonstrates a perfect example of IFS. Everything, including animal manure and weeds or other plant remnants, are utilized for feeding or composting. The manure of pigs, cows, goats and rabbits is used as an input for vermicompost and windrow compost. Urine is an input for liquid fertilizer. Cow manure is also used to feed black soldier flies. Chickens are located right above a fishpond, thus, their manure drops directly into the water, where it serves as feed for tilapia fish and water hyacinth. This practice is also mentioned by FAO (2001). The maggots of black solder flies serve as protein-rich fodder for the pigs and fish. The water hyacinth is fed to pigs and chicken, and it also provides input for the windrow compost and liquid fertilizer. Plant and vegetable off-cuts and weeds, are fed to the animals of the farm (pigs, cows, goats, rabbits, chicken and fish), while some plants are specifically grown as fodder, such as moringa, caliandra, glerecidia, mulberry and duckweed. The three types of organic fertilizer (vermicompost, windrow compost, liquid fertilizer) serve to increase soil fertility. The model is visually presented in Figure 5.

This in-house circularity of materials enables the farm to realize cost reductions for the necessary production input materials and improve soil fertility. Furthermore, CO_2-emmissions from open-air waste de-composition is minimized, as animal and plant-based materials are kept in the production circle. However, the maintenance of this continuous circularity is very labour intensive and thus generates additional labour cost burdens for the farm. In one sense, this represents a meaningful social benefit via the jobs generated, but it also raises serious questions regarding economic sustainability and economies of scale.

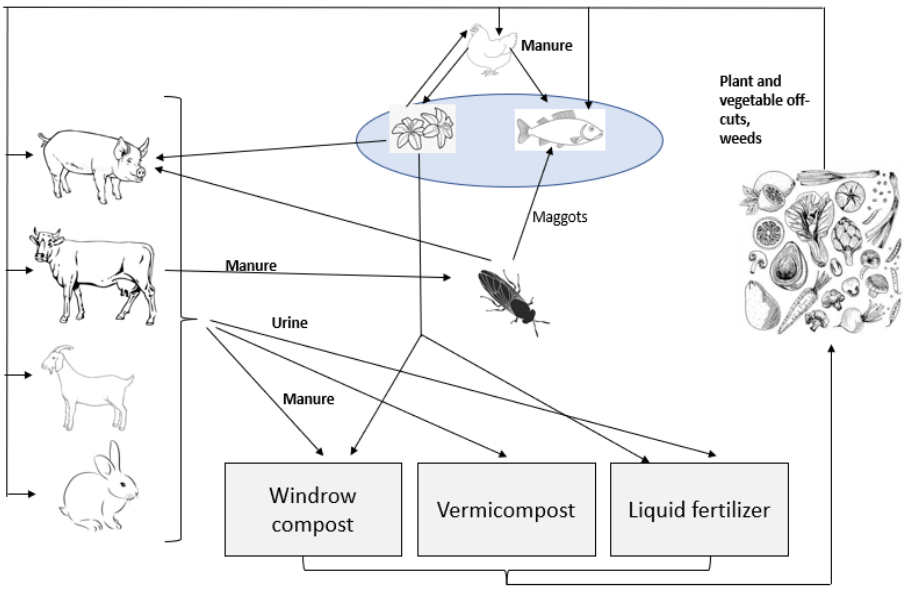

Figure 5. Within-unit circularity of materials at Amelia Agro farm. Source: author's construction

5.2.2.2. External waste exchange relationships

In this part, nine suppliers are presented from which the farm utilizes waste materials and by-products. Each material's utilization on the farm and additional desk-research results about similar application examples are also presented. Figure 6 shows the farm's primary destination of waste materials.

OBN Produce and Supply Ltd. is a rice mill in Jinja that sells rice husk to the farm to use as chicken bedding, fodder and compost input. Otherwise, the company would simply "dump or burn" this material, so the further utilization of it clearly generates environmental benefits. Among others, Zhao et al. (2022) demonstrate how rice husk can be an important component of organic fertilizer mixtures.

Bagasse is received from GM Sugar Ltd. and used as mulch, applied to the soil surface to keep soil moisture, improve the soil's fertility and health as well as reduce weed growth. Another purpose of bagasse is to supply the pigs with protein-enriched feed (Pandey et al., 2007). GM Sugar also uses this waste in-house, 70% of the bagasse goes for power generation for its factory, according to the respondent.

The Jinja City Abattoir, a slaughterhouse, supplies the farm with blood, intestines and flesh off-cuts. Other flesh residues are also received from a fish producer, Nyanza Perch Ltd., and a tannery, Mekah Leather Ltd. Composting of meat/fish processing waste such as dung from the lair age, ruminal and intestinal contents, blood, meat trimmings, floor sweepings, hair, feathers, hide trimmings, as reported by Kharat (2018), produces a very good quality bio-manure which may be utilized as fertilizer. Furthermore, slaughterhouse waste has been reported to be a significant source of proteins and fats that are convenient raw materials for processing proteinaceous animal feeds (Okanović et al., 2009). Regarding the utilization of fish waste as compost input, Mega Kusuma et al. (2019) show that the level of organic carbon, nitrogen, phosphorus and potassium makes fish waste-based compost applicable as organic fertilizer. Similarly, Ahuja et al. (2020) also reveal that fish waste-based fertilizers are rich sources of nitrogen and phosphorus for plants and positively affect soil quality by improving soil microbial activity, and soil structure and stimulating root growth.

The by-product of a local paper company, East African Packaging Solutions Ltd., carbon-rich boiler ash is another valuable source to improve soil fertility, thus it is used by the farm as a windrow compost input, mixed with other organic materials. Focusing on forest-lands in the USA, Vance (2000) concludes that paper mill boiler ash can be beneficial for plant (tree) productivity, as it is comprised largely of oxides and carbonates of kalium and calcium but also contains significant amounts of phosphorus, magnesium, and some other micronutrients. One of the most essential characteristics of ash as a soil amendment is its effect in raising the soil's pH value, as demonstrated by its effective substitution for agricultural lime. Moreover, boiler ash has generally low concentrations of heavy metals, organic compounds, and other constituents of concern and it is environmentally benign when used in reasonable quantities. This is in line with many other studies (Vance, 1996; Wang et al., 2006; Brotodjojo and Arbiwati, 2016) concluding that boiler ash can be applied as an agricultural liming material, soil conditioner, fertilizer or even plant resistance enhancer against insect pests. Beside boiler ash, other paper production by-products, such as sludge, can also be applied as organic fertilizer (Fahim et al., 2018).

Spent grain, spent yeast and malt dust from Nile Breweries are fed to the pigs and fish and then also used as compost components. Assandri et al. (2020) conclude that brewers' spent grain is not suitable for direct composting, therefore, it should be mixed with livestock manure, as it is done in practice at the farm. Another potential utilization form is to feed these residues to animals (Ajila et al., 2012; Karlovic et al., 2020). The brewing process is one of the most waste-producing ones as a proportion to the end-product, and includes waste water, spent grains, spent yeast, spent hops and germs (Amoriello and Ciccoritti, 2021).

Distillate spent wash from Buwembe Brewers and Distillers Ltd. is also used as an input to liquid fertilizer. Distillery effluents represent a significant agro-potentiality by positively affecting the moisture and mineral content of the treated soil (Chopra et al., 2013), and thus, if used in lower concentration, can positively affect seed germination and yields of several plant species, such as wheat, pea, okra (Pandey et al., 2007), rice (Arora et al., 1992), maize (Ramana et al., 2002), and Chinese cabbage (Kumari et al., 2016).

Bidco Uganda Ltd. produces cooking oil from palm. As a by-product of the palm oil extraction, between 200 and 400 tonnes of kernel expeller are produced every month. This material is utilized by the farm as animal feed input, as it is a quality stock feed containing high levels of crude protein and medium energy levels, thus safe to feed as a supplement for most classes of livestock (van Wyngaard et al., 2015; Thompson-Morrison et al., 2022).

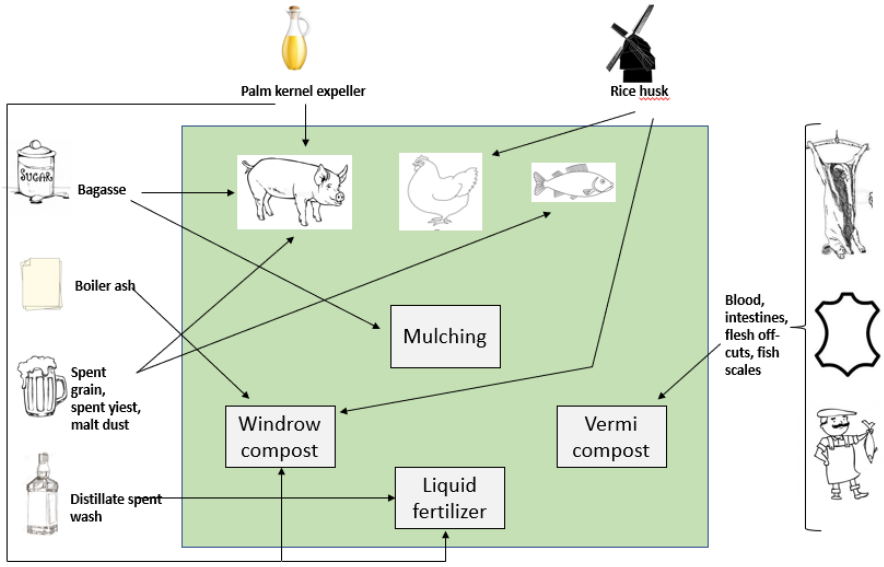

Figure 6. Waste materials received by Amelai Agro. Source: author's construction

5.2.2.3. Suppliers analysis

This part briefly presents the research results about the main motivations and the cost items for the nine supplier companies presented above.

Five of the interviewed nine companies mentioned the generation of additional revenue as the main motivation. Other four highlighted the existing or potential saving of landfill and waste management costs as their most important incentive, including the avoidance of special taxes.

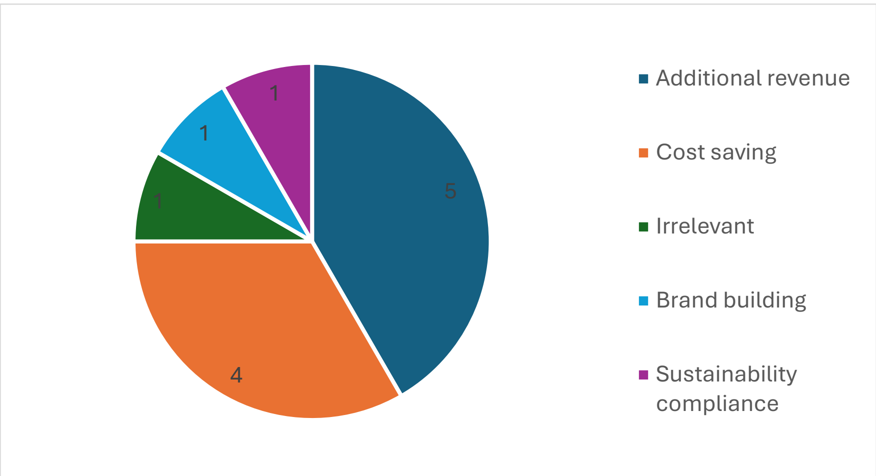

Figure 7. Motivations in waste/by-product supply of the 9 suppliers of Amelia Agro. Source: author's construction

Only three companies stated that they are already saving landfilling costs with the ongoing relationship, while the other six did not, due to different reasons such as the small quantity taken by the farm relative to the total quantity of waste or irrelevant landfilling cost in case of no purchase, such as free usage of the landfill, simple dumping, releasing to natural water bodies or giving-away for free to company workers.

Five companies realized savings on transportation costs to the landfill, this aspect was irrelevant for four other firms. The number of companies realizing savings in landfilling costs and those realizing savings in transportation costs does not overlap. This is because some companies still have to transport much of their waste or by-product to the landfill, or even if they do not have to pay for the landfill, they still have to bear the transportation costs there.

The interview questionnaire was formulated to probe the potential savings in storage costs if the farm (or any other customer) takes the provided materials. From the nine companies, only three mentioned savings of storage costs (in one case, especially high due to obligations around special storage conditions). For six companies, this was irrelevant.

Handling and pre-processing costs are realized as positive cost items for the companies and refer to additional treatments before giving away the waste or sending it to the landfill. Four companies mentioned these costs as relevant, and the other five do not face such additional costs. From the IS point of view, these costs were important for analysis since they can mean additional costs in case of a special client need or potential savings if these treatments are not necessary for the partner. However, none of these two cases occurred in the research.

The farm pays for the waste materials to six of the nine companies, while the farm in each case pays waste transportation. This indicates that only the minority of the companies are motivated to “simply get rid of” the waste materials. Even if they let the farm take it for free, they do not want to incur additional costs (for transportation).

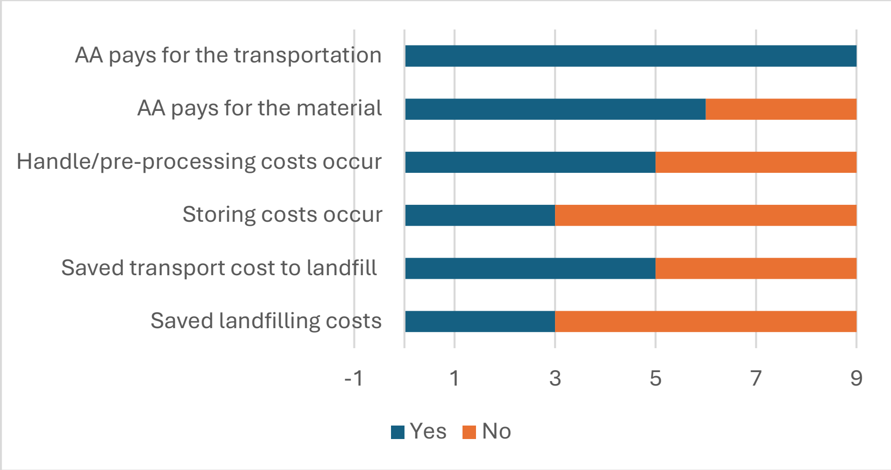

Figure 8. Occurrence of cost items by the 9 suppliers of Amelia Agro. Source: author's construction

As a last point in the data collection process, interviewees were asked to estimate a ranking among the relevant cost items to find a relative relationship among these cost items. Unfortunately, not every respondent was able to give an estimation to this question, and these cost items differ a lot depending on the exact activity and technology. On the sample of these nine companies, it seems that the waste selling price (p_w), the only negative cost (i.e. a revenue) is far the least important item for the supplier companies in this equation. It is followed by the cost of transportation to the landfill (c_{trl}) and storage costs (c_{st}. The costliest items are pre-processing or handling costs (c_p) and the payment for landfilling (I). Thus, in this sample of nine companies, the relative relationship can be expressed as follows:

$$(p_w) < (c_{trl}) < (c_{st}) < (c_p) < (I)$$

5.2.2.4. Further observations

This final subsection shares some additional information gathered during the research, which may contribute to the broader understanding of waste utilization in SSA. These insights are informed by visits to further companies not included in the supplier analysis above.

First, the sugar industry has great potential and, in many cases, already has an applied practice of in-house utilization of waste and by-products. As mentioned above, GM Sugar uses around 70% of the bagasse for power generation. Other big sugar companies, such as SCOUL (Sugar Corporation of Uganda Limited, visited as a potential new partner for the farm) reported similar practices. Besides power generation, SCOUL also makes use of molasses by operating a distillery, and sells CO_2, another by-product generated in the process.

Second, Uganda Tea Corporation Ltd. in Kasaku Estate was also visited as a potential partner for the farm. Several by-products of tea processing, such as microfine tea dust, winnowing, floor sweepings and tea seeds, can also be utilized as valuable inputs for composting and feeding (Guil-Guerrero et al., 2016).

Third, in many cases waste and by-products are re-distributed by middlemen to the farm and other customers, such as spent grain from Nile Breweries or other suppliers not included in the analysis above. These intermediaries include Jose AF, a dealer of spent grains and a company contracted by Eskom, the operator of the Jinja Damm, to clean off water hyacinth from the water surface and solve its disposal by selling it to farmers as pig fodder. The role of intermediary companies in IS may form the subject of consideration to modify the fitness condition equations above, but that is beyond the scope of this paper.

Fourth, one can detect some "low-hanging fruits" for regulation to facilitate industrial symbiosis. Certain materials, such as boiler ash or distillate spent wash, are produced in huge quantities, representing a potential added value in compost production and organic fertilization. Their storage, handling and disposal can be extremely costly for the producer and harmful for the environment. In some cases, the realized costs have already incentivized companies to look for waste-selling opportunities. In contrast, mostly due to the poor enforcement of environmental laws, the cost of disposal is still less than the cost of selling the waste, which holds companies back from being interested in further utilization of waste. This implies that supporting the waste material utilization in production might require subsidies on the waste selling price, as it is the least important cost item for most companies, and/or for the related storage, handling or pre-processing activities.

5.2.2. Answers to the research sub-questions

SQ1: How are specific waste materials and by-products exchanged, or could be exchanged, between industries to promote circular economy practices?

Rice husk, generated by rice mills such as OBN Produce and Supply Ltd., can be used for chicken bedding, fodder, or compost production, serving as a valuable component in organic fertilizers. Bagasse, a by-product from sugar production by companies like GM Sugar Ltd., is used for mulch to retain soil moisture, improve soil fertility, and reduce weeds, as well as serving as animal feed for pigs.

Slaughterhouse waste, including blood, intestines, and flesh off-cuts from facilities like the Jinja City Abattoir, can be composted into high-quality bio-manure or processed into protein-rich animal feed for pigs and fish. Fish waste, generated by fish producers such as Nyanza Perch Ltd., can also be used as compost or fertilizer, benefiting soil health due to its rich nutrient content. Paper mill boiler ash, produced by companies like East African Packaging Solutions Ltd., is a mineral-rich material that can act as a soil conditioner or liming agent to improve soil fertility.

By-products from breweries, like spent grain, spent yeast, and malt dust, can be used as animal feed for pigs and fish or as components in compost when mixed with livestock manure. Distillery spent wash, produced by distilleries such as Buwembe Brewers and Distillers Ltd., can serve as a liquid fertilizer, enhancing soil moisture and mineral content. Palm kernel expeller, a by-product of palm oil production by Bidco Uganda Ltd., is a high-protein animal feed supplement, especially useful for livestock like pigs. Finally, tea processing by-products from companies like Uganda Tea Corporation Ltd., including microfined tea dust, winnowings, and tea seeds, can be utilized for composting or as livestock feed.

These materials represent a wealth of waste that can be redirected from landfills to productive uses, contributing to sustainability, reducing environmental impact, and fostering a circular economy in the region.

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

Despite these positive examples, several challenges prevent more widespread utilization of waste and by-products. One of the main barriers is cost considerations. Some companies hesitate to sell or give away their waste due to the high costs of transportation, storage, and handling. These additional expenses often outweigh the potential benefits of waste utilization. For example, while some businesses save on landfill and waste management costs, others continue to dispose of waste cheaply, as it remains the more affordable option.

Another challenge is regulatory gaps. Poor enforcement of environmental regulations often leads companies to opt for cheap waste disposal methods instead of seeking beneficial uses for the waste. The cost of disposal may be lower than the cost of processing or selling the waste, especially in the absence of strong regulations that encourage waste utilization.

The lack of infrastructure is also a significant obstacle. Without a structured system for collecting, processing, and redistributing waste to interested parties, effective waste utilization is hindered. In some cases, intermediaries are required to handle redistribution, but their availability and reach can be limited.

Lastly, economic sustainability remains a concern. While waste recycling and utilization can create value, these practices are often labour-intensive, leading to worries about their long-term viability, particularly for smaller operations where economies of scale are not easily achieved.

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

To overcome the barriers to utilizing waste and by-product materials in integrated farming systems (IFS), several strategies can be employed. First, enhancing economic incentives is crucial. This can be achieved by offering financial benefits, such as subsidies or tax breaks, for companies that provide waste to farms, turning waste disposal into a revenue-generating opportunity. Governments can also help by subsidizing transportation and pre-processing costs, making waste exchange more accessible. Strengthening regulations to discourage inefficient waste disposal practices and incentivizing companies to sell or donate waste for reuse can also help. For instance, imposing penalties on landfilling while rewarding recycling efforts would encourage companies to engage in waste utilization.

Creating partnerships and networks between industries and farms is another key mechanism. Facilitating collaborations where one company's waste becomes another's resource can streamline the flow of materials, making it easier for farms to access waste. Encouraging the involvement of intermediaries could also help address logistical challenges. Investment in research and technology to improve the processing of waste into valuable products like fertilizers or animal feeds would make the system more efficient and scalable.

Reducing the labour intensity of circular farming practices is also essential. Automation in composting and feeding systems could reduce labor costs, making the model more economically sustainable. Training farmers on efficient waste management and improving infrastructure for waste storage and transportation can further support these efforts. Additionally, raising public awareness about the environmental and economic benefits of waste utilization, and sharing best practices, could encourage wider adoption of such systems.

Lastly, fostering a "waste-to-value" mindset where waste is seen as a resource rather than a burden is key to driving innovation and the adoption of more sustainable farming practices. By addressing these challenges through a combination of policy, technology, collaboration, and education, waste utilization in agriculture can become a sustainable and profitable practice.

5.3. Potentials and challenges of waste exchange and utilization in an African industrial park. The case of the Kampala Industrial and Business Park in Uganda[5]

This case study focuses on the meso level by presenting the potentials and challenges of waste utilization in the Kampala Industrial and Business Park (KIBP) in Uganda. Image 4 shows the location of the park in the suburbs of Kamapala. The questionnaire for the data collection can be found in Appendix 4, the list of respondents in Appendix 5 and pictures from the field research in Appendix 6.

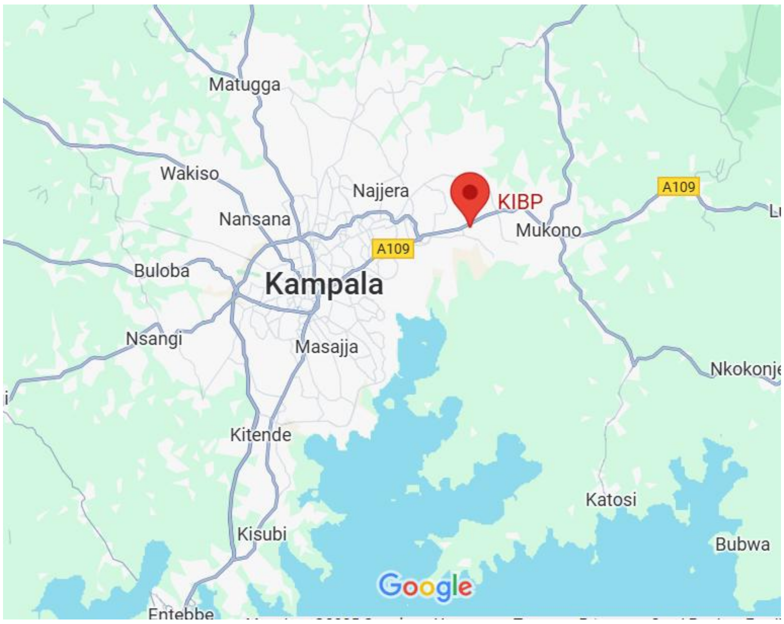

Image 4. The location of KIBP, Source: Google Maps

5.3.1. Research Results

In this part, the research results are summarized in three sub-sections. First, waste generation, usage, supply and existing industrial symbiosis activities within the park are summarized. Then, the challenges and opportunities are clustered in four categories of knowledge, economic, technological and organizational or regulatory

[5] Case study 5.3. has been reformatted into a research article, sumbitted to and is under review at the journal *Sustainable Futures* with the title „Potentials and Challenges of Sustainability, Cleaner Production and Industrial Symbiosis in Uganda's Leading Industrial Park".

aspects. Finally, companies' support needs are presented. Main results are summarized in Table 3.

5.3.1.1. Waste generation, usage, supply and existing IS relationships in KIBP

Existing industrial symbiosis relationships

From the 42 companies in the research, 31 use waste materials in production. Of these companies, 14 use waste materials only in-house, 10 use materials in-house and from other sources, and the remaining 7 firms use secondary materials only from external sources. This makes the number of receiver companies 17 in our further analysis. However, only 3 respondents reported about getting secondary materials partly from companies in the Park – meaning signs of industrial symbiosis within the park but this fact also calls for the importance of outsider firms. Regarding the supply of waste, 23 companies mentioned that they sell or supply waste materials to other companies, buyers or collectors. From the 23 companies, 19 provided information about the type of the business partner receiving their waste materials. 10 of them supply to producers (direct industrial symbiosis), 9 sell to collectors and middlemen (indirect industrial symbiosis) and 2 firms sell to both categories.

Waste generation

The study revealed information on waste material generation of 40 (from 42) companies. Plastic waste is the most commonly generated waste material by 19 firms. This is followed by paper and cardboard (typically from packaging), metals and metal oxides and organic materials. Fewer companies mentioned dust and ash, wastewater and sewage and chemicals, including hazardous materials. Other generated waste and by-product materials are stones and construction materials, oil products, wood and saw dust, carbon slag (see Figure 9).

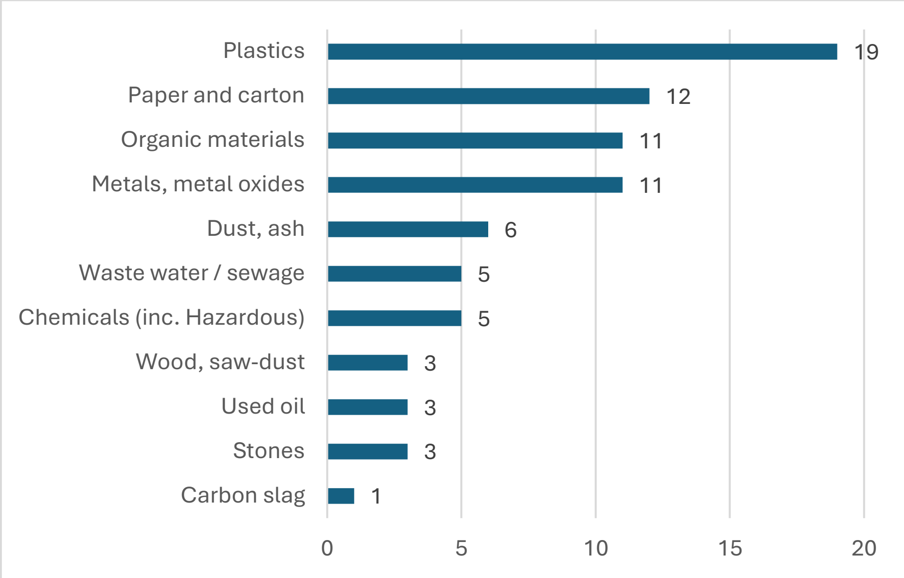

Figure 9. Waste materials generated in the KIBP, 40 respondents; Source: author's construction

Waste usage

Generally, plastic materials are by far the most common waste materials used in production by 29 companies in the park. This is followed by organic materials (5), oil and chemical -by-products (4) and metals (4). Other materials mentioned by few respondents are paper, firewood, saw dust, wastewater and carbon dioxide. Plastic materials are also those being re-used in-house most commonly (14). This is followed by metals (3), chemicals (3) and coffee husk (2). Other in-house used materials are saw dust, used oil, wastewater, stone off-cuts, tobacco and paper.

Waste reception

Among the materials received from external sources (see Figure 10), still plastics are the most common, followed by metals and firewood. Some other materials received are used oil, chemicals, CO_2, bagasse and other organic materials. Regarding the source of the waste materials, 14 companies receive them outside of the park, while only 3 respondents reported about getting secondary materials partly from companies in KIBP. With only one exception, all companies pay for the materials they receive.

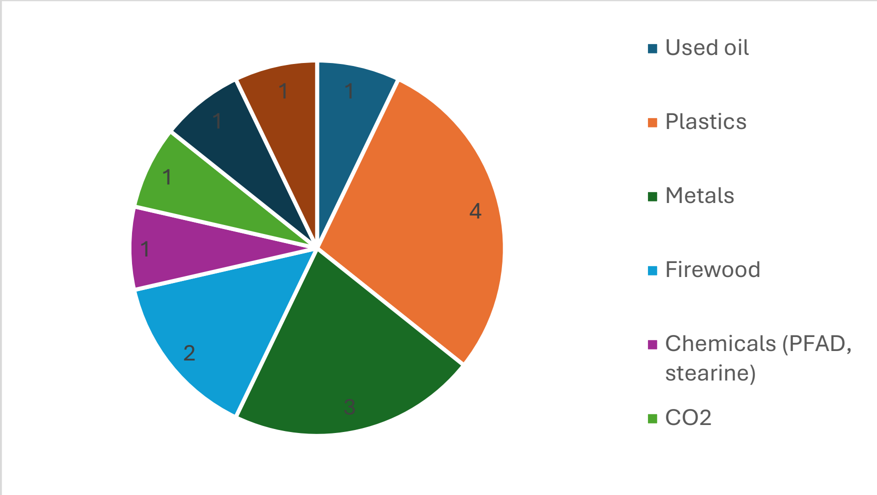

Figure 10. Detected used waste materials within KIBP, 13 respondents; Source: author's construction

Waste supply

Regarding materials supplied or sold to other actors (Figure 11), the distribution looks more balanced. Plastics and organic materials were mentioned by 9-9 firms, metals by 8, paper by 7, dust and ash by 6 companies. 1-1 respondents also supply wood and sawdust. From the 23 companies, 19 provided information about the type of the business partner receiving their waste materials. 10 of them supply to producers, 9 sell to collectors and middlemen, and 2 firms sell to both categories.

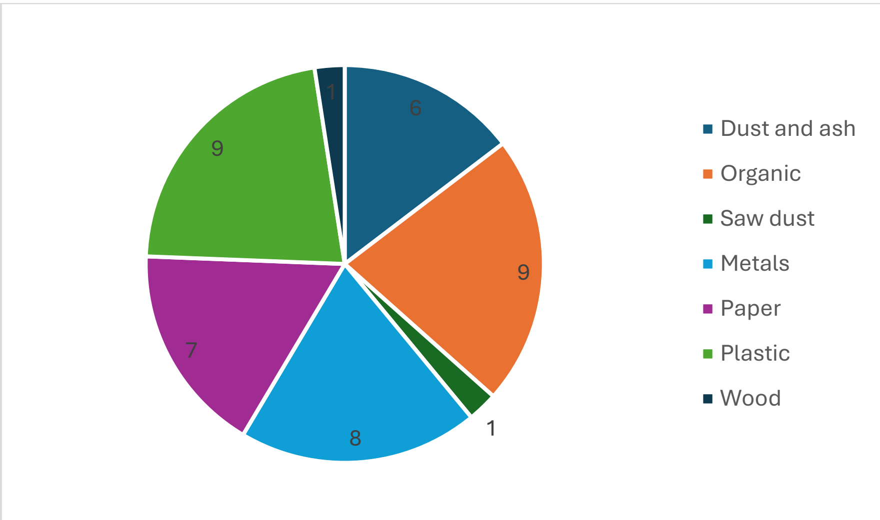

Figure 11. Detected sold / supplied waste materials within KIBP, 23 respondents; Source: author's construction

5.3.2.2. Challenges of waste exchange practices and industrial symbiosis

Attitudes and Information barriers

Waste not users

The study also established barrier factors for the adoption of waste utilization in production *waste not-user* firms. The significant barrier factors are the desire not to depend on waste materials and unwillingness to change production to be based on waste. This is followed by four conditions related to the availability of necessary technology, uncertainty of profitability, trust in other companies' waste materials and general knowledge about companies with appropriate quality, quantity and composition of waste materials (see Figure 12).

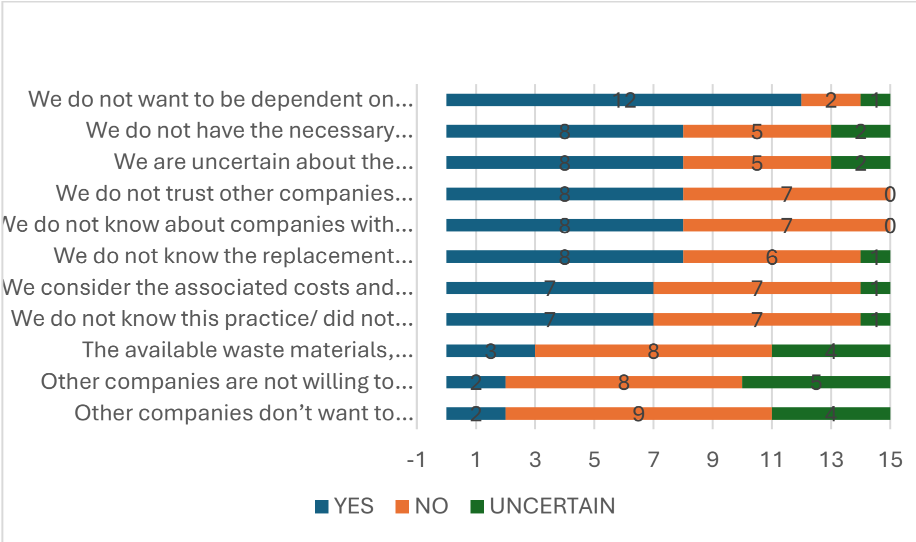

Figure 12. Reasons for not to use waste materials in production, 15 respondents; Source: author's construction

Waste not suppliers

The study detected knowledge gap about selling waste materials as an opportunity among the companies not supplying waste materials. 15 (of 22) respondents cannot imagine starting to sell their waste materials in case of demand. 13 companies mentioned that they do not know about other companies who could use their waste materials. 10 companies do not know for what materials their waste or by-product could be used as replacement alternative. Furthermore, 8 (from 23) respondents are unaware about the potential profitability of this business opportunity and two ones were uncertain in this issue. 7 companies concurred that their waste materials are not useful for any other economic utilization and 8 were uncertain. Figure 13 summarizes the respondent views on waste material as useless for any further economic utilization. Most agricultural and food processing companies still do see their materials valuable. On the other hand, plastic and metal producing or processing companies do not. Very probably because of the level of in-house usage of waste materials is also the highest in these two industries. Chemicals producers are the least uncertain about the potential value of their waste materials.

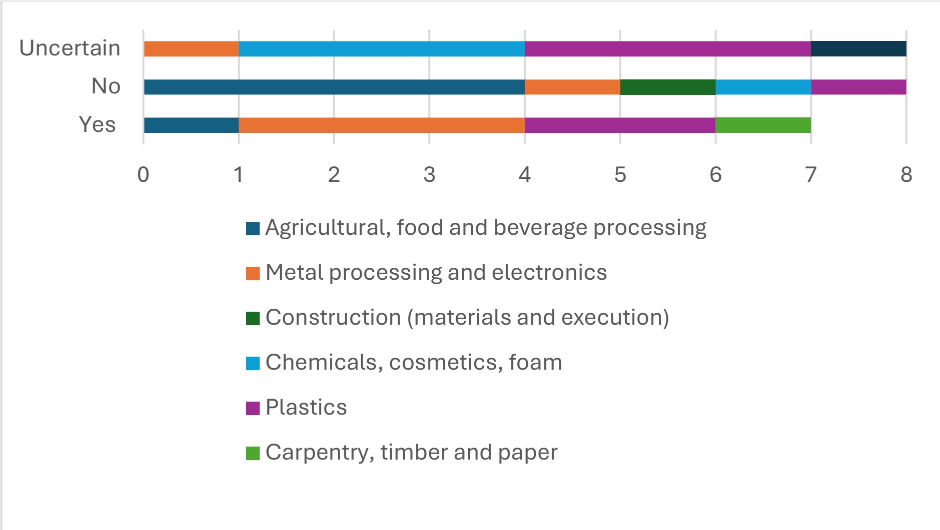

Figure 13. Considering own waste material as useless, categorized by business activity, 23 respondents; Source: author's construction

Park management

Based on the discussion with the park management, the researchers learnt that they are aware of the serious challenges related to waste management. Due to the fact that the park area has still many empty, bushy plots, in many cases, companies, even outside of the industrial park, dump their solid waste in these remote areas. Some respondents reported about the practice of burning non-usable plastic waste materials and other open-air waste burning activities were also documented by the researchers (see Image 5). Furthermore, the park management is also aware of wastewater release in the natural environment.

Image 5. Burning waste pile in KIBP. Source: author's photo, 1 February 2023

Economic barriers

Waste users

In the use of waste as a production input, eight (8) *waste user* companies reported to facing challenges in obtaining the waste materials. Among these the most significant ones are related to stiff competition for and the high price of waste materials, as well as limited supply. As for the cost items as indicators for challenges, materials costs were most frequently mentioned by the respondents, followed by cost of pre-processing and handling, treatment and utilities.

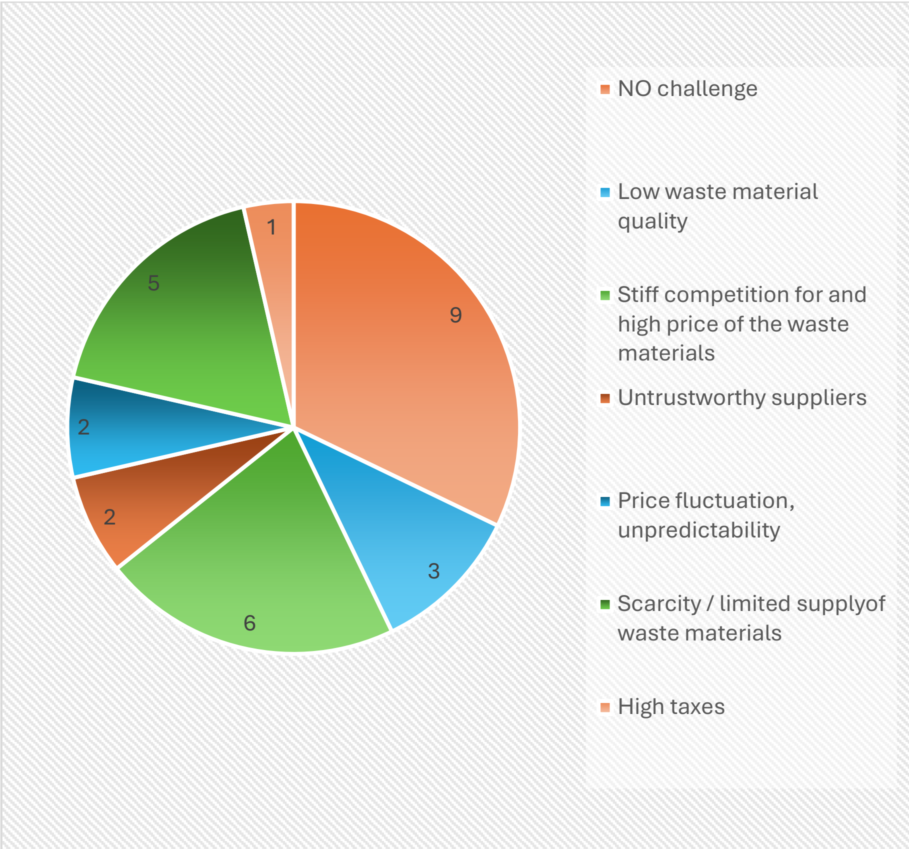

Figure 14. Challenges related to waste materials, 17 respondents; Source: author's construction

Waste not users

As one of the three most important conditions to include waste material in production (Waste Usage Condition – WUC), WUC2 referred to lower input material cost. One of the most significant potential risks of using waste materials the higher cost of production. The high production costs were related to material and labour costs (15), transportation costs (11), handling (10), storing costs (9), and treatment and/or pre-processing costs (7). The study also revealed that in case the companies start to use waste materials in their operation, the cost of labour, treatment or pre-processing, storing and handling would potentially increase. Moreover, the adoption of wastes in production tandems with additionally occurring costs, such as technological investment, additional materials, environmental and safety considerations and related permission fees, local tax, research and development. However, a high number of respondents were uncertain about transportation and material cost.

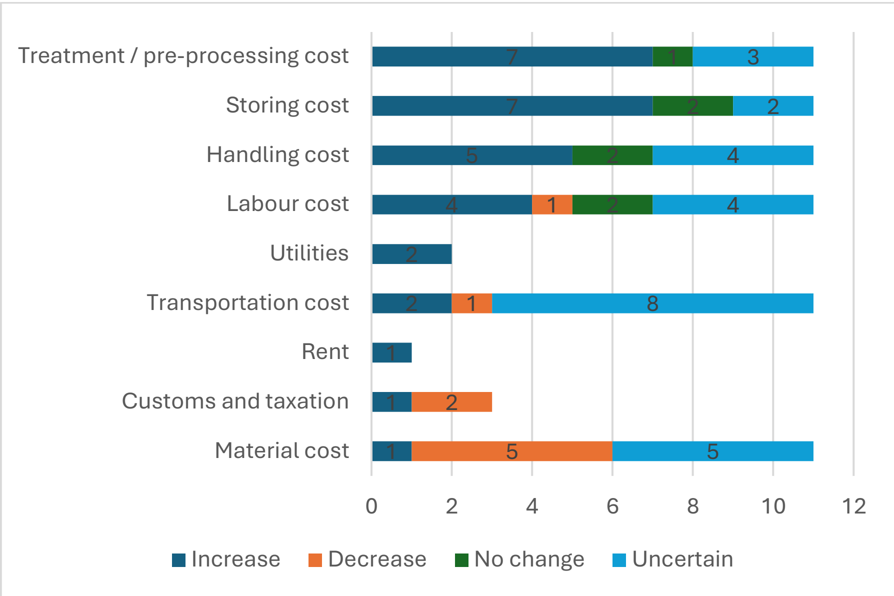

Figure 15. Estimated cost item changes in case of using waste or by-product materials, 11 respondents; Source: author's construction

Waste suppliers

Among *waste supplier* companies, in 10 cases pre-processing, handling and treatment costs occur and 7 firms also have to deal with waste-related storing cost. 6 respondents mentioned additional labour, as well.

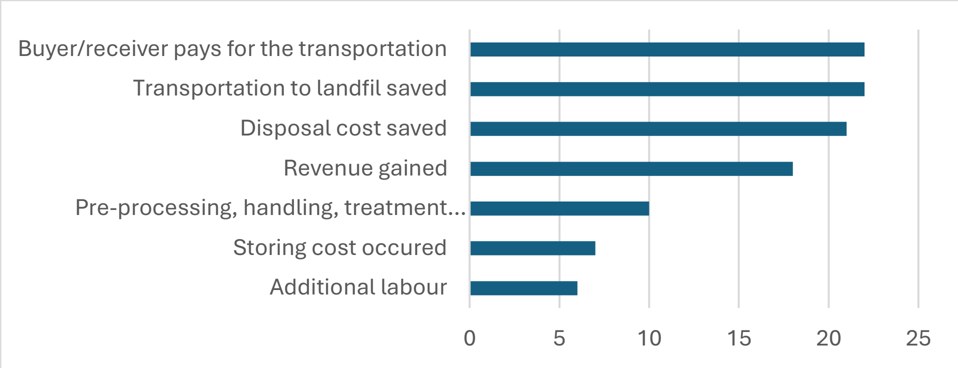

Figure 16. Occurance of negative and positive costs of selling waste materials, 23 respondents; Source: author's construction

Technological barriers

Waste not users

From waste not users, the study found that the two most important conditions for waste not user companies to include waste materials in production are the same quality as the primary one and the lack of need for technological modification. Another significant condition was technological development, as the necessary technology is unavailable. This is in line with the finding that one other frequently mentioned potential risk of using waste materials is the lower final product quality.

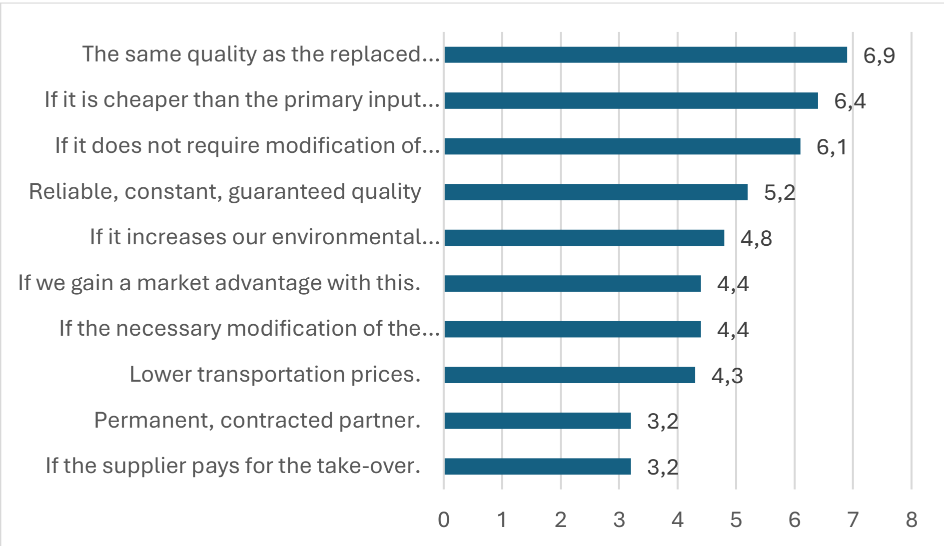

Figure 17. Ranking of necessary conditions to use waste materials, 12 respondents; Source: author's construction

Waste not suppliers

Many waste not supplier companies highlighted the inconsistent supply of waste materials in sufficient quantity and quality. Moreover 7 companies pointed out that some waste is 'problematic' and thus difficult to dispose. From these, chemical and wastewater management is the biggest issue in general.

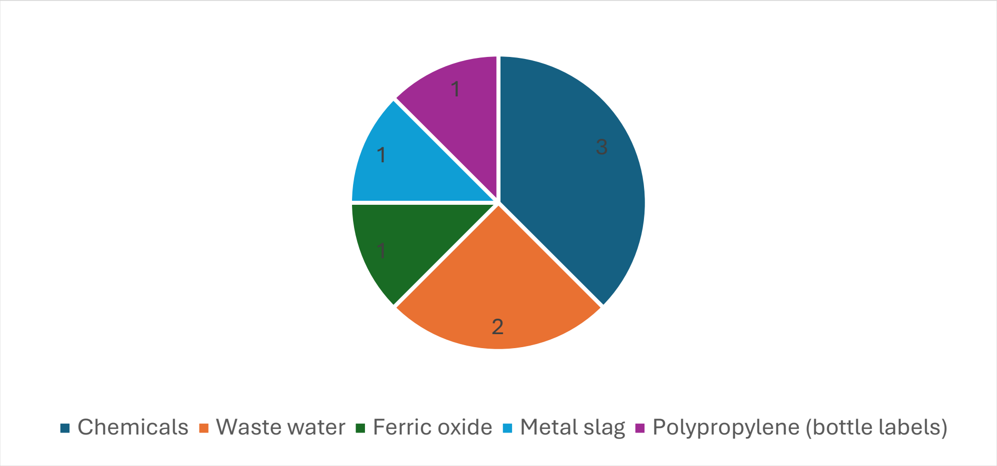

Figure 18. Waste materials problematic for disposal/waste management, 7 respondents; Source: author's construction

Park management

The realization of a central waste sorting and treatment facility is being considered. However, since all plots are already allocated, finding a new fitting location for these activities involves necessary contractual and technological changes and is hindered by capacity shortages. Instead of 10 hectares, now the park authority has to find a solution for 2 hectares and alternatives for material sorting at this central facility. Potential programmes for the reduction and sorting of waste materials generated at the producers' site have to be elaborated.

Another serious dilemma related to the approach of facilitation and support is related to the choice between reusability and recyclability. This is a common problem for plastic companies. Regulations on material composition enable only single-time recycling. In case of promoting reusability, serious sensitization programmes are needed nation-wide.

Organizational and regulatory barriers

Park management

Regarding the illegal disposal activities, park authority pointed out the lack of capacity and competence. This is compounded by limited monitoring and strong reliance on feedback from surveillance audits executed by the tenant firms and/or occasional visits and observations by the personnel. There is a police unit in the park, but environmental performance is not covered in its competence. Beside the limited workforce assigned to this issue, UIA has only a consultative role towards the tenant firms. Even though, it is the contracting partner with the tenants, enforcement efforts are expected from the National Environmental Management Authority and local municipal authorities, as environmental management is decentralized. This hinders prompt and comprehensive actions. Moreover, resource efficiency and the general principles of circular economy are not included in the tenant agreements as mandatory tasks.

Another question is if and how these networks should be formalized and incentivised within the limited regulatory and financial capacities. Taxes on power and local raw materials have already been reduced for tenant firms. Given the revenue collection task of the park authority, the possibility of further tax reduction is very limited. The only one potential solution was mentioned related to the reduction of taxes on collected and used waste materials. Thus, the promotion and facilitation of circular economic practices can concentrate on non-financial and rather encouraging than regulating tools.

5.3.2.3. Opportunities of waste exchange practices and industrial symbiosis

Attitudes and Information opportunities

Waste not suppliers

8 companies did not agree that their waste materials are not useful for any further utilization and 7 companies can imagine starting to sell their waste materials in case of demand. 10 (of 23) companies know about other companies who could use their waste materials and 12 of them know for what materials their waste or by-product

could be used as replacement alternative. 13 respondents are aware about the potential profitability of waste selling as a business opportunity.

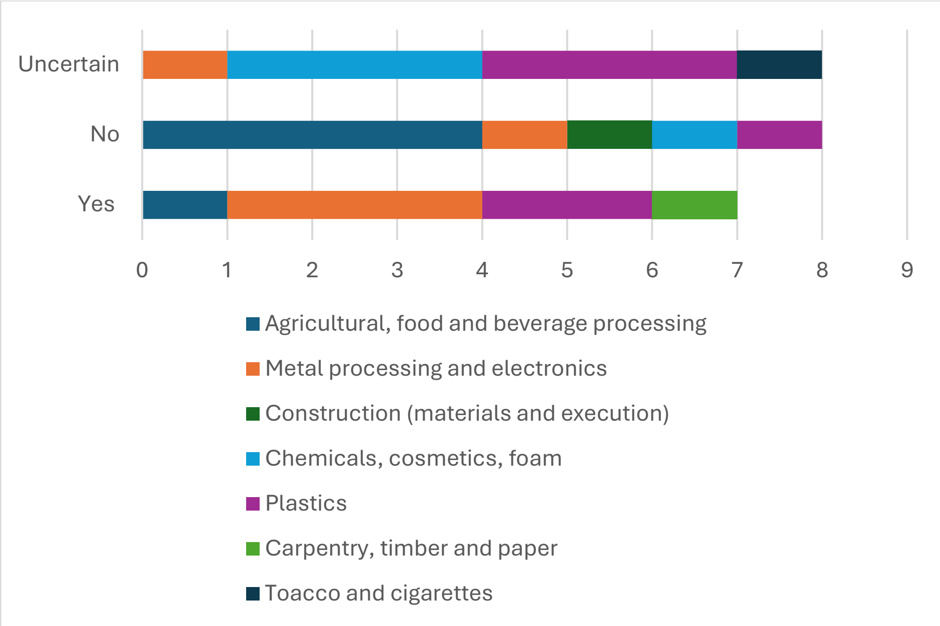

Figure 19. Considering waste material as useless, categorized by business activity, 23 respondents; Source: author's construction

Park management

To reduce or even eliminate illegal waste disposal activities within the park territory, the management plans to sensitize and raise awareness within the park and in connecting communities on waste materials as resources and potential sources of income instead of useless materials. Beyond, the park management is aware of voluntary networks of waste material exchange and usage. As examples, our respondent mentioned one of the biggest beverages producer and plastic recycling companies collaborating in the collection and processing of plastic bottles, or a rice mill selling rice husk for many clients. Furthermore, the management is also aware of private waste collection and trade activities within the park territory. Most companies reported that they supply materials not directly to other producer companies but to collectors and middle-men. This is especially common for plastic, metal and paper. For example, Respondent 8 mentioned that "the role of collectors, as middle-men, is very important in the separation of products and provide scale of the materials for economical usage". Another telling evidence for the existence of trade with waste materials comes from the answer of Respondent 14 when we asked about the destination of waste and by-products: "There is a market for it." This has been supported the researchers' observations of collection and semi-sorting of waste materials, with advertisements to buy them along one of the main roads of the Industrial Park (see Images 6 and 7). Besides, expanding the scope beyond the boundaries of the industrial park would also increase the potential for industrial symbiosis networks in agro-processing and other solid industrial waste (but not in wastewater and effluent treatment). Other positive learnings refer to companies with international certification which go beyond the national environmental expectations.

Image 6. Private (informal?) waste collection and sorting site in KIBP. Source: author's photo, 2 February 2023

Image 7. Waste purchase ad in KIBP. Source: author's photo, 2 February 2023

Economic opportunities

Waste users

The most common motivation to use waste and by-product materials is to reduce input costs and save taxes / disposal fees. Nearly half of the companies also highlighted corporate social responsibility, environmental and sustainability concerns. From 16 respondents, 13 mentioned that virgin materials are more expensive than waste materials. From 10 respondents, 6 mentioned that the virgin material's transportation is more expensive, 4 were uncertain. No one said that the waste material's transportation is more expensive. (In contradiction with the logical implications of the two former findings (generally, both the transportation and the price of waste materials are cheaper), from 16 respondents only 8 mentioned the overall usage of waste materials being cheaper/less costly instead of virgin materials, while 5 companies reported about higher overall costs when using waste materials.)

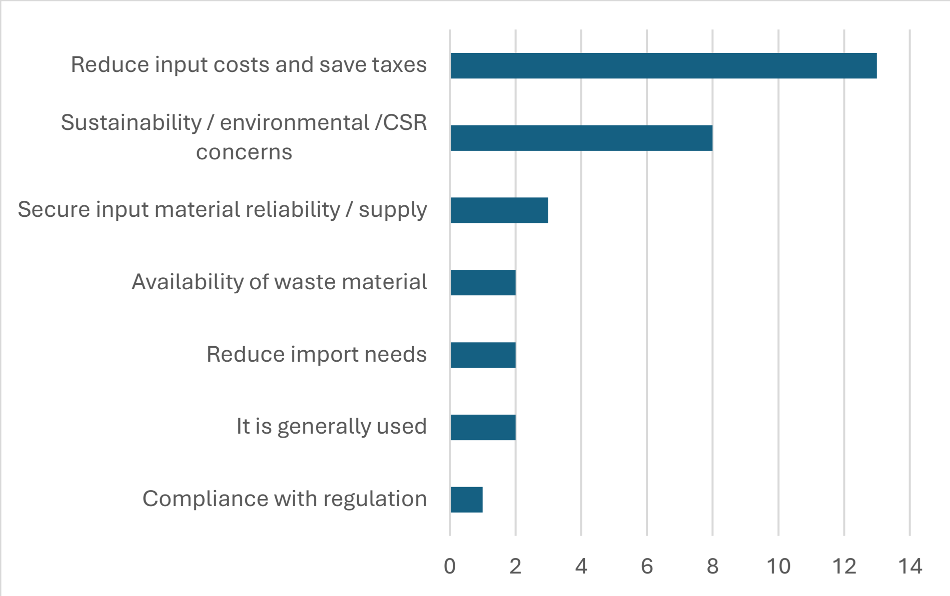

Figure 20. Motivations for using waste materials, 16 respondents in KIBP; Source: author's construction

Waste not users

The two major potential advantages of including waste materials in production mentioned by *waste not-user* companies who do not use waste are lower input material costs and lower environmental impact. These are followed by lower transportation costs. Material cost, customs and taxation were mentioned as potentially decreasing cost items if the companies would use secondary materials.

Waste suppliers

By far the most important motivation of waste suppliers was to generate additional revenue and use resources efficiently. Other important aspects were to create space, sustainability concerns and to reduce or save disposal cost. In all cases, transportation is no cost for the suppliers. This is in line with saving transportation to the landfill and saving disposal cost. 18 companies gain revenue from the waste supply, though 3 of them give away some parts of the waste materials for free. Based on the ranking provided by 20 respondents, the generated revenue is by far the most important item in the cost-benefit framework (see Figure 21).

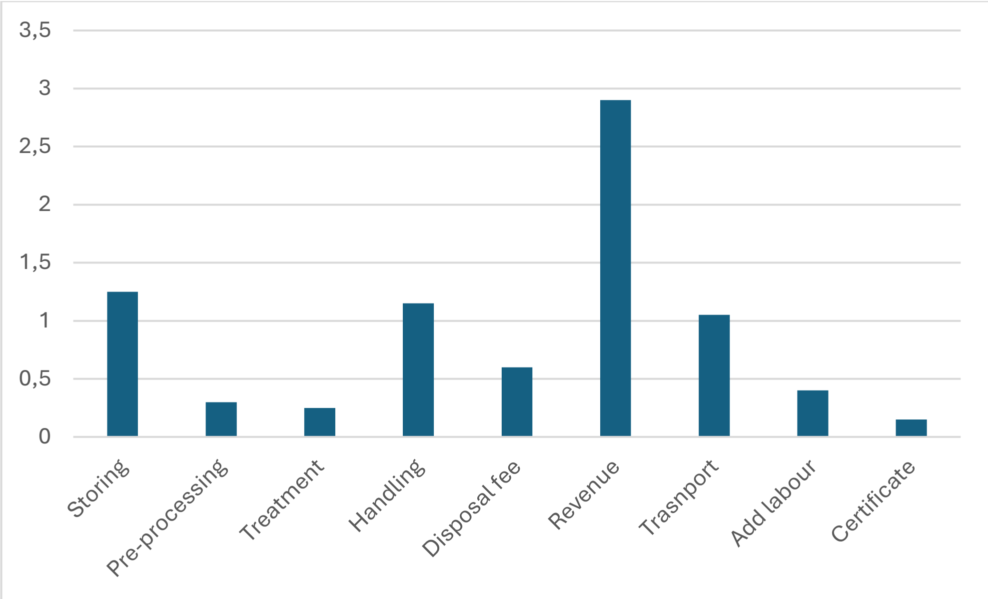

Figure 21. Ranking of positive and negative costs of selling waste materials, 20 respondents; Source: author's construction

Technological opportunities

Waste not users

10 waste not user companies mentioned the following materials which could be used by them (in some cases after serious technological development): used chemicals, dust, maize combs and other maize waste products, insulation paper, metal scrap and steel waste, LPDE.

Waste not suppliers

7 waste not supplier companies mentioned the following materials they could supply for further utilization: wood-offcuts, paper cartons, plastic, foil, sewage (non-hazardous), used oil, metal scrap, old wires, ferric oxide, effluents, molten slag. Moreover, the majority of *waste not-supplier* companies do not consider the lack of technology as a barrier.

Organizational and regulatory opportunities

Park management

As one of the main opportunities is that the operational companies in the park cover only 30% of the territory, according to the discussion with the park management. Thus, the implementation and monitoring of circular economy principles, industrial symbiosis for tenant firms in the remaining plots might be easier in this initial phase.

Among non-financial tools to facilitate waste usage, in our discussion with the park management the recognitions of complying companies was highlighted which can help in marketing and brand-building. For examples, adding a nationally approve label on products. Another opportunity was mentioned related to extension of certificates and licenses of these companies.

Table 5. Challenges and opportunities of industrial symbiosis in KIBP in four aspects; Source: author's construction

Aspects	Challenges	Opportunities
Economic	**Waste Users**: High competition, elevated prices, limited supply; overall higher costs for some when using waste.	Motivated to reduce input costs and save on disposal fees; potential corporate social responsibility benefits.
	Waste Not Users: Increased production costs (labour, transportation, etc.); uncertainty about cost changes.	Potential for lower input costs and reduced environmental impact; belief in decreased material costs if using waste.
	Waste Suppliers: Costs related to pre-processing, handling, and storage; need for additional labour.	Generate additional revenue; resource efficiency; reduced disposal costs.
Attitude and Information	**Waste Not Users**: Reluctance to depend on waste; lack of necessary technology; distrust in waste quality.	Opportunity for knowledge enhancement about waste materials; potential to rethink production processes.
	Waste Not Suppliers: Knowledge gap on selling waste; doubts about profitability.	Awareness of potential buyers and markets for waste; recognition of waste value, especially in agriculture.
	Park Management: Illegal dumping, burning waste, wastewater issues; limited capacity to enforce regulations.	Plans to raise awareness about waste as a resource; potential for enhancing waste exchange networks.
Technological	**Waste Not Users**: Need for waste to match virgin material quality; lack of necessary technology.	Identification of various materials that could be used with further technological development.
	Waste Not Suppliers: Inconsistent quality and quantities of waste; challenges in managing specific waste types.	Supply of diverse materials for reuse; recognition that technology is not a barrier to supply.

	Park Management: Difficulty in establishing a waste sorting facility due to land shortages.	Potential for comprehensive awareness programs to promote reusability and recycling.
Org. and regulatory	Limited capacity to address illegal disposal; reliance on tenant firms for monitoring.	Opportunities for improving tenant agreements to incorporate circular economy principles; recognizing compliant companies.
	Limited regulatory and financial resources to incentivize waste management networks.	Potential to reduce taxes on utilized waste; implementing better regulation of waste management practices.

5.3.2.4. Support needs to facilitate waste exchange and utilization

Companies not using waste or by-product materials in their production activities were asked about the support types from the Namanve Industrial Park management and the national government they would need to start to do so. From both the Park management and national government, the most important support these companies would need are awareness-raising, registry of waste materials available, partner search and match-making, support in investment and in research, development and technology. Specifically, from the Park management, respondents mentioned necessary support as identifying a central waste collection and sorting area, support in training, improved drainage system and water purification as well as tree planting. Regarding the national government, most requests refer to a reward system potentially with fiscal incentives for using secondary materials. This is followed by a very similar need for a clear policy framework that recognizes and provides protection (license) for participating and complying entities. One respondent also mentioned the need for the national promotion of organic fertilizers.

For companies not supplying waste or by-product materials, by far the most frequently mentioned support need from the Park management and the government is to establish one central waste collection and sorting facility, including the treatment of chemical waste materials. Four respondents also mentioned as a general support from the park management in waste collection. Other support aspects both from park and the government refer to partner search and matchmaking; support in research, development and technology; investment; training. Least frequently mentioned support needs addressed to the park management are connected to the registry of licensed waste-collecting companies, awareness-raising and promotion of waste utilization; infrastructural improvements (rainwater collection, dust mitigation, roads; and the registry and categorization of waste materials in the park. Other support forms expected from the national governments are to provide permission for in-house waste utilization (for electronics producers); to ease bureaucratic procedure; provide a clear policy framework; and tax reduction for waste collection companies.

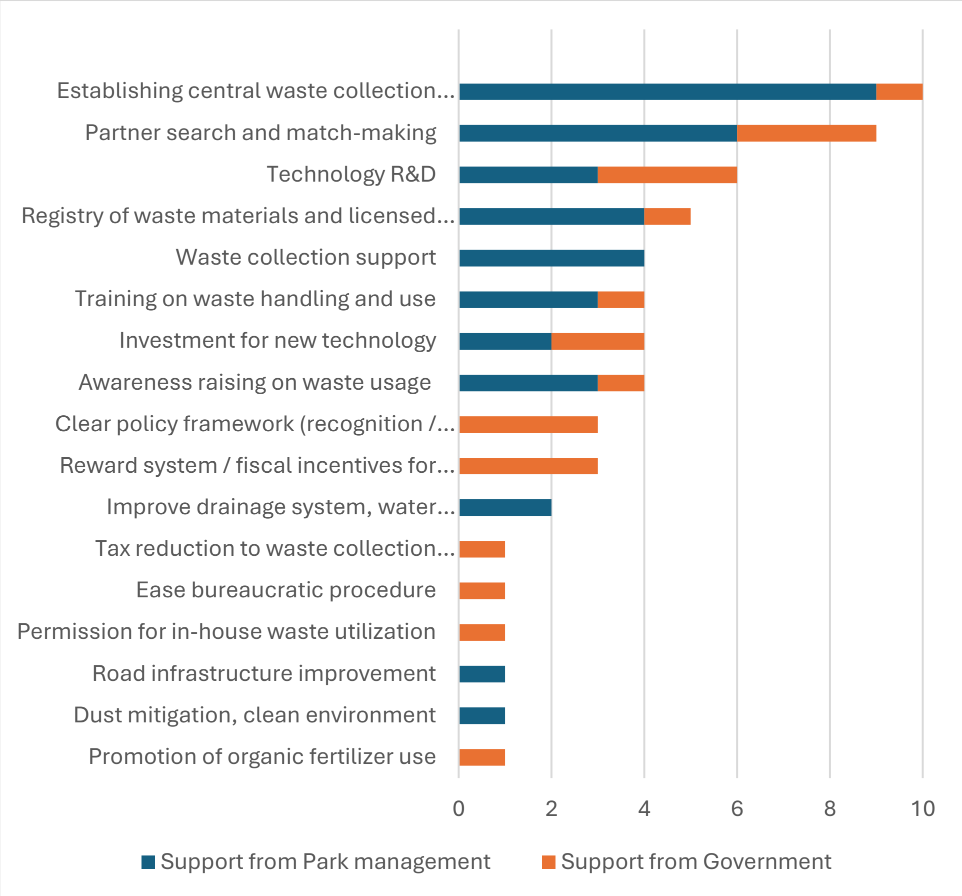

Figure 22. Support needs to improve waste management and facilitate waste exchange in KIBP; Source: author's construction

5.3.2. Answers to the research sub-questions

SQ1: How are specific waste materials and by-products exchanged, or could be exchanged, between industries to promote circular economy practices?

To promote circular economy practices within the Kampala Industrial and Business Park (KIBP), various waste materials and by-products can be exchanged among industries. Research findings identify specific waste materials for potential exchange, offering opportunities for enhancing resource efficiency and reducing waste. Plastic waste, which is both commonly generated and utilized by 19 companies producing it and 29 companies using it in production, can be exchanged for recycling or repurposing in various manufacturing processes. Paper and cardboard, generated by multiple firms, can be reused or recycled by companies requiring packaging materials. Metal scrap, a significant waste type from manufacturing processes, can be supplied to companies involved in metal fabrication or recycling. Organic materials, produced by food processing and agricultural firms, can be utilized by composting operations or energy recovery systems.

Used chemicals also present potential for reuse in industries that require similar chemical inputs, provided they meet quality standards. Dust and ash, by-products of industrial processes, may be repurposed in construction or used as filler materials. Non-hazardous sewage can be treated and potentially reused in other industrial processes or for agricultural applications. By-products such as old wires and ferric oxide, from the electrical and metal industries, can be processed for metal recovery. Molten slag, a by-product of metal processing, can be used in construction or as a raw material for cement production. Additionally, firewood sourced from companies engaged in timber or agriculture can be reused for energy generation or heating.

Among the materials received and used by companies in KIBP, still plastics are the most common, followed by metals and firewood. Some other materials received are used oil, chemicals, CO_2, bagasse and other organic materials. However, most companies receive them outside of the park, while only 3 respondents reported about getting secondary materials partly from companies in the KIBP. With only one exception, all companies pay for the materials they receive. Regarding materials supplied or sold to other actors, the distribution looks more balanced. Plastics, organic materials, metals and paper were mentioned by most companies. 19 provided information about the receiving partners. 10 of them supply to producers, 9 sell to collectors and middlemen, and 2 firms sell to both categories.

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

The adoption of industrial symbiosis at the Kampala Industrial and Business Park (KIBP) is hindered by several primary barriers. Economic challenges play a significant role, as companies face difficulties in sourcing waste materials due to high competition, elevated prices, and limited supply. The costs associated with material sourcing, pre-processing, handling, and treatment also discourage participation (See Figure 15). Additionally, there is often uncertainty about whether using waste materials will be more cost-effective than using virgin materials, further deterring companies from engaging in waste exchange.

Technological barriers also pose challenges, as many companies lack the necessary technology to effectively utilize waste materials. This raises concerns about maintaining product quality and competitiveness. Moreover, there are apprehensions about whether waste materials will meet the quality standards required for production, which makes companies hesitant to incorporate them into their processes.

Regulatory and organizational issues further complicate the adoption of industrial symbiosis. The absence of strong regulatory frameworks that encourage resource efficiency and circular economy practices limits the effectiveness of such initiatives. Additionally, the limited capacity of park management to monitor and enforce environmental compliance, including illegal waste disposal practices, makes it difficult to implement industrial symbiosis effectively.

Knowledge and awareness gaps also present obstacles. Many companies are unaware of the potential value of their waste or how it can be repurposed, leading to missed opportunities for industrial symbiosis. Furthermore, companies that are not currently utilizing waste materials may resist changing their established production processes, fearing risks associated with dependence on waste inputs.

Infrastructure limitations also contribute to the problem, particularly the lack of central waste collection and sorting facilities, which limits the ability to process and exchange waste materials efficiently. Attitudinal barriers, such as distrust in the quality and reliability of waste materials from other companies, discourage participation in waste exchanges. Finally, financial constraints are a significant hurdle, as the investment required for technological upgrades and the costs associated with compliance and regulatory fees can be prohibitive for many companies.

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

To enhance the exchange of waste materials and by-products among industries within the Kampala Industrial and Business Park (KIBP), several mechanisms can be implemented. A centralized waste exchange platform could be established, creating an online registry where companies can list available waste materials and by-products for exchange (see Figure 22). This would facilitate matching waste suppliers with potential users. Additionally, a waste collection and sorting facility should be set up to streamline the processing of waste materials, ensuring consistent quality and reducing logistical challenges.

Economic incentives can play a key role, with financial support such as tax reductions for companies that actively participate in waste exchanges, utilize collected and processed waste materials and demonstrate effective waste management practices, encouraging greater participation in industrial symbiosis. Additionally, establishing funding programs or grants for businesses investing in waste management technologies and practices can alleviate financial burdens and facilitate their adoption of circular economy principles. Beyond, non-financial tools to facilitate waste usage include recognizing compliant companies, which could aid in marketing and brand-building, such as through nationally approved labels on products. Additionally, extending certificates and licenses for these companies was highlighted as another opportunity.

Improving stakeholder collaboration is another key strategy. Facilitating networking opportunities through events or platforms where businesses can connect, share resources, and explore waste exchange opportunities can significantly enhance cooperation. Recognizing the role of waste collectors and middlemen in waste management will lead to better coordination and efficiency in these exchanges. For example, Respondent 8 mentioned that “the role of collectors, as middle-men, is very important in the separation of products and provide scale of the materials for economical usage”. Another telling evidence for the existence of trade with waste materials comes from the answer of Respondent 14 when we asked about the destination of waste and by-products: "There is a market for it." Images 6 and 7 illustrate this evidence.

To further promote these efforts, knowledge and capacity building are crucial for the widespread adoption of industrial symbiosis. Awareness campaigns aimed at educating companies about the benefits and opportunities of industrial symbiosis can inspire more businesses to adopt these practices. Moreover, offering training sessions and workshops to improve understanding of waste utilization and exchange practices will empower companies to engage more fully in the process.

Technological support is another critical factor. Investing in research and development (R&D) initiatives focused on developing technologies for waste processing and reuse can improve the feasibility and efficiency of industrial symbiosis. In addition, the creation of central waste sorting and treatment facilities can streamline the waste exchange process.

Enhancing the regulatory framework is also essential. Strengthening existing regulations to include mandatory requirements for resource efficiency and circular economy practices in tenant agreements can help promote accountability among companies. Developing clear policy guidelines that outline compliance requirements and protections for companies engaging in waste exchanges will reduce uncertainty and provide a more supportive environment for industrial symbiosis. Improvements could come from better implementation of existing regulations, including the National Environmental Actoni Waste Management Regulations (NEMA, 2020a), and Environmental and Social Assessment Regulations (NEMA, 2020b).

Monitoring and support mechanisms are also essential. Establishing a system to monitor waste exchanges and resource efficiency will help ensure compliance with regulations and provide valuable data to refine practices. Implementing recognition programs for companies that successfully engage in industrial symbiosis can motivate other businesses to follow their example.

Moreover, to promote informal collaborations, voluntary networks and alliances among companies could be fostered, leveraging existing relationships for mutual benefit. Expanding the scope of industrial symbiosis beyond KIBP is important for broadening the impact. Encouraging cross-border and inter-industry collaborations, particularly with companies in related sectors like agro-processing, can open new opportunities for waste exchanges and create a more sustainable ecosystem.

5.4. Potentials and challenges of the utilization of mining waste materials. The case of copper mining waste in Zambia[6]

This Sub-chapter opens the perspective towards the macro level by presenting waste usage potentials and challenges in one specific and very important sector in Sub-Saharan Africa, mineral extraction, through the case of copper mining waste materials in Zambia. Image 8 shows the location of the research area, the Copperbelt Province in Zambia. The questionnaire used for this case study can be found in Appendix 7, the list of respondents in Appendix 8, and pictures from the field research in Appendix 9.

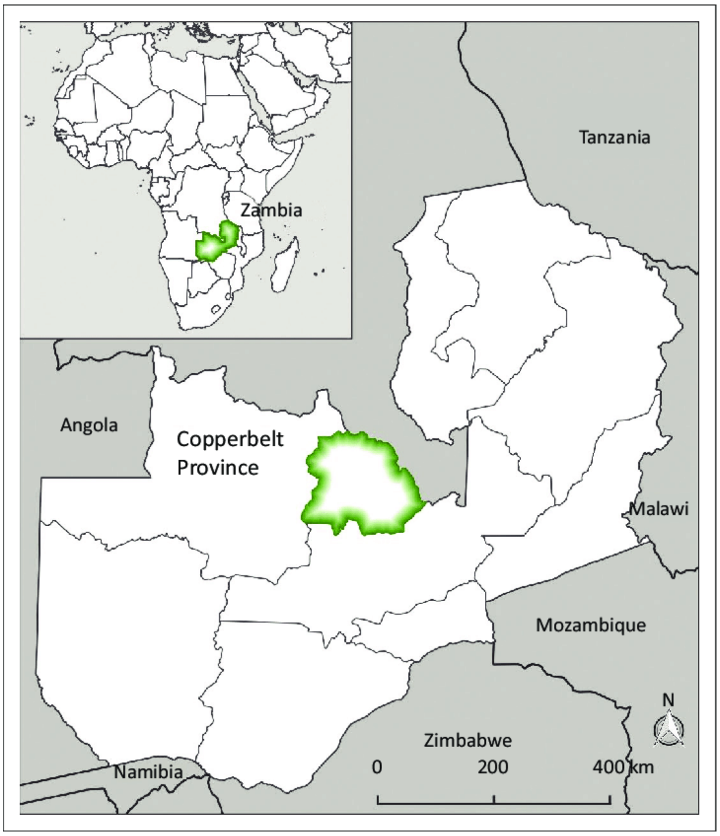

Image 8. Location of the research area, the Copperbelt Province of Zambia; Source: ResearchGate, 2025

[6] Case study 5.4. has been reformatted into a research article and published as:
Buda, G. (2025). Black Mountains and White Deserts – Why are copper mining waste materials not
utilised for other products and economic diversification in Zambia? Külgazdaság, 69(1), 1–23. https://doi.org/10.47630/KULG.2025.69.eng.1

5.4.1. Research Results

As mentioned above, the research focused on exploring the aspects hindering or facilitating the utilization of copper mining waste materials. Hereby, the main aspects are shortly presented in four categories: knowledge, economic, technological, legal. Main results are summarized in Table 3.

Knowledge aspects

One of the main knowledge or informational barrier is well represented by the first answer of Respondent 5, in line with many other respondents, to the question why mining waste is piled-up and not used for other purposes: "No-one even thought to use the waste". These materials are considered only as resources for re-mining (Resp. 2). Parallelly, destination companies never considered using copper mining waste (Resp. 14), even if the transportation of it would be much cheaper than that of the conventional input materials (Resp. 7). As Respondent 19 precisely expressed: "Nobody has come to ask for it." These results point out how strongly the general mindset related to mining materials is locked within the linear economy and blocks out-of-the-box way of thinking and innovation: "As a mine, your main interest is the minerals" (Resp. 16) and "It is not our core business" (Resp. 15). Furthermore, the exact amount of the waste materials and the exact mineral content are not clear either (Resp. 4, Resp. 13), as the understanding of the composition (Resp. 6) and the destination product what one may use these materials for (Resp. 1.), are also key information in this puzzle. The research work also detected the lack of related competence and need for capacity-building within the organizations (Resp. 10, Resp. 13) and clarification of useability, qualities, properties, and cost-benefit analysis of the materials via further research (Resp. 13, 14, 16, 19). Finally, the main unanswered question is related to technological development: when, with what intensity and what costs (both economically and environmentally) the full mineral content can be extracted. Respondents 11 and 12, for instance, pointed out the lack of clarity related to the time dimension, namely, for how long time the tailing materials will remain within the re-mining process until all minerals can be extracted.

Nevertheless, the research discovered that many respondents do know about purposes these waste materials could be used for. In accordance with the potential destination products described above, the respondents mentioned tiles or rooftiles (Resp. 1, 3, 6), concrete or bricks (Resp. 3, 7, 11, 16, 17), glass or ceramics (Resp. 4, 11, 12, 15), roads or pavements (Resp. 3, 7, 17) and aggregates (Resp. 15). Furthermore, on the destination side it was also detected that the understanding of these materials not being waste but potential inputs for new products (Resp. 8).

Technological aspects

Most respondents mentioned technology as the highest barrier for utilization, including the destination companies. One of the main technological barriers is the toxicity or unclear status of neutralization of these materials which makes them not applicable for the human environment. Respondent 1 and 4 mentioned the removal of heavy metals, chromium and cadmium as one of the biggest technological challenges. Moreover, typically sulphite and oxide contents worsen important properties of concrete and pavements, such as binding Resp. 4, 5, 6, 18). The technological requirements and necessary equipment for different treatment methods, such as chemical, mechanical or other treatments, are missing or hardly available. As Respondent 1 pointed out, "the processes how these materials can be utilized is the key problem", therefore, technology determines the cost of production (Resp. 1) and one has to look at the economics for whatever purpose to use these materials (Resp. 7.).

Economic aspects

Two major economic aspects were discovered blocking the utilization of mining waste materials for other purposes. First and most importantly, even if as mentioned above the exact amount of mineral content is not clear, one knows that there is still a certain amount of valuable minerals within the black mountains and the white desserts (Resp. 7., 10, 11, 12, 13, 16, 17). Specially, older tailings and black mountains contain a higher proportion of valuables, since the older technologies were less efficient in mineral extraction (Resp. 4, 5, 7, 13, 16). As Respondent 16 stated, "there is a general understanding that in the near future they can be of economic value." Based on the respondents' estimations, on average copper mining slag and tailings contain 0.1-0.3%

copper, 0.01-0.02% cobalt, and several additional metals such as lead, zinc, nickel, silver, iron, and a dominant volume of silica. This gives the motivation to mining companies to keep and store these materials as long as technological development will enable full extraction, and therefore blocking the access by other actors and side stream development.

On the other side, at the so-called destination companies, the cost of necessary treatment against toxicity and for stability of the materials are much higher than using conventional input materials, even if imported. Regarding the different cost factors in the analysis, Respondent 3 pointed out that the material price for other production purposes would be very low in the case of using the tailings, while very high in the case of using the smelter slag. For using the tailing, treatment and pre-processing would be the highest costs, followed by storing and handling, and material price could be inevitable. For using the smelter slag, the highest cost would still e the treatment, then material price, followed by pre-processing, storing and handling (Resp. 3.). Similarly, Respondents 11 and 12, working at a tailing re-mining facility, described pre-processing and chemical treatment as the highest costs, followed by transportation, storing, sorting and handling. Respondent 6 also mentioned the cost of equipment, testing facility and the high cost of energy necessary for crushing slag material.

Meanwhile the black mountains and white desserts pose serious costs and management tasks, including environmental and employer safety risks to mining companies. It can be most precisely described by the statement of Respondent 17: "In a smelter the biggest risk is how to manage your waste." Respondent 3 told us about a recent construction of two tailings dams costing 54 million USD for one of the main mining companies. Management costs include security, inspection and monitoring, dust mitigation, keeping the integrity and stability, reporting. One respondent mentioned 60.000 USD monthly cost of the tailing dam maintenance, apart from 150.000 USD annual cost of molasses to ensure dust mitigation (Resp. 16.). At the same time, "we know that the volume of waste will increase" – as Respondent 19 pointed out. Just to show some examples, the amount of tailing material in one of the dams grows by 181 million tonnes every year (Resp. 15), while one of the smelters produces approximately 180.000 tonnes of slag, being added to the one of the black mountains (Resp. 17.) Another tailing dam occupies 900 ha of land that could be used for agricultural purposes (Resp. 10). Finally, as one of the environmental specialists interviewed highlighted, still many dams are untouched and contaminated, causing serious harms to the environment by leaching in natural water bodies, flying dust during the dry season and mud in the rainy season (Resp. 13.). This increasing amount indicates increasing costs for the mining companies. As respondent 10 mentioned, “we do realize that there is a little value in them but until technology goes somewhere, we have to look after it”.

Legal aspects

As already mentioned at the economic aspects, these waste materials form the property of mining companies and, thus, they can block access by other actors (Resp. 14, 15), such as potential researchers or destination companies. Many of the respondents also highlighted the lack of political will, governmental effort of legislation focusing on the utilization of these waste materials (Resp. 1., 7, 13). The analysis of the three relevant regulatory documents (Environmental Management Act, 2011; Environmental Management Act – Licensing Regulations, 2013; Mines and Mineral Act, 2015) also shows that it is not set in legislation until what time or mineral content these materials should remain within the mining industry or for what other purposes they could and should be used for. While older regulations obliged mining companies only to environmentally friendly disposal, new ones focus on storing for future mineral extraction.

Table 6. Identified barriers for copper slag and tailings utilization in four categories; Source: author's construction

Aspects	Identified barriers
Knowledge	• Mindset locked within the linear economy – blocks out-of-the-box thinking and innovation • Present value of the mineral content • Waste materials as resources for other purposes – not clear • Exact amount of waste materials • Technological development – time and quality/intensity
Technological	• Toxicity (neutralized?) • Technological requirements (chemical, mechanical, etc.) and equipment • Sulphite and oxide content • Binding properties

Economic	• Mineral content – copper, cobalt, rare earth metals
	    • Storage and waiting for technology development for future remining / mineral extraction
	    • Blocking side-stream development

	• Cost of treatment compared to conventional inputs for destination products
Legal	• Earlier: These materials are useless, obligation for environmentally friendly disposal • Recently: These materials will have a future value for remining, storage for future • Waste materials are the property of mining companies • Blocking access to materials by other actors (researchers, destination companies)

5.4.2. Answers to the research sub-questions

SQ1: How are specific waste materials and by-products exchanged, or could be exchanged, between industries to promote circular economy practices?

In the mining sector, several waste materials and by-products can be exchanged among industries to promote a circular economy. Copper slag, a by-product of copper extraction through smelting, can be reprocessed to extract remaining valuable minerals or utilized in products such as blended cement, road pavement, abrasives, and roofing granules. Mine tailings, which are the residual materials left after mineral extraction and beneficiation, can be used as a feedstock for products like concrete, tiles, and glass once they are reprocessed. Waste rock, which often contains small mineral concentrations, can be reused in construction, particularly for building roads and infrastructure. Overburden, the soil and rock removed to access ore deposits, can be reused for backfilling or land reclamation projects. By incorporating these waste materials into various industrial processes like construction, cement production, and road building, the mining sector can significantly contribute to a circular economy. This not only reduces waste and environmental impact but also creates economic value by transforming by-products into useful materials for other industries.

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

The primary barriers hindering the adoption of waste exchange and utilization in the mining sector are knowledge, technological, economic, and legal factors. From a knowledge perspective, many mining companies and destination industries are unaware of the potential uses for mining waste, as the mindset remains largely within a linear economy framework. Many respondents noted that there is little exploration into alternative uses for waste materials like copper slag and mine tailings, and there is a lack of clarity on the materials' composition and potential product applications. Additionally, there is a significant gap in organizational competence and the need for capacity-building to explore the full range of possibilities for waste utilization.

Technologically, one of the main challenges is the toxicity or unclear status of neutralization processes for mining waste, which makes these materials unsuitable for certain applications. Removing harmful substances like heavy metals, chromium, and cadmium is a major hurdle, as is addressing the poor properties of materials like copper slag, which can negatively affect products like concrete and pavements. The absence of appropriate treatment technologies and the high costs associated with these processes further complicate the adoption of waste utilization.

Economically, two key issues arise: the unclear value of mineral content in waste materials and the high costs associated with utilizing mining by-products. Many mining companies are hesitant to allow others to access their waste materials, as they believe there may be economic potential for future mineral extraction. Furthermore, the costs associated with pre-processing, treatment, and transportation of mining waste for use in alternative industries are often prohibitive, especially when compared to using conventional materials.

Lastly, legal barriers also play a significant role. The ownership of mining waste materials lies with the mining companies, which may restrict access for other potential users, including researchers and destination companies. Additionally, there is a lack of political will and clear regulations on how mining waste should be managed or utilized. Current regulations primarily focus on environmentally safe disposal or storage for future extraction, but do not encourage or mandate alternative uses, such as for product manufacturing or land reclamation.

These combined barriers create significant challenges in transitioning to a circular economy within the mining sector, limiting the potential for waste exchange and utilization.

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

To facilitate waste exchanges and address the challenges in copper mining waste utilization, a multifaceted approach that combines policy innovation, technological development, and strategic economic interventions is essential. One key mechanism is the introduction of a policy that sets a minimum threshold for mineral content in waste materials, such as copper mining slag and tailings, below which they should be repurposed for other productive uses. This would standardize the materials, making them more predictable for use in industries like construction, paving, and manufacturing. It would also encourage research and innovation by reducing the uncertainty around the composition of these materials, helping to drive down costs and speed up product development.

From a policy perspective, setting this threshold would help to move the industry from a linear to a circular economy mindset. In the linear model, these waste materials are stored with the hope of future mineral extraction, contributing to environmental risks and missed economic opportunities. A circular approach, however, would see these materials repurposed as valuable inputs for products like tiles, concrete, and road pavements. By setting a policy that mandates the utilization of materials once their mineral content falls below a certain value, policymakers could foster innovation, reduce reliance on a single industry (mining), and drive economic diversification.

To address the technological barriers, investment in research and development is crucial. There is a need for further exploration into non-toxic and non-contaminated prototypes of products that can be made from mining waste. This research could focus on finding ways to neutralize harmful substances like heavy metals, making these materials safer for use in construction and other industries. Once these technological hurdles are cleared, the utilization of mining waste could provide a significant economic boost, create new industries, and generate employment opportunities.

Additionally, policies could encourage the formation of partnerships between mining companies and destination industries that could benefit from these by-products. These partnerships could help share the costs of research, pre-processing, and material transportation, making it more feasible for both parties to utilize mining waste. This would also facilitate the creation of a more robust value chain, with better integration between the mining industry and other sectors of the economy.

On the economic front, a "materials-as-service" model could be explored, where mining companies lease raw materials to manufacturers and other industries, rather than owning them outright. This model would allow mining companies to still extract economic value from these materials, but without the risk of keeping them in storage indefinitely. Such a system would also make it easier to track and manage these materials as they move through the supply chain, ensuring that they are used in a way that benefits the broader economy.

Lastly, a shift in legal and regulatory frameworks is necessary. Governments should create a clear set of regulations that guide the management and use of mining waste materials. These regulations should incentivize innovation and ensure that materials are not held up by outdated legislation that prioritizes storage over productive reuse. Strong enforcement mechanisms are needed to ensure that mining companies adhere to these new policies, and international collaboration is also essential to manage the trade of waste materials and products derived from them.

By combining these mechanisms—policy changes, technological innovation, economic models like "materials-as-service," and legal reforms—the mining sector can overcome its linear economy mindset and transition toward a more sustainable, circular approach. This shift will not only benefit the mining industry but will also support broader societal development, environmental sustainability, and economic diversification.

5.5. Waste utilization potentials and challenges on micro, meso and macro levels in Ghana[7]

This last case study includes micro, meso and macro level aspects by presenting results based on interviewing twenty-three individual companies, highlighting three mini case studies of waste recycling companies, and discussing with four local experts and policy-makers related to waste utilization and the broader perspective of the circular economy and green industrialization in Ghana. Image 9 shows the location for the research, the Greater Accra region in Ghana. The questionnaire used for data collection is in Appendix 10, the list of respondents in Appendix 11, and pictures from the field research can be found in in Appendix 12.

Image 9. Location of the research area for Case study 5, the Greater Accra Region of Ghana; Source: author's construction based on Google Earth construction

5.5.1. Research Results

The presentation of research results for Case study 5 starts with the company interviews. Among these, three waste recycling firms are highlighted and introduced in more details afterwards. At the end, the discussions with for policymakers and experts about meso and macro level aspects are summarized.

[7] Case study 5.5. has been reformatted into a research article, submitted and is under review at the journal *Humanities and Social Sciences Communications* with the title „ The Promise and Challenges of Circular Economy in Ghana’s Transition to a Green Economy”.

5.5.2.1. Company interviews

The sample of 23 respondents is divided into four categories: Waste Users (WU), Waste not Users (WnU), Waste Suppliers (WS), and Waste not Suppliers (WnS). Among the respondents, 16 are Waste Users (WU), who utilize a variety of waste materials, including organic (5), plastics (4), paper (2), wood (1), metals (1), textiles (1), and waste management services (2). The Waste not Users (WnU), consisting of 6 respondents, mainly work with organic waste (3), plastics (2), and metals (1).

On the other hand, the Waste Suppliers (WS), with 6 respondents, 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 Suppliers (WnS) category, mostly supplying plastics (2), along with textiles (1) and organic materials (1).

Waste Users

Various waste materials are being recycled and repurposed to promote sustainability and reduce environmental impact. These materials include wood waste like pallets, waste paper, and organic materials such as coconut waste, bamboo, and cocoa by-products, which are commonly used for composting or biofuel production. Plastics, including PET, PS, LDP, PP, and HD, are essential for recycling efforts, along with textiles, which contribute to waste diversion and reuse. Food waste, such as cereals, fruits, and vegetables, is processed into compost, while plastics from sachets, broken chairs, and containers are recycled into new products. Metals are recycled for industrial purposes, and municipal mixed waste requires careful sorting to maximize its recycling potential. Additionally, sewage (liquid waste) is treated for energy recovery, supporting the goal of reducing waste and promoting a circular economy. These efforts help enhance sustainability and reduce the environmental impact of waste.

Waste materials are sourced from various places, such as industrial areas, packaging companies, educational institutions, and informal collectors. Coconut waste, for example, is typically sourced from vendors, while waste from farms, schools, ministries, and banks also contributes to the waste stream. The food and construction industries, including chocolate producers, construction companies, and coconut oil producers, play significant roles in the waste supply. Middlemen and waste collection points also facilitate the gathering of materials from second-hand shops, plastic producers, and individual collectors, ensuring a continuous flow of materials for recycling.

Challenges in obtaining waste materials include increasing competition and rising prices, making it harder for companies to secure the necessary resources at affordable rates. The varying types and quality of waste further complicate efforts to standardize operations. Waste is often not available in the required quantities or specifications, and transportation issues arise when moving materials from collection points to processing facilities. Companies must also contend with fluctuating prices, which are impacted by the prioritization of non-essential materials. Moreover, ensuring the quality of waste materials is another hurdle, as businesses need to meet the necessary standards for reuse or recycling.

The motivations for using waste materials are centered around sustainability, resource efficiency, and environmental impact. Many companies are drawn to waste materials because they are often pre-treated, helping to save on processing costs. Reducing carbon footprints, lowering landfill costs, and improving resource efficiency are significant drivers, as is the effort to support local communities through job creation. Some companies view it as a business opportunity, while others are focused on reducing plastic waste and promoting recycling. Climate change concerns also play a role, with companies aiming to lessen their environmental impact.

Key cost factors in using waste materials include transportation, which is one of the most significant expenses, followed by the cost of the waste itself, which varies depending on the type and quality of materials. Pre-processing, treatment, and handling are also essential steps that contribute to overall costs. Sorting and storing waste add to operational expenses, particularly when dealing with large volumes of mixed waste. Electricity costs are another concern, as energy is required to power machinery used in the treatment and processing stages. Finally, quality control is important, though it represents a smaller, yet still significant, cost in ensuring that materials meet the necessary standards for recycling or reuse. These costs highlight the complexity of efficiently utilizing waste materials and the challenges involved in waste management.

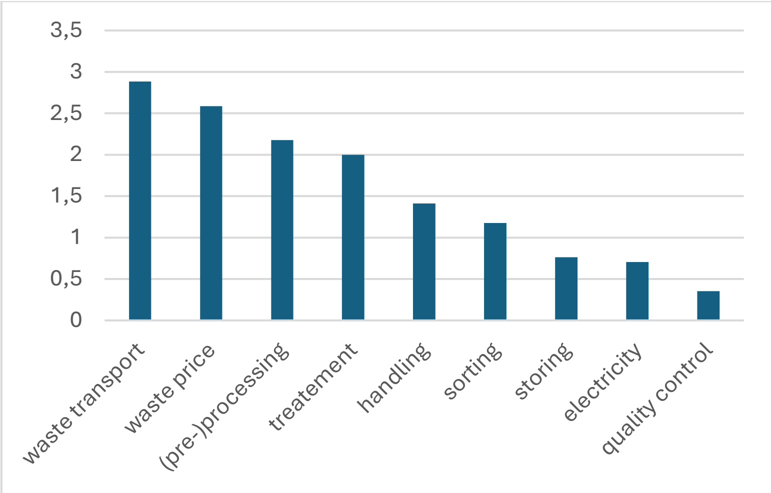

Figure 23. Relative significance of cost items in waste usage, 17 respondents in Ghana; Source: author's construction

The waste users have expressed several needs to support their operations. One key request is for VAT tax reductions, which would help reduce the financial burden on businesses using waste materials. There is also a call for tax reliefs and a reduction in duties on machinery, which would make it more affordable to invest in the necessary equipment. Another expressed need is the subsidization of organic fertilizers, as opposed to the current system that favors chemical ones. Waste users also highlighted the high costs of imported virgin materials, exacerbated by high fuel prices and taxes, making it more difficult to compete with locally sourced waste materials. These needs highlight the desire for greater support and incentives to make waste utilization more cost-effective and sustainable.

Waste not Users

Incorporating waste materials into production processes carries several risks, such as the potential for business failure due to unforeseen challenges. One of the main concerns is the low quality of the final product, which could result from the use of substandard waste materials. Additionally, unwanted materials or quality problems can arise, impacting the overall production process. There are also significant risks related to food contamination and environmental pollution, especially if the waste materials are not properly processed or handled.

However, there are notable potentials in using waste materials for production. One of the key advantages is the opportunity to access alternative energy sources, which can help reduce reliance on traditional energy. Furthermore, incorporating waste materials can lead to significant cost reductions, making the production process more economical and sustainable. Despite the challenges, these potential benefits highlight the value of integrating waste materials into production systems.

Based on responses from five waste not using companies, there are varying trends in the changes of cost items when using waste materials. For materials, 1 respondent reported an increase, 3 noted a decrease, and 1 was uncertain about the change. Labour costs saw an increase for 1 respondent, with 3 stating no change and 1 uncertain. Storing costs remained the same for 3 respondents, while 2 were uncertain about any potential changes. In terms of handling, 2 respondents reported an increase in costs, 2 saw no change, and 1 was uncertain. Treatment costs increased for 2 respondents, decreased for 1, and remained the same for 2. Transportation costs showed a decrease for 2 respondents, no change for 1, and uncertainty for 2. Sorting costs were more evenly split, with 1 respondent reporting an increase, 1 a decrease, 1 stating no change, and 1 uncertain. Overall, the total responses showed 7 increases, 6 decreases, 11 unchanged, and 10 uncertain, indicating a mixed but largely stable cost landscape for waste usage.

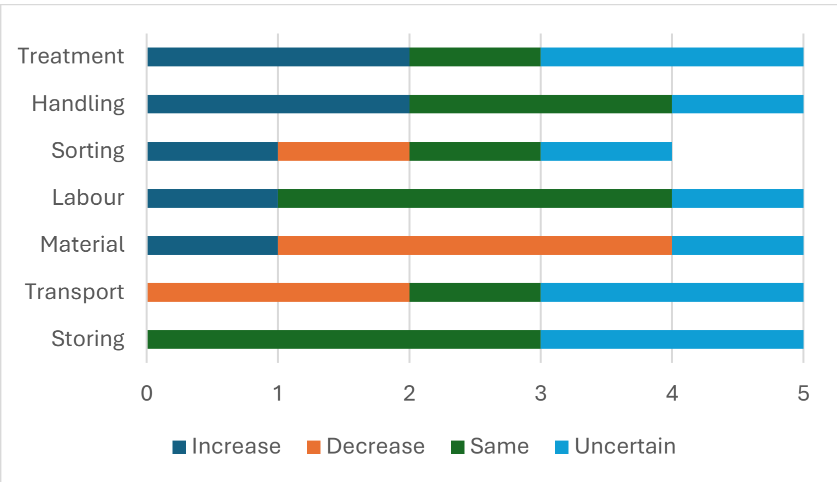

Figure 24. Estimated change of cost items if using waste, 5 respondents in Ghana; Source: author's construction

For the successful inclusion of waste materials in production, several conditions must be met. Firstly, it is essential that using waste materials enhances environmental protection performance and recognition. Ensuring the waste materials provide reliable, constant, and guaranteed quality, or match the quality of the replaced primary input, is another crucial factor. Companies are also motivated to incorporate waste if it offers a competitive market advantage. Additionally, the integration of waste materials should not require significant modifications to existing technology.

However, if modifications are necessary, financial support for these changes is a key condition for moving forward. A permanent, contracted partner is also important for stability and long-term success in sourcing waste materials. The cost-effectiveness of the process is another factor, with companies preferring scenarios where the supplier covers the take-over costs. Finally, the waste materials must be cheaper than the primary input material, and lower transportation prices can further incentivize their use. These conditions ensure that using waste materials is both financially viable and beneficial from an operational and environmental perspective.

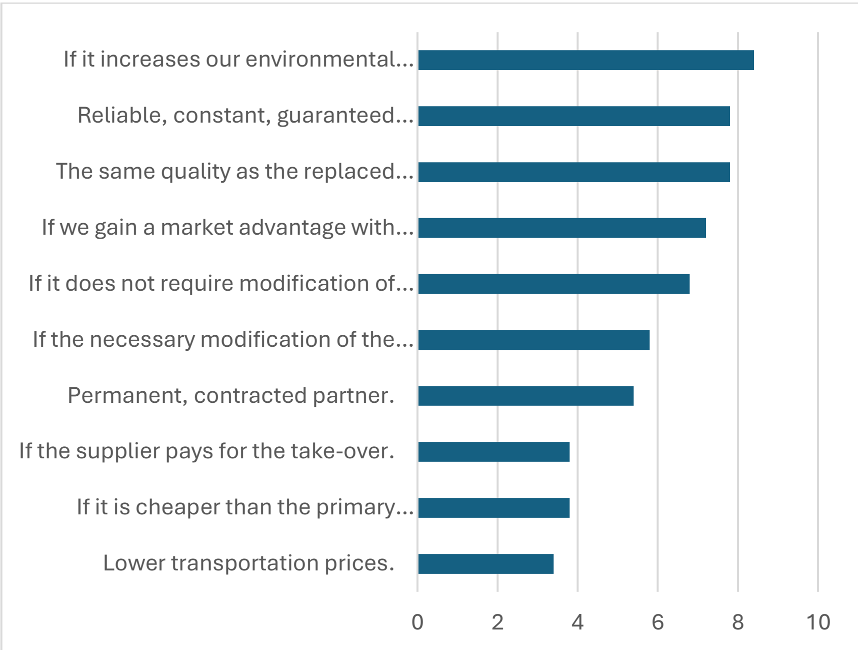

Figure 25. Conditions for starting to use waste, 5 respondents in Ghana, Source: author's construction

To facilitate the inclusion of waste materials in production, several key needs must be addressed for waste non-users. One crucial need is that the treatment of waste should be free, reducing the financial burden on businesses looking to adopt waste materials. Additionally, tax reliefs and incentives are necessary to encourage companies to transition to more sustainable practices. The implementation of local standards for recycled products is also vital, ensuring that the recycled materials meet quality and regulatory requirements for use in production. Finally, higher taxes on imported virgin materials would create a financial incentive for businesses to consider using waste materials instead, fostering a more sustainable and cost-effective approach. These measures would help create a more favourable environment for incorporating waste into production processes.

Waste Suppliers

The waste materials supplied include a variety of items, such as binding wires, which are commonly used in packaging and industrial applications. In addition, materials from industries like dairy and culinary production contribute to the waste stream, alongside paper and plastic waste, which are prevalent across various sectors. Other waste materials include a mix of paper, scrubs, and plastics, highlighting the diverse nature of waste generated across different industries. These materials are collected and managed to be reused or processed, contributing to sustainability efforts.

The motivations for supplying waste materials are driven by a variety of factors. Income generation plays a key role, as many suppliers seek to earn revenue by providing waste materials for recycling or repurposing. Another major motivation is the savings on disposal costs, as suppliers aim to reduce expenses associated with waste management. Environmental protection is also a significant motivator, as contributing waste materials to recycling efforts helps reduce the environmental impact of waste. Additionally, suppliers aim to avoid landfill usage, further aligning with sustainability goals. Ultimately, recycling serves as both an environmental and financial incentive for those supplying waste materials.

In terms of landfilling, the majority of respondents (5 out of 6) confirmed that they saved costs by avoiding the need to landfill waste. Similarly, 4 respondents reported saving on transport costs associated with sending waste to the landfill. Storing costs, however, presented a more mixed response, with 3 respondents indicating savings and 3 others reporting no significant change due to waste supply. Notably, a strong majority of respondents (5 out of 6) stated that the receiver pays for the waste material, suggesting a favourable financial arrangement for businesses. Additionally, 5 respondents also noted that the receiver covers the costs of waste transportation, further reinforcing the financial advantages of using waste materials in production.

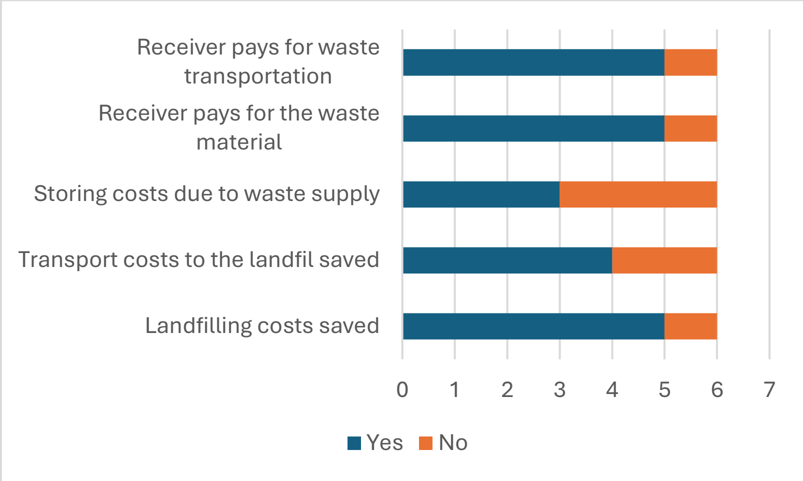

Figure 26. Implications of waste supply, 6 respondents in Ghana; Source: author's construction

The relative order of cost items in waste supply reflects the primary expenses businesses incur when integrating waste materials into their production processes. Transport emerges as the most significant cost, as it involves the logistical expenses of moving waste from collection points to processing facilities. Sorting follows closely behind, as separating different waste types is crucial for effective recycling and reuse, requiring both labour and equipment. Pre-processing comes next, encompassing the initial treatment of materials to make them suitable for use in production, adding further costs for machinery, labour, and energy.

Treatment costs rank next in importance, as this stage often involves chemical or mechanical processes to ensure the waste is safe and effective for production use. Handling, which involves the physical management of materials during various stages of processing, is also a notable expense but ranks lower in comparison. Lastly, storing waste materials incurs the least cost, as it typically involves space and basic infrastructure to keep materials ready for further use, though it remains a necessary expense in the overall process.

This hierarchy shows that transportation and sorting are the most significant factors in the waste supply chain, with pre-processing, treatment, and handling following in importance. Storing costs, while still relevant, tend to be the least costly aspect.

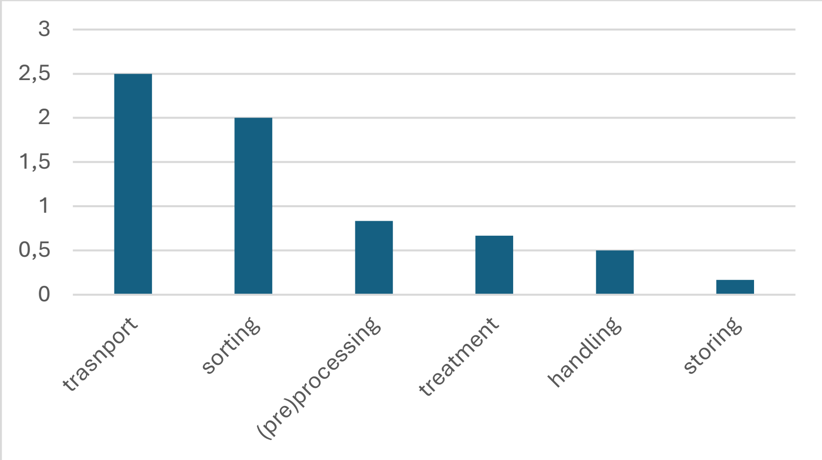

Figure 27. Relative order of cost items in waste supply, 6 respondents in Ghana; Source: author's construction

5.5.2.2. Waste recycling companies

Accra Compost and Recycling Plant

The Accra Compost and Recycling Plant (ACARP), located in Adjen Kotoku, is West Africa's first advanced waste sorting and composting facility. Established to address Accra's growing waste management challenges, ACARP processes solid and liquid waste into valuable products like compost for agriculture. The plant encourages recycling, transforming waste materials into reusable products, supporting environmental sustainability and economic growth.

ACARP processes 600 tons of municipal solid waste (MSW) daily using a combination of manual sorting, Chinese-German technology, and mechanical systems to separate organic from inorganic materials. Organic waste is composted, while recyclables are recovered for reuse. The facility employs forced-aeration windrow systems to decompose organic materials, producing nutrient-rich compost in 75 to 90 days. Additionally, ACARP produces Refuse Derived Fuel (RDF) from non-degradable waste, which is used in energy-intensive industries.

The plant was created in response to Accra's reliance on landfills and the environmental impact of organic waste. Organic waste, when composted, can improve soil health and support agriculture. ACARP's operations aim to reduce pollution, divert waste from landfills, and support recycling practices. Looking ahead, ACARP plans to expand with new plants for plastic processing, medical waste, and faecal sludge treatment, as well as extend its operations to Kumasi and improve waste transportation infrastructure.

Despite progress, challenges remain, including changing public attitudes toward waste disposal. A large portion of Accra’s waste still ends up improperly disposed of, contributing to pollution and public health risks. Continued investment in infrastructure, public education, and behavior change will be essential to improving waste management and achieving long-term environmental sustainability in Ghana.

ACARP faces a variety of costs both as a waste receiver and supplier. As a waste receiver, the main costs involve several key processes. Sorting waste materials into different categories is essential for recycling, but 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. Storing waste materials and finished products requires space and management, adding another layer of expense.

On the supply side, ACARP provides a range of materials to other companies, including plastics (15%), paper (5%), textiles (2%), metals (3%), and the remainder as Refuse Derived Fuel (RDF), according to the respondent. As a supplier, the main costs include pre-processing, which involves washing, shredding, and pelletizing the materials before they can be sold. Sorting materials into appropriate categories for resale adds further costs to the operation. Like waste receiving, handling materials for supply also requires resources and labor. In-house transportation costs are incurred when moving materials within the facility before they are shipped out. Storing materials for later sale or distribution, especially in large volumes, also results in significant expenses.

In both roles, whether as a waste receiver or a supplier, ACARP’s primary operational costs are tied to sorting, pre-processing, handling, transportation, and storage of materials.

Sewerage Systems Ghana Limited

Sewerage Systems Ghana Limited (SSGL) was established in July 2012. The company operates as an engineering and construction firm specializing in the provision of efficient liquid waste treatment solutions. Since its inception, the company has successfully built two faecal treatment plants: the Lavender Hill Faecal Treatment Plant, located near the Korle Lagoon, and the Kotoku Faecal Treatment Plant in Adjen Kotoku. Additionally, SSGL has rehabilitated the Mudor Sewerage Treatment Plant in James Town, contributing to the overall improvement of sewage treatment capabilities in Ghana.

SSGL takes pride in its dedicated workforce, trained to utilize environmentally friendly technical innovations that enhance waste treatment processes. The company ensures that its employees are well-equipped with the necessary skills and knowledge to meet the high standards of service expected in the industry. As part of its growth strategy, SSGL is eager to expand its operations and engage with Metropolitan, Municipal, and District Assemblies (MMDAs) throughout Ghana. Moreover, the company is working towards replicating its success in other parts of Africa, aiming to build similar treatment plants across the continent.

At SSGL, stakeholder satisfaction is of utmost importance. The company is committed to fostering long-lasting relationships with governments, regulators, local authorities, and the communities it serves. Through these efforts, SSGL aims to contribute positively to public health, environmental sustainability, and the overall development of the waste management sector in Ghana and beyond.

Sewerage Systems Ghana Ltd. is an innovative company focused on transforming sewage into valuable products that serve both agricultural and environmental needs. The company produces four main products from sewage: fish food, biochar, organic fertilizer, and irrigation water. These products help to address waste management issues while promoting sustainable practices in farming and energy production.

Biochar is one of the products with significant potential. The production of biochar involves several stages, beginning with the treatment of sewage, which requires energy for the carbonization of sludge mixed with starch additives. After treatment, the sludge undergoes sorting to remove plastics and other non-essential materials. The next steps are handling, which further refines the product. However, there are challenges associated with biochar, particularly public perception. As biochar is derived from sewage, it often carries a negative connotation as a sewage-based solid fuel. Additionally, there are skill-related challenges, particularly in the usage of machinery and ensuring proper quality control during the carbonization process, which requires careful management of oxygen-heat balance. Despite these hurdles, biochar has strong potential for commercialization. The company is exploring using biogas in the carbonization process, reducing reliance on other energy sources. This could also improve its competitiveness against traditional solid fuels like charcoal.

The organic fertilizer produced by SSGL is considered the highest potential product, being regarded as a "low-hanging fruit" due to the growing demand for organic alternatives to chemical fertilizers. The demand surged particularly after the Russian-Ukrainian war, which caused a sharp rise in the cost of chemical fertilizers. The company produces organic fertilizer in two categories: dry faecal sludge for ornamental plants and compost for food production. The dry sludge is currently being bagged and stored, awaiting certification, while the compost is still under testing. The process involves several stages, including treatment, processing, sorting, and handling. One of the main challenges for the company is the need for a large-scale facility to handle the input materials, as the production requires large quantities of sludge. Additionally, certification is a critical factor for commercialization, with an estimated 3-4 months required to complete the certification process.

Irrigation water is another product that holds great potential, as it is rich in nutrients. However, transporting this water to farms presents a serious challenge, as many farms are located far from the production site. Treatment of the water is also a significant cost factor. Despite these challenges, the nutrient-rich nature of the irrigation water makes it a valuable resource for farming, offering an alternative to chemical-laden water sources.

Lastly, the company is also in the research and testing phase for fish food. This product is formulated using mixtures of palm kernel cake and soybeans, and it is currently being tested on catfish. The testing phase will determine its effectiveness and potential for large-scale production in the future.

SSGL is not only contributing to waste management solutions but is also making strides in developing sustainable alternatives for agriculture and energy. Despite the challenges in production and certification, the company's innovative approach to transforming sewage into valuable products positions it as a leader in sustainability.

Universal Plastic Products and Recycling Limited

Universal Plastic Products and Recycling Limited (UPPR), a subsidiary of Jospong Group of Companies, was established in 2013 with the mandate to manufacture a variety of plastic products, including waste bins in different colours and sizes. The company also distributes these products to traders in neighbouring countries and across the West African sub-region.

UPPR's recycling activities aim to reduce environmental pollution by collecting old waste bins, used water sachets, and other forms of plastic waste for recycling. This process not only helps minimize plastic waste in Ghana’s cities but also creates jobs and promotes environmental sanitation. The company has established recycling plants across various regions of Ghana. Through the promotion of the three Rs - "Reduce, Reuse, and Recycle" - UPPR seeks to raise awareness about the environmental challenges posed by plastics and work toward mitigating their impact.

UPPR's corporate strategy is focused on addressing plastic waste, both on the streets and in the minds of the people of Ghana. The company is committed to combating the plastic waste problem and encourages everyone to join the mission.

Furthermore, UPPR emphasizes the crucial role of waste bins in managing waste effectively. They believe that waste bins are key to preventing uncollected waste and clogged drains, which can lead to perennial flooding. UPPR urges all households, shops, and companies to acquire waste bins for the hygienic storage of waste until collection.

UPPR receives plastic waste materials from several sources, including contracted waste collectors, other companies within the Jospong Group, and landfills managed by the group. Additionally, UPPR utilizes in-house produced waste materials for recycling purposes. These materials typically arrive in three forms, each with varying costs: 60% of the materials are pelletized, 30% are cleaned, and 10% are dirty or mixed waste, according to the respondent.

One of the main challenges UPPR faces with the received waste materials is the quality, as the waste often arrives in a mixed form. This means that the waste is frequently contaminated with dirt, unwanted particles, and other elements that complicate the recycling process.

The production costs associated with recycling these materials include several stages: pre-processing, the price of the waste material itself, handling, treatment, transportation, and sorting. Each of these steps contributes to the overall cost of production.

UPPR also faces challenges beyond the recycling process itself. Fluctuations in exchange rates impact the cost of importing virgin plastic materials, while rising fuel prices affect transportation costs. Additionally, taxes present another financial challenge for the company, impacting its overall expenses and profitability. Despite these obstacles, UPPR continues to work toward efficient recycling and sustainable plastic waste management.

5.5.2.3. Interviews with local experts and policy makers

Expert Interview 1 – Ministry of Environment, Science, Technology and Innovation

The government has drafted a list of priority sectors for the green transition, identifying key areas that require urgent attention. These include plastics, textiles, food systems, the built environment, water, and waste management, with metal still under review. While some sectors are still awaiting implementation, plastics have already been analysed and selected as a pilot area for change.

Plastic waste is a significant issue, with approximately 1 million tonnes generated each year in Ghana. Alarmingly, only 6% of this plastic is recycled, and much of it is not even collected, according to the respondent. This waste often ends up in landfills or, worse, in the ocean. The government has initiated the National Plastic Management Policy (2017), alongside the World Economic Forum's Global Plastics Action Partnership. Ghana's own version of this partnership was launched in 2019 with the backing of the World Bank, which is helping fund an Extended Producer

Responsibility (EPR) scheme. The pilot project on plastics is supported by the Global Environmental Facility, with a collaboration between UNIDO and Ghana's Ministry of Environment, Science, Technology, and Innovation (MESTI). The project, running from 2022 to 2027, aims to tackle plastic waste more effectively and sustainably.

Textiles have also emerged as a key focus. A feasibility study is underway to assess the sector's potential for a green transition. According to the respondent, Ghana imports approximately USD 420 million worth of second-hand textiles each year, with 30,000 people employed in the second-hand textile industry and a total of 600,000 working in the broader textile sector. However, 45% of these second-hand clothes are deemed unsuitable for use due to being too old, the wrong size, or too warm. These textiles often end up in landfills or water bodies. As the respondent recalled, the government is working with funding from the African Development Bank (USD 1 million) and the Development Bank of Ghana (USD 300,000) to address these issues. A key challenge here is the lack of infrastructure for waste collection and sorting, though efforts are underway, including the construction of a large-scale sorting centre in Ghana. There is also a need to explore fibre-to-fibre recycling, as seen in countries like Bangladesh. In addition to plastics and textiles, the food system remains largely untouched, presenting an opportunity for future work.

One of the main challenges facing all these sectors is the lack of adequate funding for waste collection, transportation, and sorting. The informal sector, which plays a key role in waste management, remains underfunded and undervalued. According to the respondent, nearly 70% of informal sector workers are women and vulnerable individuals, making their inclusion in green transition plans essential. Private sector recycling facilities are also underdeveloped, and more infrastructure, such as collection bins and sorting centres, is needed. Currently, Zoomlion, the leading waste management company in Ghana, is overwhelmed by demand, highlighting the need for increased competition and private sector involvement.

Waste management in Ghana is the responsibility of the Ministry of Local Government, but challenges such as the lack of self-separation of waste, insufficient infrastructure, and the informal sector's role complicate the situation. Recycling in industries such as construction and furniture, as well as chemical recycling (including the conversion of waste into fuel), is still underdeveloped and not yet fully analysed.

Despite the obstacles, there is hope for a more circular economy, where waste is minimized, materials are reused, and sustainability is prioritized. However, it remains clear that funding, infrastructure, and public awareness must be prioritized for the green transition to succeed. The government is working hard to address these challenges, but the successful implementation of these green strategies will require coordinated efforts across sectors, with strong support for both the informal sector and vulnerable populations.

Expert Interview 2 – Africa Environmental Sanitation Consult

The principles of the circular economy were first introduced in Ghana's Sanitation Policy of 2010, under the theme "materials in transition." This marked the beginning of a strategic approach to waste management that emphasizes segregation at source, recycling, and composting. A strategic plan was developed to implement these principles, but several challenges and opportunities still exist in fully realizing the potential of a circular economy.

Currently, less than 10% of waste in Ghana is recycled, with the majority being disposed of or sent to landfills, according to the respondent. The country has a significant potential to improve waste management practices, particularly by increasing recycling rates and developing more composting plants. As the respondent recalled, it is estimated that about 56% of waste is currently collected, amounting to nearly 6 million tons per year. However, the remaining 44% of waste, which is not collected, presents a significant opportunity to be harnessed for the circular economy. Materials like sand, dust, and ash, which are abundant in the waste stream, can be used in the construction industry, while organic waste (around 40-60%, resp.) and plastic waste (around 15%, resp.) hold the highest potential for recycling and reuse.

Despite this potential, several challenges hinder the transition to a circular economy. One of the most pressing issues is the lack of an enabling environment and regulatory framework to support waste management practices. Dumping remains cheaper than composting, which discourages investment in more sustainable alternatives. Additionally, the overall economics of waste management are not functioning optimally. There are significant barriers, including the lack of upfront investments in facilities, technologies, and skilled human resources needed to scale circular economy practices. Fossil fuel subsidies also create economic distortions, as renewable energy options, such as solar power, remain underdeveloped. A key recommendation is to remove these subsidies to encourage a green transition.

Transportation is another major challenge, as it relies heavily on fossil fuels, contributing to the environmental impact of waste management systems. There is also a need for more specific policies targeting different types of waste, as well as for a more efficient system of waste collection that would reduce the cost of disposal fees for households. In this regard, the current Sanitation Policy is under review to better incorporate circular economy principles.

The potential for circular economy practices also extends beyond waste management, particularly in industries such as construction. Investigating ways to incorporate circular principles into sectors like construction could significantly reduce material waste and create new economic opportunities.

Waste management in Ghana currently operates in three phases: public health (removing waste), environmental protection (disposing of waste in a controlled manner), and circular economy (utilizing waste as a resource). Presently, the country is largely focused on the first two phases, with the third phase still in the early stages of development. To transition into a fully functioning circular economy, Ghana will need to address the challenges of enabling infrastructure, policy frameworks, and financial investments while also tapping into the vast potential of its waste materials.

Expert Interview 3 – Association of Ghana Industries

Industrialization in Ghana faces several significant challenges that hinder its growth and transformation. A key obstacle is the high cost of capital, with interest rates ranging from 20-42%, according to the respondents, making it difficult for businesses to access affordable financing. Additionally, there are significant gaps in capacity, particularly in technological, infrastructural, software, and knowledge sectors, which further constrain industrial development. Another critical issue is market access, especially when it comes to exporting products to international markets. The business climate in Ghana is tough, exacerbated by challenges in securing reliable electricity and utilities, which are essential for industrial operations.

However, there are notable potentials and opportunities for industrial growth in Ghana. Innovative financial products, such as single-digit interest loans from the financial sector, present an encouraging avenue for industrial expansion. Digitalization, particularly mobile cash transfers, is playing a crucial role in facilitating access to financial services and improving business efficiency. Additionally, Ghana stands to benefit from greater market access through the African Continental Free Trade Area (AfCFTA), which could open up new export opportunities for Ghanaian industries. While the business climate remains challenging, there is room for improvement, particularly in developing solar energy systems, which could offer a sustainable solution to power needs.

Ghana’s Industrial Policy, notably the "1 District, 1 Factory" (1D1F) initiative, aims to foster industrial development by establishing factories in each district, promoting local production, and reducing dependence on imports. The country also has a Digitalization Policy, which, along with mobile cash transfer systems, has provided significant support to businesses, especially in terms of financial inclusion and ease of transactions.

The Green Industrial Policy in Ghana, however, raises some concerns and challenges. While there is a push for carbon footprint reduction, the country has faced difficulties in implementing a comprehensive carbon tax, as the Carbon Tax Act was withdrawn. There is also an environmental tax aimed at reducing plastic waste, but this policy remains limited in scope. Main issues include the need for alternative solutions for industrial equipment and processes, as well as securing reliable and sustainable power sources. Nuclear energy is considered a potential solution, and there are ongoing subsidies for solar power generation, but concerns about greening’s impact on productivity and competitiveness remain. Further research is required to understand how green practices can be integrated without compromising industrial growth.

Although the transition to greener industrial activities in Ghana has been slow, there have been some positive steps. Locally operating multinational companies, such as Volkswagen (VW) and Toyota, serve as flagships for industrial development and offer potential opportunities for knowledge transfer and the sharing of best practices. The big question for industrialization in Ghana remains: how to secure energy for industrial growth. Options such as wind, solar, hydro, and nuclear energy are being considered, but clear policy direction on how industries should transition to greener practices remains elusive. As one respondent in the sector, PM3, noted, “There is no clear policy direction on how industry should transition to green.”

To facilitate sustainable industrialization, several actions are needed. Import duties on green technologies should be reduced to make these solutions more affordable. Policies should be developed to encourage the production of green equipment locally, and knowledge transfer should be promoted to build local expertise. Additionally, recycling tax reductions or tax repayments could incentivize businesses to adopt more sustainable practices. Companies that engage in green activities, such as using more efficient equipment, reducing waste, and improving resource use efficiency, should be supported and recognized through incentives. Furthermore, fostering an attitudinal change toward sustainability within the business community is crucial for the long-term success of green industrialization in Ghana.

Expert Interview 4 – Ghana National Cleaner Production Centre

Cleaner production in Ghana, particularly for Micro, Small, and Medium Enterprises (MSMEs), faces significant challenges that hinder its adoption and growth. One of the major obstacles is resistance to change within businesses, where there is often a reluctance to adopt new, more sustainable practices. Additionally, MSMEs struggle with a lack of funding to invest in cleaner production technologies. The reliance on imported equipment exacerbates these issues, as maintenance can be problematic, and locally fabricated equipment is often inefficient, further hindering progress in adopting cleaner production practices. However, there is notable potential in locally fabricated equipment, which, if improved, could provide more cost-effective and sustainable solutions for MSMEs.

To overcome these barriers and promote cleaner production, several needs must be addressed. One critical need is for incentives, such as tax reliefs, to encourage businesses to adopt more efficient processes and reduce pollution. There is also a pressing need for technical and vocational education and training (TVET) focused on climate change and cleaner production. By building local capacity in these areas, Ghana can equip its workforce with the skills needed to support the transition to cleaner, more sustainable industrial practices.

Waste management in Ghana also presents both challenges and opportunities. Textiles and plastics are particularly promising for upcycling, offering a high potential for recycling and reuse. However, the country faces a significant challenge in terms of upfront investment in the necessary infrastructure to support effective waste management. Source segregation, or separating waste at its origin, is essential to improving recycling and upcycling rates, but it is not yet widespread. Moreover, waste usage needs to make economic sense for it to be viable; if businesses cannot profit from recycling or reusing waste materials, they will not engage in these practices.

Recycling efforts are mixed across different types of waste. Metals present a particularly tough challenge in terms of effective recycling, while paper recycling in Ghana is progressing well. Glass recycling, however, is still virtually non-existent and remains an area in need of development. A common issue across all waste management efforts is the lack of enforcement. Without proper regulatory frameworks and enforcement mechanisms, many businesses and individuals are not motivated to engage in sustainable waste management practices.

Further support is needed to improve waste management and recycling efforts. This includes incentives and subsidies to encourage businesses to adopt waste reduction and recycling practices, as well as efforts to create market demand for recycled products. Enhancing technical capacity in waste management is also essential, as is providing clear permits and conditions for businesses engaged in waste-related activities. As one respondent (PM4) aptly stated, “If using or properly disposing of waste materials will be economically beneficial, people will do that. It is guaranteed.” Financial support will play a critical role in making waste management and cleaner production economically viable for businesses and communities alike.

In conclusion, while there is great potential for cleaner production and improved waste management in Ghana, addressing challenges related to funding, technology, education, and infrastructure will be crucial. By providing the necessary support in the form of incentives, technical capacity building, and financial assistance, Ghana can move toward a more sustainable industrial and waste management system.

5.5.2. Answers to the research sub-questions

SQ1: How are specific waste materials and by-products exchanged, or could be exchanged, between industries to promote circular economy practices?

To promote a circular economy in practice, various waste materials and by-products can be exchanged among industries, fostering sustainability and reducing environmental impact. Organic waste, such as coconut waste, bamboo, cocoa by-products, food waste like cereals, fruits, and vegetables, and other agricultural residues, are commonly recycled into compost or used for biofuel production. These materials are typically sourced from farms, food industries, and local vendors. Plastics, including PET, PS, LDP, PP, and HD, are frequently recycled and repurposed into new products, with sources ranging from packaging companies to waste collectors and plastic production industries. Waste paper from offices, schools, and packaging companies can also be recycled into new paper products, contributing to the reduction of waste and the reuse of materials.

Textiles, often sourced from second-hand shops, clothing industries, and consumers, play a significant role in waste diversion by being recycled or repurposed into new fabrics or products. Metals, collected from industrial waste, scrap materials, and old infrastructure, are commonly recycled for industrial purposes, such as manufacturing new goods or contributing to construction projects. Food waste from various industries, such as cereals, fruits, and vegetables, can be processed into compost or used for biofuel production, which helps reduce waste while supporting agricultural sustainability. Liquid waste, primarily sewage, is treated and transformed into valuable by-products like biochar, organic fertilizers, fish food, or even irrigation water. This process contributes to energy recovery and sustainable waste treatment.

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

Several primary barriers hinder the adoption of waste exchange and utilization, as identified by the survey of companies and expert interviews. One of the key challenges is resource competition, as different industries vie for the same waste materials, which can drive up prices and limit availability. This, coupled with transportation issues, makes it difficult for companies to efficiently source and deliver waste materials for recycling. Cost remains a significant barrier, especially for companies in the recycling and waste management sectors. Many businesses face increased material and treatment costs, which can be further exacerbated by fluctuating exchange rates, rising fuel costs, and taxes.

Another challenge is the quality of waste materials, particularly when dealing with mixed or low-quality waste. For instance, companies like UPPR struggle with managing mixed waste, which complicates the recycling process. Similarly, businesses that handle organic waste or metals may face environmental risks and pollution due to low-quality or contaminated materials. Additionally, lack of certification for products derived from waste, such as biochar, and the negative public perception around some waste-derived products, further limit their widespread adoption.

Inadequate infrastructure for waste collection, sorting, and recycling also hampers efforts to fully implement circular economy practices. The informal sector, which plays a crucial role in waste management, remains underfunded and lacks the support needed to integrate effectively into the formal system. There is also a lack of regulatory frameworks and financial incentives to support the growth of waste recycling and exchange networks. While some companies highlight the importance of tax reliefs, subsidized fertilizers, and local standards for recycled products, the absence of consistent policies and sufficient funding limits progress.

Finally, in the broader industrial context, high capital costs, technological gaps, and unreliable utilities pose significant barriers, especially for Micro, Small, and Medium Enterprises (MSMEs). Many MSMEs face resistance to change, inadequate funding, and the use of inefficient locally fabricated equipment, which discourages the adoption of cleaner production practices. To overcome these barriers, incentives, technical training, and better waste management infrastructure are needed, alongside creating stronger market demand for recycled products.

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

To facilitate waste exchanges and address the challenges identified, several mechanisms can be implemented through both policy and practical measures. One key mechanism is improving waste collection, sorting, and infrastructure, especially within the informal sector. The government can invest in better waste management infrastructure to ensure that waste is properly separated and processed before it can be exchanged or repurposed. Policies that integrate the informal sector into formal waste management systems would also be beneficial, providing funding and resources to help informal waste workers access proper tools and training.

Another critical mechanism is the use of financial incentives. Both waste users and suppliers have emphasized the importance of incentives such as tax relief, subsidized fertilizers, and local standards for recycled products. The government could implement subsidies or financial rewards for businesses that engage in recycling or adopt circular economy practices, reducing the financial burden on companies involved in waste exchange. Additionally, grant programs or low-interest loans could help businesses in the recycling sector offset the high upfront costs of adopting cleaner technologies.

Addressing the negative public perception of waste-derived products, such as biochar, is also essential. Public awareness campaigns promoting the environmental benefits of recycling and waste exchange could help shift attitudes and make the adoption of circular economy practices more widely accepted. By demonstrating the value of waste-derived products, both economically and environmentally, public behavior could change in favor of sustainable practices.

Establishing clear regulatory frameworks that support the recycling and waste exchange industries is another key mechanism. Governments can introduce regulations that require industries to meet sustainability standards, such as mandatory recycling quotas or incentives for using recycled materials. Expanding waste management policies, such as the National Plastic Management Policy, to include additional waste types can ensure that there are clear rules guiding the disposal, recycling, and reuse of various materials.

To address technological gaps, governments and the private sector can collaborate to promote the development and adoption of advanced recycling technologies. Funding for research and development into more efficient waste processing methods would be beneficial. Additionally, supporting the use of renewable energy in recycling operations can make these processes more sustainable and cost-effective over time.

Creating market demand for recycled products is also crucial. Policies and practices that establish local standards for recycled goods, along with market access initiatives like those under the African Continental Free Trade Area (AfCFTA), can help boost the use of recycled materials in new products. Certifications for products made from recycled materials can further enhance consumer confidence and drive demand.

Improved collaboration and partnerships among industries, waste users, suppliers, and the informal sector can streamline waste exchange processes. Creating platforms or marketplaces for waste materials can help businesses find suitable waste streams for recycling or repurposing, facilitating the exchange of materials and negotiations over pricing. Public-private partnerships (PPPs) can support the scaling of recycling infrastructure and technologies, particularly in areas where resources are scarce.

Finally, offering training and technical support to companies, especially Micro, Small, and Medium Enterprises (MSMEs), is crucial to overcoming resistance to change and inefficiencies in equipment. Government and industry bodies could offer training programs to help businesses adopt cleaner production techniques and use waste materials more efficiently.

By implementing a combination of these mechanisms, both in policy and practice, the challenges surrounding waste exchange and utilization can be effectively addressed. Strong policy frameworks, financial incentives, public engagement, technological advancement, and improved infrastructure will help build a more robust system for waste recycling and the circular economy.

CHAPTER 6: CONCLUSIONS AND POLICY RECOMMENDATIONS

This dissertation aimed to enhance the understanding of sustainable development and green industrialization in Sub-Saharan Africa, with a particular focus on the utilization of waste materials within the framework of the circular economy. Its central research question explored the challenges and opportunities associated with the exchange and utilization of waste materials and by-products. This question was addressed through five case studies deriving from field research conducted in Uganda, Zambia, and Ghana between May 2021 and April 2024. Using both qualitative and quantitative data from these case studies, the dissertation sought to answer the main research question (RQ) and three sub-questions (SQ).

In the following, first, answers derived from the five case studies to the three sub-questions are summarized. Then, the main research question is answered in the form of conclusions. After this, the dissertation closes with policy recommendations to enhance waste exchange and circular economy in Sub-Saharan Africa.

6.1. Summary of the Answers to the Sub-Qestions

SQ1: How are specific waste materials and by-products exchanged, or could be exchanged, between industries to promote circular economy practices?

The case studies in Chapters 5.1 to 5.5 showcase diverse waste materials and by-products exchanged across various industries to promote sustainability and the circular economy. A range of organic and industrial waste, such as water hyacinth, sawdust, bagasse, slaughterhouse by-products, plastic waste, and food scraps, are repurposed into valuable products like biodegradable trays, compost, animal feed, bricks, and organic fertilizers, just to mention some examples. These exchanges contribute to waste reduction, resource efficiency, and environmental sustainability.

In addition to industrial by-products, waste from agriculture and food processing, such as rice husk, fish waste, and palm kernel expeller, is used for animal feed, compost, and soil fertility enhancement. The Kampala Industrial and Business Park (KIBP) exemplifies how industrial symbiosis can foster circular economy practices through the exchange of materials like plastic, paper, metals, and organic materials. In the mining sector, waste such as copper slag and mine tailings could ne repurposed for construction materials, further contributing to sustainability.

Additionally, waste from various industries, including plastics, textiles, food waste, and liquid waste, is recycled or converted into products like new fabrics, biofuels, biochar, and fertilizers. These practices promote waste reduction, the creation of new products, and the reduction of resource consumption.

Overall, the common thread across these case studies is the exchange of waste materials for productive uses, contributing to both environmental and economic benefits. However, challenges such as high costs, lack of infrastructure, and technological limitations combined with selected and sorted quantity and quality of waste materials remain, which need to be addressed to scale these practices and maximize their impact on the circular economy. Table 7 summarizes what specific waste materials are or could be exchanged and utilized for the production of further goods in the Sub-Saharan African context.

Table 7. Waste and by-product materials and their exchanges across various industries based on the 5 case studies; Source: author's construction

Waste Material/By-product	Use/Exchange
Water hyacinth	Used to create biodegradable products like trays and packaging, reducing plastic use.
Sawdust	Used to produce briquettes and compost, replacing charcoal.
Bagasse	Used for composting, animal feed, mulch, and improving soil fertility.
Slaughterhouse by-products (blood, off-cuts)	Used for composting and animal feed.
Boiler ash (carbon-rich)	Used to maintain soil fertility or as a soil conditioner.
Plastic waste	Recycled into products like tiles and bricks, reducing plastic pollution.
Banana stems	Fiber extracted for weaving, and remaining material used for organic fertilizers and briquettes.

Food waste	Processed to feed black soldier flies that produce animal feed, oil, and fertilizer.
Rice husk	Used for chicken bedding, fodder, or compost production.
Fish waste	Used as compost or fertilizer to improve soil health.
Brewery by-products (spent grain, spent yeast)	Used for animal feed or compost.
Distillery spent wash	Used as liquid fertilizer, enhancing soil moisture and mineral content.
Palm kernel expeller	Used as high-protein animal feed, especially for pigs.
Tea processing by-products (tea dust, winnowings)	Used for composting or livestock feed.
Paper and cardboard	Reused or recycled for packaging materials.
Metal scrap	Recycled or used in metal fabrication.
Organic materials (food processing, agriculture)	Used for composting or energy recovery.
Used chemicals	Reused in industries requiring similar chemical inputs.
Dust and ash	Used in construction or as filler materials.
Non-hazardous sewage	Treated and reused in industrial or agricultural applications.
Molten slag	Used in construction or cement production.
Firewood	Reused for energy generation or heating.
Copper slag	Reprocessed for blended cement, road pavement, abrasives, and roofing granules.
Copper mine tailings	Used in concrete, tiles, and glass production.
Waste rock	Reused for construction, especially road building.
Overburden	Reused for backfilling or land reclamation projects.

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

The challenges hindering the adoption of waste exchange and utilization across industries share common patterns and themes. A primary barrier identified in multiple sectors is the high cost of waste management. This includes the expenses related to transportation, storage, handling, and processing, which often outweigh the potential benefits, leading businesses to dispose of waste cheaply rather than repurpose it. This is reflected in the answers of many respondents in the different case study, describing the usage of waste materials more costly compared to virgin materials, even imported. Additionally, limited access to affordable machinery, technology, and research and development stifles innovation and production scalability, especially for small businesses.

Infrastructure limitations also emerge as a recurring issue, with inadequate waste collection, sorting, and processing facilities hindering effective waste utilization. This is compounded by a lack of skilled labour in most of the sectors, as well as logistical challenges. These barriers are particularly prevalent in the informal sector and in small- and medium-sized enterprises, which struggle with inefficient equipment and lack of technical support.

Regulatory barriers are another common theme. Weak enforcement of environmental regulations and unclear policies or legal frameworks create uncertainty, deterring businesses from adopting waste exchange practices. This is well seen in industries such as mining in Chapter 5.4., where ownership issues and unclear regulations limit the potential for utilizing mining waste.

Economic factors also play a significant role, with many businesses questioning the cost-effectiveness of using waste materials instead of virgin resources, as mentioned above. Competition from cheaper imported goods further discourages the adoption of eco-friendly alternatives. This is particularly evident in Chapter 5.1, where local eco-friendly products face significant challenges in competing with cheaper imports.

Additionally, there is a general lack of awareness about the value of waste, both in terms of economic potential and environmental benefits. This leads to reluctance in changing established processes and a failure to recognize the long-term value of waste exchange. Quality concerns regarding waste-derived products, along with a lack of certification and market demand, further hinder the acceptance and adoption of waste utilization practices.

Table 8. Detected barriers for waste exchange and utilization based on the 5 case studies; Source: author's construction

Sector	Key Barriers
Chapter 5.1 (General)	Limited access to affordable, reliable machinery and technology
	Competition from cheaper imported alternatives, such as plastic products
	Low consumer demand for organic and alternative products

	High R&D costs, particularly for small businesses
	Logistical issues and inadequate infrastructure for waste collection
	Lack of skilled local labour for manufacturing and machinery repair
	Economic sustainability challenges, reliance on grants or donations
	Unclear government policies and regulatory challenges
Chapter 5.2 (Industrial Waste Utilization in Agriculture)	High costs of transportation, storage, and handling, making waste utilization unfeasible
	Poor enforcement of environmental regulations
	Lack of waste collection, processing, and redistribution infrastructure
	Labor-intensive recycling practices raise concerns about economic sustainability
Chapter 5.3 (Waste Usage in an Industrial Park)	High sourcing costs, material competition, and uncertainty about cost-effectiveness of waste vs. virgin materials
	Technological barriers and concerns over maintaining product quality
	Regulatory and organizational issues, including weak monitoring of compliance
	Knowledge gaps and lack of awareness about the value of waste
	Reluctance to change established production processes
Chapter 5.4 (Using Mining Sector Waste)	Lack of knowledge about alternative uses for mining waste (e.g., copper slag, mine tailings)
	Toxicity and high treatment costs for mining waste
	Unclear value of mineral content in waste materials
	Ownership and legal barriers preventing access to mining waste for alternative uses
Chapter 5.5 (General)	Resource competition and rising costs (material, transportation, treatment)
	Low-quality or mixed waste, complicating recycling
	Lack of certification for waste-derived products (e.g., biochar)
	Inadequate waste management infrastructure
	Underfunded informal sector hindering integration into formal recycling systems
	Lack of financial incentives and regulatory frameworks to support recycling and waste exchange
	Resistance to change, funding issues, and inefficient equipment in Micro, Small, and Medium Enterprises (MSMEs)

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

The solutions proposed across the chapters emphasize several key strategies for overcoming challenges in waste utilization and promoting a circular economy. A common theme is the need for economic incentives, such as tax breaks, grants, subsidies, and financial support like micro-financing, to make waste exchange and utilization more accessible and attractive to businesses. These incentives aim to reduce the financial burden and encourage the adoption of sustainable practices.

Capacity building is another critical element highlighted across sectors. Initiatives to raise awareness about the environmental and economic benefits of waste utilization, along with investments in research, technology, and training, are essential for overcoming barriers related to knowledge gaps and technological challenges. These efforts help foster innovation, improve efficiency, and support the transition to more sustainable practices.

Collaboration between industries, farms, and other stakeholders is emphasized as a way to streamline waste access, reduce costs, and facilitate resource sharing. For example, partnerships between industries in the Kampala Industrial and Business Park (KIBP) and between mining companies and destination industries can help reduce costs and improve integration. Furthermore, creating centralized platforms for waste exchange, such as a collection and sorting facility, can improve efficiency and encourage wider participation.

Regulatory frameworks also play a crucial role in supporting waste exchange and utilization. Clear and strong regulations can discourage inefficient waste disposal, ensure proper management practices, and promote industrial symbiosis. Monitoring systems to track compliance and reward successful waste exchanges can further incentivize businesses to engage in circular economy practices.

In the mining sector, policies such as setting minimum thresholds for mineral content in mining waste and investing in research to address technological barriers (e.g., neutralizing harmful substances) can help encourage the repurposing of waste materials. A "materials-as-service" model is also suggested to better track and manage waste usage.

Improving infrastructure for waste collection, sorting, and recycling, particularly in the informal sector, is seen as essential to enhancing waste exchanges. Public awareness campaigns, along with regulatory support and collaboration between governments, the private sector, and the informal sector, can help shift attitudes and promote the recycling industry. Finally, providing technical support for micro, small, and medium enterprises (MSMEs) will help them adopt cleaner production techniques and make better use of waste materials.

Table 9. Detected mechanisms and potential solutions for waste exchange and utilization based on the 5 case studies; Source: author's construction

Mechanism/Solution	Description
Affordable and durable machinery	Develop machinery locally or through partnerships to reduce equipment costs.
Awareness and education	Raise awareness about the environmental and economic benefits of waste utilization through education and government campaigns.
Government incentives	Offer tax breaks, grants, and clear waste management policies to support businesses.
Business collaboration	Encourage businesses to collaborate by sharing resources, infrastructure, and technologies to improve efficiency and reduce costs.
Efficient waste collection systems	Set up waste collection systems to ensure a steady supply of materials for processing.
Access to finance	Provide micro-financing or impact investment to support business scaling and innovation.
Capacity building	Implement training programs for workers and entrepreneurs in waste processing, machinery maintenance, and sustainable practices.
Expanding markets for waste-derived products	Explore export opportunities and increase market demand for sustainable products to ensure financial sustainability.
Economic incentives (subsidies, tax breaks)	Offer financial benefits like subsidies or tax incentives for companies engaging in waste reuse or recycling.
Strengthening regulations	Create regulations to discourage inefficient waste disposal and incentivize recycling and waste reuse practices.
Industry-farm partnerships and networks	Facilitate collaborations between industries and farms for waste access, and encourage intermediary involvement to address logistical challenges.
Investment in research and technology	Fund R&D to improve waste processing methods and create valuable products like fertilizers or animal feeds.
Automation and reducing labour intensity	Introduce automation in processes like composting and feeding systems to reduce labour costs and improve economic sustainability.
"Waste-to-value" mindset	Promote the idea that waste is a valuable resource, not a burden, to encourage more sustainable practices.
Centralized waste exchange platform	Create an online platform for companies to list available waste materials for exchange, facilitating the matching of suppliers and users.
Waste collection and sorting facility	Set up centralized facilities to process waste materials, ensuring consistent quality and reducing logistical challenges.

Stakeholder collaboration	Facilitate networking and cooperation between businesses, waste collectors, and middlemen to improve waste exchange efficiency.
Technological support	Invest in R&D to develop technologies for better waste processing and reuse.
Strengthening regulatory frameworks	Develop clear policy guidelines and regulations that promote waste utilization and ensure compliance with circular economy principles.
Monitoring and support mechanisms	Implement systems to track waste exchanges, compliance, and provide data for improving practices.
"Materials-as-service" economic model	Explore leasing models for mining materials, allowing mining companies to track and manage materials more effectively.
Public awareness campaigns	Raise awareness about the environmental and economic benefits of waste-derived products to change public perception and increase acceptance.
Clear regulatory frameworks for recycling	Introduce and enforce regulations that support recycling practices, such as mandatory recycling quotas and sustainability standards.
Market demand for recycled products	Create standards and market access initiatives for recycled products, enhancing consumer confidence in recycled goods.
Collaboration and partnerships (PPP)	Foster collaboration between industries, waste users, and suppliers to streamline waste exchange and scale recycling infrastructure.
Training and technical support for MSMEs	Offer training programs for MSMEs to help them adopt cleaner production techniques and more efficient waste use practices.

6.2. Conclusions

The utilization of waste and by-product materials in Sub-Saharan Africa (SSA) offers both significant opportunities and considerable challenges. Several drivers are pushing the adoption of waste utilization practices, contributing to the growth of a circular economy in the region. Sustainability and resource efficiency remain key drivers. The repurposing of waste materials, such as plastics, organic waste, and by-products from various industries, helps reduce pollution, conserve natural resources, and promote cleaner production. For example, companies like Hya Bioplastics utilize water hyacinth to create biodegradable products, which help reduce plastic waste. Similarly, industries in the Kampala Industrial and Business Park (KIBP) have embraced industrial symbiosis, exchanging materials like plastics, metals, and organic waste to increase resource efficiency. Further research into industrial symbiosis (IS) in SSA could explore additional sectors, such as textiles in Ethiopia, sugar in Tanzania, and oil refineries in Mauritius, which would help broaden the understanding of IS across SSA and drive further innovation.

Economic incentives play a critical role in motivating businesses to adopt waste utilization practices. Governments across SSA offer tax breaks, grants, and subsidies to encourage sustainable practices, making recycling and repurposing waste more financially viable. Additionally, technological innovations and research and development (R&D) are key drivers. Advancements in waste processing technologies, such as ProTeen's food waste-to-feed system using black soldier flies, enable businesses to convert waste into valuable products. Innovations like these could be further explored in smaller and emerging industries that are not yet integrated into established IS networks. Research into developing new IS networks would be crucial to connect industries that generate diverse waste materials, thus facilitating better resource sharing.

Collaboration across industries also strengthens waste utilization efforts. Partnerships between agriculture, manufacturing, and mining sectors streamline waste exchange and reduce operational costs. For instance, bagasse from sugar processing is repurposed for composting and animal feed by companies like Amelia Agro Ltd., improving soil fertility. Public-private partnerships between governments, businesses, and communities foster better waste management infrastructure, technology transfer, and resource sharing. Research could focus on how the local regulatory environment and government policies can help strengthen these partnerships and incentivize waste exchange in SSA.

Rising awareness of the environmental and economic benefits of waste utilization is driving demand for sustainable products. Public education campaigns on waste-to-value approaches help shift consumer attitudes, encouraging the adoption of waste-derived products. As awareness increases, businesses are incentivized to adopt waste utilization practices. Research could address social acceptance and cultural barriers to adopting circular economy practices, ensuring these sustainable practices are more accessible to local communities and industries.

Despite these promising drivers, several barriers hinder the widespread adoption of waste exchange and by-product utilization. Economic challenges such as high transportation, storage, and handling costs make waste utilization unprofitable, particularly for small businesses. The high costs of machinery and technology, coupled with competition from cheaper imported products, stifle waste management practices. Limited access to finance, especially for micro, small, and medium enterprises (MSMEs), prevents many businesses from investing in the necessary infrastructure and technology for waste utilization. Research could focus on exploring ways to reduce costs and improve access to finance, particularly for MSMEs, to overcome these financial hurdles.

Logistical barriers and infrastructure constraints present another significant challenge. Inadequate waste collection, sorting systems, and poor infrastructure, particularly in informal sectors, limit the amount of waste that can be repurposed. Transportation issues, coupled with fluctuating costs, further complicate the movement of waste materials between businesses. Research into improving waste collection and sorting systems, as well as efficient transportation networks, could help streamline waste exchanges and support larger-scale implementation of waste utilization practices.

Regulatory and legal challenges also pose obstacles. Weak enforcement of environmental regulations and unclear policies about waste ownership and classification discourage businesses from engaging in waste exchange programs. Additionally, industries such as mining face knowledge gaps regarding alternative uses for mining waste, and toxicities in the waste materials create both technological and financial barriers to their repurposing. Legal ambiguities surrounding waste ownership, especially in extractive industries, further restrict access to waste materials for alternative utilization. Research could address these gaps by exploring the regulatory environment and identifying clear policies to encourage waste repurposing in mining and other sectors.

Technological limitations and a lack of expertise in waste processing further hinder the adoption of waste utilization. Many businesses face challenges in processing waste materials due to technological gaps, particularly with materials containing harmful substances, like mining waste. Furthermore, limited technical knowledge means that many businesses struggle to adopt waste utilization practices effectively. Research into waste processing technologies and the development of training programs could help bridge this gap and enable businesses to better utilize waste materials.

Resistance to change is another barrier. Many businesses are hesitant to switch from established processes, due to concerns over product quality and uncertainties regarding return on investment. Moreover, locally produced eco-friendly products often face stiff competition from cheaper imported goods made from virgin materials. Addressing these concerns through education and by ensuring clear certifications for waste-derived products can help mitigate resistance and build confidence in the benefits of waste-based alternatives.

Finally, concerns regarding the quality and certification of waste-derived products can deter their adoption. Products made from recycled or waste-derived materials may face scepticism regarding their safety and quality. The lack of formal certification systems to validate these products discourages businesses and consumers from embracing them. Research into establishing certification systems and quality standards for waste-derived products would help to foster trust and promote their wider acceptance.

In conclusion, while drivers like economic incentives, technological innovations, and increasing awareness support the utilization of waste materials in Sub-Saharan Africa, several barriers remain. Addressing research gaps related to industrial symbiosis, waste streams, regulatory environments, and technological challenges will be crucial in overcoming these barriers. By improving infrastructure, strengthening regulatory frameworks, enhancing access to finance, and building technical expertise, Sub-Saharan Africa can unlock the full potential of waste utilization and advance the circular economy in the region.

6.3. Policy Recommendations for Enhancing Waste Utilization and Circular Economy in Sub-Saharan Africa

Based on the above conclusions, the following policy recommendations are designed to address the key barriers identified in the study and promote the widespread adoption of waste utilization and circular economy practices across various sectors in Sub-Saharan Africa.

Develop Affordable and Durable Machinery

Recommendation: Governments and private sector stakeholders should invest in the development of affordable, durable, and efficient waste processing machinery. This can be achieved through local production or partnerships with international manufacturers to reduce costs and enhance accessibility for small businesses.

Rationale: By addressing the high cost of machinery, businesses will be better positioned to scale up production and improve waste processing efficiency.

Government Incentives for Waste Utilization

Recommendation: Introduce tax breaks, grants, and other financial incentives to businesses that adopt waste utilization practices, both in manufacturing and farming sectors. This can include subsidies for businesses that incorporate waste into their processes, as well as tax incentives for companies that engage in recycling and circular economy practices.

Rationale: Economic incentives are crucial to motivate businesses to transition to sustainable practices and promote waste reuse.

Foster Business Collaboration

Recommendation: Encourage partnerships between businesses, industries, and farms to share resources, technologies, and infrastructure. This can include creating platforms or networks for businesses to collaborate on waste exchanges and joint waste management solutions.

Rationale: Collaboration between industries helps reduce costs, improves resource efficiency, and fosters innovation, ultimately driving the adoption of sustainable practices.

Establish Efficient Waste Collection and Sorting Systems

Recommendation: Develop and implement efficient waste collection and sorting infrastructure, particularly in industrial parks such as Kampala Industrial and Business Park (KIBP), as well as in local communities. This should be complemented by centralized waste exchange platforms to facilitate smooth waste processing and exchange.

Rationale: Proper waste collection and sorting are essential for ensuring that materials can be reused effectively, and centralized platforms will streamline the process.

Promote Awareness and Education on Waste Utilization

Recommendation: Launch public awareness campaigns to educate the general public, businesses, and farmers about the environmental and economic benefits of waste utilization. This should focus on shifting attitudes towards waste as a valuable resource and highlight the importance of sustainable practices.

Rationale: Education will drive behavioral change, fostering a "waste-to-value" mindset and creating market demand for waste-derived products.

Support Research and Technological Innovation

Recommendation: Increase investment in research and development (R&D) to address technological barriers in waste processing, particularly in mining, agriculture, and manufacturing. Focus on developing cost-effective and environmentally safe methods for neutralizing harmful substances in waste.

Rationale: Technological innovation is key to overcoming barriers in waste reuse and ensuring that waste-derived products meet safety and quality standards.

Strengthen Regulatory Frameworks

Recommendation: Develop and enforce clear and robust regulations that encourage circular economy practices, such as mandatory waste recycling quotas, incentives for using recycled materials, and penalties for inefficient waste disposal. Include specific policies for industries like mining and agriculture to manage waste more sustainably.

Rationale: Strong regulatory frameworks provide clear guidelines and legal certainty, driving compliance and promoting sustainable waste management practices.

Promote Economic Models like “Materials-as-Service”

Recommendation: Explore the implementation of a "materials-as-service" model, particularly for industries like mining, where companies can lease or share raw materials instead of hoarding waste. This will promote a more circular flow of materials and reduce environmental risks.

Rationale: This model will help optimize resource utilization while allowing businesses to extract economic value from materials that might otherwise be wasted.

Create Financial and Technical Support for MSMEs

Recommendation: Provide training, financial support (e.g., micro-financing, low-interest loans), and technical assistance to Micro, Small, and Medium Enterprises (MSMEs) to help them adopt cleaner production techniques and improve waste processing efficiency.

Rationale: MSMEs often face barriers to adopting circular economy practices due to limited resources. Financial and technical support will enable them to make the transition and improve their environmental impact.

Integrate the Informal Sector into Formal Waste Systems

Recommendation: Invest in infrastructure to integrate the informal sector into formal waste management systems, ensuring that informal waste workers have access to proper tools, training, and resources. Establish public-private partnerships to scale up recycling and waste management solutions.

Rationale: The informal sector plays a critical role in waste management. By formalizing their operations, waste collection and recycling processes can become more efficient and standardized.

Monitor and Support Waste Exchange Systems

Recommendation: Implement monitoring systems to track the progress of waste exchanges and ensure compliance with regulations. Recognize and reward businesses that excel in waste utilization with certifications or labels, which could enhance their marketability.

Rationale: Monitoring and recognition programs will incentivize businesses to adopt best practices and engage more actively in circular economy initiatives.

Develop Clear Policies for Mining Waste Utilization

Recommendation: Establish policies that set minimum thresholds for the repurposing of mining waste (e.g., copper slag, tailings) and encourage the development of new uses for these materials, such as in construction or road paving.

Rationale: Mining waste often remains underutilized due to uncertainty around its composition. Clear policies will help industries repurpose waste for productive uses, reducing environmental harm and increasing economic value.

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APPENDICES

Appendix 1: Pictures for Case study 1

Image 16. Hya Bioplastics trays as an alternatives to plastic, Source: www.hyabioplastics.com, 2022

Image 12. Boiler ash in windrow compost at Amelia Agro farm, 12.5.2021, author's photo (a.p.)

Image 15. Hand-woven carpet from banana fibre and textile off-cuts under preparation at TexFad in Kampala, 19.5.2021, a.p.

Image 13. Wall tiles representing 650 recycled soda and water plastic bottles at TakaTaka Plastics office in Gulu, 21.5.2021, a.p.

Image 14. Brick, black board and frame from plastic at Ecobrixs in Masaka, 17.5.2021, a.p.

Image 11. Black soldier flies at Proteen's site in Kampala, 25.5.2021, a.p.

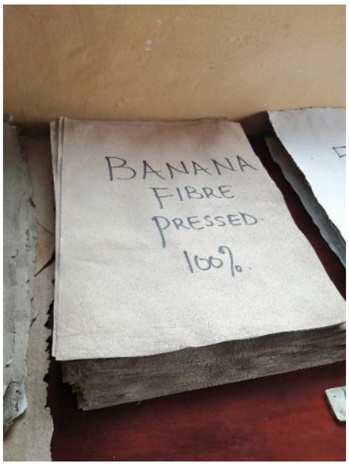

Image 10. Paper sheets from banana fibre at UIRI in Kampala, 6.5.2021, a.p.

Appendix 2: Questionnaire for Case study 2

Information and Consent Form

Regarding / pertaining to the research of Gergely Buda, PhD Student of Corvinus University of Budapest, Hungary, on Industrial Symbiosis in Sub-Saharan Africa

Dear Interviewee,

My name is Gergely Buda, PhD student at the Corvinus University of Budapest and Junior Research Fellow at the Global Institute for Advanced Studies of the Central European University in Budapest, Hungary. As part of my dissertation project, I am conducting research on industrial symbiosis in Sub-Saharan Africa. Industrial symbiosis refers to the relationship between companies where one party utilizes the waste or by-products of another party as a production input. This business model is supposed to contribute to resource efficiency and cleaner production.

Your company ____________________________ was included in this research because you produce____________________________ waste material(s) and by-product(s).

This research project focuses on factors influencing the establishment or maintenance of industrial symbiosis, such as: landfilling costs, transportation costs, waste material pre-processing or handling costs, waste material storing costs, and income gained from selling the waste material(s).

All information from this interview will be used exclusively for research purposes. Please indicate whether your name and identity shall remain anonymous in any publication following from this research. yes / no

Participation in the research and responding to the questions are voluntary and do not imply financial compensation. You can deny giving answers to any of the questions or ask for stopping the interview anytime.

For any further information and requests related to this interview afterwards, you can reach me at +36203111604 (Phone and WhatsApp) or at gergely.buda2@stud.uni-corvinus.hu.

Please indicate whether you would like to receive a copy of the results of the research. yes / no

If you understand and agree with the above, please sign below to indicate your consent.

Place:

Date:

Name and company of the interviewee:

Signature: ___________________________________

Questionnaire for semi-structured interview

Industrial Symbiosis – Case Study in Uganda

Supplier (company):

Interviewee, position:

Place and date:

1. Please shortly introduce me your company ___________________. What is your basic
activity, years of operation, personnel, etc.?

2. Do you produce waste material(s) or by-product in your production process? YES/NO

3. What is the monthly average amount of this waste or by-product? ______________________

4. What do you do with this waste / by-products ?

5. Do you supply this waste or by-product to any other company for production? If yes, to whom? If no, why not?

6. What is your company's main motivation to supply this waste to other companies?

7. Do you save landfilling costs/taxes by this supply? If yes, how much, if it is possible to share this information?

8. Do you save the transportation costs to the landfill with this supply? If yes, how much, if it is possible to share this information?

9. Do you have any costs related to storing this waste before supplying it? If yes, how much, if it is possible to share this information?

10. Do you have any costs related to handling/pre-processing this waste before supplying it? If yes, how much, if it is possible to share this information?

11. Does the receiver pay for this waste / by-product material? Do you gain income from the supply? If yes, how much (just if possible to share this info)?

12. Does the receiver pay for the delivery of this waste? If yes, how much? Or do you bear the costs of delivery/transportation?

Now, I would like to ask about the relationship among these costs and revenues above. I examine the following equation:

$$c_{st} + c_p - p_w \leq l + c_{trl}$$

where

- c_p is the pre-processing and/or handling cost of waste;
- c_{st} is the storing cost of waste;
- p_w is the waste selling price;

Total cost of waste selling

and

- l is landfill tax;
- c_{trl} is the transportation cost to the nearest landfill location.

Total cost of waste disposal

13. Are there any other costs that you would add to this equation?
NO/ YES: ______________________________

14. Please put these above elements of the equation in a descending order where 1 stands for the biggest amount (cost) and 5 stands for the smallest amount.

    Which one is the biggest amount of costs and which one is the smallest?

Further notes:

I, the interviewee ____________________ hereby prove with my signature that the above notes are in accordance with my statements in this interview.

____

Appendix 3: Pictures for Case study 2

Image 24. Leather off-cuts at Mekah Leather Ltd., 7.6.2022; a.p.

Image 23. Distillate spent wash at Buwembe Distillers, 9.06.2022; a.p.

Image 22. Organic waste containers at Zahra Food Industries Ltd, 24.06.2022; a.p.

Image 21. Chicken coop above the fishpond at Amelia Agro Farm, 6.6.2022; a.p.

Image 20. Ash spread on soil at Amelia Agro Farm, 6.6.2022; a.p.

Image 19. Windrow compost at Amelii Agro, 6.6.2022; a.p.

Image 18. Animal intestinal contents collection at Jinja Abattoir, 8.6.2022, a.p.

Image 17. Visit at Jinja Abattoir, 8.6.2022; a.p.

Image 26. Dried blood at Jinja Abattoir, 8.6.2022, a.p.

Image 27. Visit at Mekah Leather, 7.6.2022; a.p.

Image 25. Rise husk outlet at OBN, 7.6.2022; a.p.

Image 28. Mill dust at OBN, 7.6.2022; a.p.

Image 30. Defective grains at Jose AF, 7.6.2022; a.p.

Image 29. Compostable tea dust at Uganda Tea Corporation, 17.6.2022; a.p.

Appendix 4: Questionnaire for Case study 3

Exploring the rationale for industrial symbiosis in an African industrial park: a case study of the Namanve Industrial Park in Uganda

Section 1 – General Information about the Research and Consent of the Respondent

In this research, Namanve Industrial Park (NIP) is used as a case study to explore the rationale for industrial symbiosis in industrial park development. Industrial symbiosis is among the business models of circular economy and a type of B2B-synergies whereby one actor uses the waste or by-products of another actor as a production input. Industrial parks represent specifically great potential for the realization of industrial symbiosis due to the density of companies as well as waste materials in geographic proximity and the coordinating role of park management bodies. Therefore, among other aspects, waste management practices and how industries do or potentially can utilize each other's waste or by-product materials is to be explored. The research also includes an examination of the role of government (political and technical leadership), park management and individual industries in fostering the adoption of principles of industrial symbiosis in industrial parks. Lastly, the incentives, barriers and opportunities facilitating industrial symbiosis within industrial parks in Uganda are explored. Research Team members are:

1. Gergely Buda – PhD Student at Corvinus University of Budapest – Hungary
2. Tom I'Geme – Circular Economy Research Associate at African Leadership University
3. Aaron Werikhe – Senior Planner Environment and Natural Resources – National Planning Authority (NPA)
4. Andrew Remmy Muwaza – Research Assistant

All information from this interview will be used exclusively for research purposes. Data collection (interview) is carried-out by Gergely Buda (PhD student from Hungary) and Andrew Remmy Muwaza (research assistant) and data collection sheets for each respondent will be coded to avoid identification later.

The interview will last approximately for 30-45 minutes. Participation in the research and responding to the questions are voluntary and do not imply financial compensation. You can deny giving answers to any of the questions or ask for stopping the interview anytime.

For research purposes the interviews will be recorded and transcribed. Afterwards all recordings will be deleted. Do you agree to have the interview recorded? Yes/ No

For any further information and requests related to this interview afterwards, you can reach at +36203111604 (Phone and WhatsApp) or at gergely.buda2@stud.uni-corvinus.hu.

Please indicate whether you would like to receive a copy of the results of the research. yes / no

1.1. Do you agree to participate?

Yes […․], please give your signature_____________________ No […․]

S/N	Item	Response
1.2	**Date**	
1.3	**Respondent code**	
1.4	**Respondent's position**	

Section 2 – Introduction

2.1. What is your company's name and website (if you have)?

2.2. Please shortly introduce your company. What is the main activity of your company?

2.3. How many employees do you have?

2.4. What kind of materials do you use in your production activity? Do you use waste or by-products from other companies?

2.5. What kind of waste or by-product materials do you generate and how do you manage the disposal? Do you use some of them in your own production 8in-house circulation)? Or do you hand it over to any other partner?

Material(s) regularly	Material(s) occasionally	Receiver
		Manufacturer(s)/producer(s) using it/them as input for production
		Waste recycling organization(s)
		Private collectors, traders, intermediaries
		Public waste management and landfilling organization

- If they use <u>waste or by-products</u> from other companies or any other sources in your production or other operational activity, go to Section 3 (Waste receiver)

- If they do not, go to Section 4 (No waste receiver)

- If they generate waste or by-products which are handed over/supplied to other companies/organizations, go to Section 5 (Waste supplier)

- If they do not, go to section 6 (No waste supplier)

Section 3 – Using waste or by-product materials from other companies (Waste receiver)

This section refers to companies which utilize waste or by-product materials from other companies.

3.1. Please list what waste or by-product(s) you are using and for what purpose (production input / energy generation / etc.)

3.2. How do you receive the waste or by-product materials? Please indicate if the source is within the NIP or not (in-house, from another partner).

3.3. Do you pay the supplier for the waste materials, or the supplier pays you for take-over?

Material	In-house	We pay	Supplier pays	Depends

3.4. Do you face challenges or problems to obtain these waste or by-product materials? If yes, what?

3.5. Who does the necessary treatments or pre-processing (if any) of the waste-based input materials before using them?

3.6. What is your company's main motivation in using waste materials instead of primary materials as production inputs?

3.7. What costs do you realize by using the waste (waste price, waste transportation, treatment, pre-processing, etc.)?

3.8. Which cost item is bigger: price of the waste material / price of the primary material?

3.9. Which cost items are bigger: transportation of the waste material / of the virgin material

3.10. Who does the pre-processing/treatment on the material (if any), and why?

3.11. Which cost is the bigger overall: using waste material / using virgin material?

Section 4 – Not-using waste or by-product materials from other companies (No waste receiver)

This section is for respondents/companies who reported not using waste or by-product materials.

4.1. Are the following statements true a reasons for why your company does not use waste or by-products of (an)other company(ies)?

	Yes	No	Uncertain
We do not know this practice/ did not even think about this opportunity.			
We do not know the replacement alternatives, substitution options.			
We do not know about companies with the potential to supply waste/by-product materials in appropriate quantity, quality or composition.			
We do not trust other companies enough to take-over their waste materials. (We only use primary, reliable, proven raw materials for quality purposes.)			
Other companies don't want to provide information about their generated waste.			
Other companies are not willing to collaborate in this practice.			
We are uncertain about the profitability of this practice.			
We consider the associated costs and risks too high (equipment, storing, treatment, transportation, etc.).			
We do not want to be dependent on waste materials (operation based on primary materials are more predictable).			
The available waste materials, including their necessary treatments, are more expensive than the primary materials.			
We do not have the necessary technology for this (for example, pre-processing or special treatment).			

4.2. What cost items do you realize related to input materials (from purchase of primary materials to final product)? Material costs (price of the material), Labour costs, Storing costs, Handling costs, Treatment costs (necessary before production), Transportation costs, Other:

4.3. If you would have to use waste or by-product materials instead of the usual primary materials, how would these above cost items change (increase/decrease)? What additional costs would occur for your production activities?

Cost item	Increase	Decrease	Uncertain	Complementary note (if any)
Material costs				
Labour costs				
Storing costs				
Handling costs				
Treatment costs				

Transportation costs				
Other:				

Additional costs:

4.4. What potential risks/disadvantages can you imagine/mention for using waste and by-product materials?

4.5. What potential opportunities/advantages can you imagine/mention for the above imagined case of using waste and by-product materials?

4.6. Do you have any production activity where it could be possible to use waste or by-product materials instead of primary (virgin) raw / input materials? No / Yes, for example:

4.7. Would you be willing to replace the primary raw materials with waste or by-product materials? No / Yes, we could replace the following materials waste or by-product materials:

4.8. Under what conditions would you be willing to include waste or by-product materials in your production activity? Please indicate the importance of the conditions in the ranking below from 10 to 1, where 10 is the most important and 1 is the least important for you.

	Condition	**Rank (10-1)**
A	If it is cheaper than the primary input material.	
B	Lower transportation prices.	
C	If the supplier pays for the take-over.	
D	The same quality as the replaced primary input material.	
E	Reliable, constant, guaranteed quality	
F	Permanent, contracted partner.	
G	If it does not require modification of existing technology.	
H	If the necessary modification of the technology and/or product is financially supported.	
I	If we gain a market advantage with this.	
J	If it increases our environmental protection performance and recognition.	

4.9. What kind of support would you expect from the Namanve Industrial Park management to start using waste or by-product materials as production input?

4.10. What kind of support would you expect from the local/municipal government to start using waste or by-product materials as production input?

Section 5 – Waste supplier

This section is for respondents/companies who reported that they supply waste materials to other companies.

5.1. Could you estimate what proportion of your generated waste and by-product materials are supplied to another company?

5.2. What is your company's main motivation to supply the waste materials to other companies?

5.3. If it is not confidential, please tell us the exact companies (partners) you supply with waste or by-product materials. (We might include these receiver companies in the research, as well.)

5.4. Do you save landfilling costs/taxes by supplying your waste(s) to this(these) partner(s)? Yes / No

5.5. Do you save the transportation costs to the landfill with this supply? Yes / No

5.6. Do you have any costs related to storing this waste before supplying it? Yes / No

5.7. Do you have any costs related to handling/pre-processing/treatment of this waste before supplying it? Yes / No

5.8. Does the receiver pay for this waste / by-product material? Yes / No, they get it for free

5.9. Who pays for the transportation of the material? We pay / The receiver pays

5.10. What kind of costs do you realize by supplying/selling waste or by-product materials? (storing cost of waste; pre-processing, treatment, handling cost, additional labour cost, other:…………..)

5.11. Please put these cost items from the highest to the lowest, including the absolute amount of revenue from waste selling.

Section 6 – No waste supplier

This section is for respondents/companies who reported that they do not supply waste or by-product materials to other companies.

6.1. Are the following statements true as reasons for why your company does not supply its waste to (an)other company(ies)?

	Yes	No	Uncertain
We do not know this practice/ did not even think about this opportunity.			
We do not know for what materials our waste/by-products could be replacement alternatives, substitution options.			
We do not know about companies with the potential to take-over and use our waste/by-product materials in appropriate quantity, quality or composition.			
We do not trust other companies enough to hand-over our waste materials.			
We don't want to provide information about our generated waste.			
Other companies are not willing to collaborate in this practice.			
We are uncertain about the profitability of this practice. (The potential revenue is lower than related costs.)			
We consider the associated costs and risks too high (equipment, storing, treatment, transportation, etc.).			
We cannot supply waste flow in sufficient quantity and quality			
We fear to get involved in such a relationship			
Virgin/primary material prices are low, our waste materials are not considered valuable (for example, because of related necessary treatments, etc.)			
We do not have the necessary technology for this (for example, pre-processing or special treatment).			

6.2. What cost items do you realize in waste management (from waste generation to landfill)? (Storing costs, Handling, Pre-processing, Treatment costs (necessary before landfill), Transportation cost, Landfilling costs (disposal fee or taxes), other:__________)

6.3. Please put these cost items from the highest to the lowest.

6.4. Do you generate any waste in your operation of which disposal causes a problem/burden for the company?

- No, the handling of outgoing material flows is in order and we consider it appropriate.
- Yes, we have to take special care of the disposal of the following materials:

6.5. Are you looking for partners who would pay for your waste/by-products? No / Yes, materials we could sell:

6.6. What support would you need to start supplying/selling your waste materials?

- In general:
- From the NIP management:

- From the local or national government:

Appendix 5: List of respondents for Case study 3

Interviewed companies in KIBP:

Aliyzeco Industries

Alfasan (U) Ltd

Bajaber Industries Ltd.

Coca Cola Beverages U Ltd.

Crown and Packaging Ltd.

Equator Seeds Ltd.

Export Trading Company Ltd.

Fei Long Investment Ltd.

Friendship Container Manufacturers

Galaxy Ken Universal Ltd.

Generation Bottling Co Ltd.

Granite Marble Stone

Green Power Systems U Limited

Hangqui Import and Export Co.

Hechuang Industries

Heng Cheng Ltd.

Interior Technologies Ltd

Kawacom U Ltd.

Kansai Plascon Uganda Ltd.

King Millers

Kyagalanyi Coffee Ltd.

Leaf Tobacco and Commodities Ltd.

Luuka Plastics Ltd.

Modern Agro Investments Ltd.

Moon Mattrasses Ltd.

Orions Transformers and Electrics

Periak Recycling

Proteen

Rainbow Dairy Uganda Ltd.

Roke Investments International

Roofings Rolling Mill Ltd.

Sameg Chemical Products Ltd.

Seven Hills Impex Ltd.

Simlaw Seeds Ltd.

Steema Transformers and Electricals Ltd.

Star Café Ltd.

Talian Company Ltd.

Tembo Aluminium Ltd.

Tong Young Ltd.

Uganda Batteries Ltd (UBL)

Uganda Lubricants Factory Ltd.

Zahra Food Industries

Appendix 6: Pictures for Case study 3

Image 32. Metal waste at Roofings Rolling Mill Ltd., 30.1.2023; a.p.

Image 38. Visit at Coca Cola Beverages U Ltd., 2.2.2023; a.p.

Image 37. Plastic leftovers to recycle at Green Power Systems U Ltd., 31.1.2023; a.p.

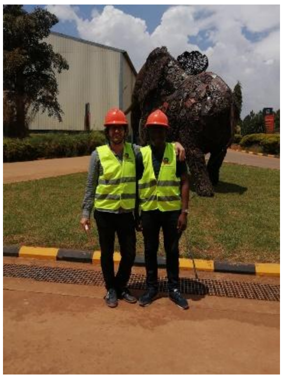

Image 31. Visit at Roofings Rolling Mill Ltd., 30.1.2023; a.p.

Image 36. Visit at Roofings Rolling Mill Ltd. 2, 30.1.2023; a.p.

Image 35. Visit at Export Trading Company Ltd., 28.1.2023; a.p.

Image 39. Visit at Rainbow Dairy U Ltd., 27.1.2023; a.p.

Image 34. Rice husk at King Millers, 24.1.2023; a.p.

Image 33. Visit at Tembo Aluminium Ltd., 24.1.2023; a.p.

Appendix 7: Questionnaire for Case study 4

What are the barriers to mining waste utilization in Sub-Saharan Africa?

A case study from the Copperbelt province of Zambia

General Information about the Research and Consent of the Respondent

This research project aims to explore and analyse the factors that facilitate and hinder the utilization of copper mining waste in Zambia, particularly in the Copperbelt Province.

Research Team members are:

1. Gergely Buda – PhD Student at Corvinus University of Budapest – Hungary
2. Edwin Bwanga Kasanda, Lecturer and Researcher, School of Business, Copperbelt University, Zambia

All information from this interview will be used exclusively for research purposes. Data collection sheets for each respondent will be coded to avoid identification later. Participation in the research and responding to the questions are voluntary and do not imply financial compensation. You can deny giving answers to any of the questions or ask to stop the interview anytime.

For research purposes the interviews will be recorded and transcribed. Afterwards all recordings will be deleted. Do you agree to have the interview recorded? Yes/ No ………………

For any further information relating to this interview afterwards, you can contact Mr Kasanda (0977696454, edwin.kasanda@cbu.ac.zm, edwinkasanda@gmail.com) or Mr Buda (+36203111604, gergely.buda2@stud.uni-corvinus.hu).

Please indicate whether you would like to receive a copy of the results of the research. yes / no …………….

Do you agree to participate?

Yes [….], please give your signature_____________________ No [….]

Date	
Respondent code	
Respondent's position	

Questionnaire for Mining companies (suppliers)

Introduction

1. Could you shortly introduce your company?
    a. How many employees do you have?
    b. How many sites do you operate?
    c. What mining method do you use?
    d. What is your annual production?

Waste generation

2. What waste materials do you generate overall along the copper mining activity?

3. What is the monthly quantity of these materials?

4. What is the mineral composition of these materials?

5. What is the chemical content in these materials?

6. What happens with these materials after extraction or use? (How do you solve their disposal? Do you hand them over to any other partner? What do they use them for or do with them?)

7. Could you estimate what proportion of your generated waste materials are supplied to another company?

Waste materials supplied to other companies (per material)

8. What is your company's motivation or gain in supplying these materials?

9. What kind of activities do you do on these materials before the customer takes it over or receives it?
    a. storing
    b. sorting
    c. pre-processing
    d. any chemical or physical treatment
    e. handling
    f. transportation
    g. other

10. Could you arrange the activities above starting with the most costly to the least costly?

Waste materials not supplied to other companies (per material)

11. What specific costs does this waste material pose to your company? (Do you have to pay any fee for it? Does it require any special work, treatment, other….. specify?)

12. In general, what do you see as the main reasons for not being able to supply this material to any other producing company? Please consider the following aspects (not exclusively):
    a. Technological
    b. Geographical
    c. Economic
    d. Organizational
    e. Legal, regulatory

13. Do you know of any production or economic purpose this material could be used for? If yes, please explain?

14. Do you know of other material(s) this waste material could replace? What is the price of this replaceable material(s)?

15. Do you know of any company interested in processing or using these materials for economic activity? Please explain.

16. What kind of activities or work you would need to do to sell this material for further economic usage?
    a. storing
    b. sorting
    c. pre-processing
    d. treatment (chemical, physical, mechanical)
    e. handling
    f. transportation
    g. other

17. Could you arrange the activities above starting with the most costly to the least costly?

Support

18. Have you or do you receive any support to enable process the mining waste materials? Please explain.

19. What sort of support would you appreciate to enable you process and/or sell your mining waste?

Treatments:

a. pyrometallurgy
b. hydrometallurgy
c. bioleaching
d. gravitational separation
e. magnetic separation

Questionnaire for Destination companies (receivers)

Introduction

1. Could you shortly introduce your company?
    a. How many employees do you have?
    b. How many sites do you operate?
    c. What is your production activity?
    d. What is your annual production?
    e. How would you categorize your company size? (large, medium, small)

Materials used in production

2. What input materials do you use in your production activity?

3. Where do you receive/buy these materials from?

4. What cost items do you incur related to input materials (from purchase of materials to final product)?
    a. Material costs (price of the material),
    b. Labour costs,
    c. Storing costs,
    d. Handling costs,
    e. Treatment costs (necessary before production),
    f. Transportation costs,
    g. Utilities (water, electricity),
    h. Other:

5. Could you arrange the selected cost items starting with the most expensive to the least expensive?

Using mining waste materials

6. Have you ever considered using copper mining waste materials (waste rock, tailings, smelter slag) as input materials?

7. In general, what do you see as the main reasons for not using this material as input? Please consider the following aspects (not exclusively):
    a. Technological
    b. Geographical
    c. Economic
    d. Organizational
    e. Legal, regulatory

8. If you would have to use copper mining waste materials instead of the usual input materials, how would the following cost items change (increase/decrease)?

Cost item	Increase	Decrease	No change	Uncertain	Complementary note (if any)
Material costs					
Labour costs					
Storing costs					
Handling costs					
Treatment costs					
Transport costs					
Utilities					
Other:					

9. What additional costs would occur for your production activities?
    a. Certification, licensing
    b. Training
    c. Inspections
    d. Others, specify….

10. What potential risks or opportunities can you imagine/mention for using mining waste materials?
    a. Risks:
    b. Opportunities:

11. From these risks and opportunities which ones do you consider to be the most significant? (Arrange them in an order of importance starting with the most significant to the least significant.)

12. Do you have any production activity where it could be possible to use copper mining waste materials instead of your regular input materials? No / Yes, for example:

13. Under what conditions would you be willing to include copper mining waste materials in your production activity?

Support

14. Have you or do you receive any support from any entity (NGO, government, large mining companies)? Please explain.

15. What sort of support would you appreciate to enable you starting using copper mining waste in your production activities?

Appendix 8: List of respondents for Case study 4

RESP	Category
1	Mining and environmental specialist, lecturer at CBU
2	Metallurgy expert and lecturer, CBU
3	Coordinator, ZCCM
4	Chemical engineer
5	Chemical engineer, former worker in copper mining
6	Lecturer and researcher of architecture, CBU
7	Former ZCCM leader
8	Production manager, concrete producer company
10	Manager, Mining company
11	Chief Metallurgist, Re-mining company
12	Environmental officer, Re-mining company
13	Environmental specialist, waste management expert
14	Production manager, concrete and interior design company
15	Concentrator manager, Mining company
16	Concentrator manager assistant, Minig comp,
17	Smelter manager, Mining company
18	Concentrator manager, Mining company
19	Superintendent - Environment, Mining company

Appendix 9: Pictures for Case study 4

Image 40. One of the Black Mountains in a Smelter of Mopani Mines, 24.4.2023; a.p.

Image 41. Visiting one of the White Deserts of Mopani Mines, 25.4.2023; a.p.

Image 45. Copper mine slag, 24.4.2023; a.p.

Image 43. First look at the Black Mountain of Mufulira, 6.2.2023; a.p.

Inside a mine facility of Mopani Mines, 25.4.2023; a.p.

Image 44. First visit at the Konkola Mines, 7.2.2023; a.p.

Image 42. First visit at the Copperbelt University in Zambia, 9.2.2023; a.p.

Appendix 10: Questionnaire for Case study 5

Questionnaire for production and recycling companies

Information and Consent Form

Regarding the research of Gergely Buda, PhD Student of Corvinus University of Budapest, Hungary, on Industrial Symbiosis in Sub-Saharan Africa

Dear Interviewee,

My name is Gergely Buda, I am a PhD student at the Corvinus University of Budapest and the Central European University, Hungary. As part of my dissertation project, I am conducting research on circular economy and industrial symbiosis in Sub-Saharan Africa. Industrial symbiosis refers to the relationship between companies where one party utilizes the waste or by-products of another party as a production input.

This research project focuses on factors influencing industrial symbiosis, such as: landfilling costs, transportation costs, pre-processing, treatment or handling costs, waste material storing costs, and income gained from selling the waste material(s).

All information from this interview will be used exclusively for research purposes. Participation in the research and responding to the questions are voluntary and do not imply financial compensation. You can deny giving answers to any of the questions or ask for stopping the interview anytime. Each respondent will receive a code number to provide anonymity in the report.

For any further information and requests related to this interview afterwards, you can reach me at 0534773022 (Phone); +36203111604 (WhatsApp) or at budagergely@gmail.com and gergely.buda2@stud.uni-corvinus.hu.

Please indicate whether your name and identity shall remain anonymous in any publication following from this research. yes / no

Please indicate whether you would like to receive a copy of the results of the research. yes / no

If you understand and agree with the above, please sign below to indicate your consent.

Company:

Date:

Name of the respondent:

Position of the respondent:

Signature:

Section 2 – Introduction

4.1. Please shortly introduce your company. What is the main activity of your company?

4.2. How many employees do you have?

4.3. What kind of materials do you use in your production activity? Do you use waste or by-products from other companies?

4.4. What kind of waste or by-product materials do you generate and how do you manage the disposal? Do you use some of them in your own production (in-house circulation)? Or do you hand it over to any other partner?

- If you use waste or by-products from other companies or any other sources in your production or other operational activity, go to Section 3 (Waste receiver)
- If you do not, go to Section 4 (No waste receiver)
- If you generate waste or by-products which are handed over/supplied to other companies/organizations, go to Section 5 (Waste supplier)
- If you do not, go to section 6 (No waste supplier)

Section 3 – Using waste or by-product materials from other companies (Waste receiver)

This section refers to companies which utilize waste or by-product materials from other companies.

3.1. Please list what waste or by-product(s) you are using and for what purpose (production input / energy generation / etc.)

3.2. How and from where do you receive the waste or by-product materials?

3.3. Do you pay the supplier for the waste materials, or the supplier pays you for the take-over?

3.4. Do you face challenges or problems to obtain these waste or by-product materials? If yes, what?

3.5. Who does the necessary treatments or pre-processing (if any) of the waste-based input materials before using them?

3.6. What is your company's main motivation in using waste materials instead of primary materials as production inputs?

3.7. What costs do you realize by using the waste (waste price, waste transportation, treatment, pre-processing, sorting, storing, handling etc.)?

3.8. Please order these cost items from the highest to the lowest cost.

3.9. Which cost item is bigger: price of the waste material / price of the primary material?

3.10. Which cost items are bigger: transportation of the waste material / of the virgin material

3.11. Which cost is the bigger overall: using waste material / using virgin material?

Section 4 – Not-using waste or by-product materials from other companies (No waste receiver)

This section is for respondents/companies who reported not using waste or by-product materials.

4.1. Are the following statements true as reasons for why your company does not use waste or by-products of (an)other company(ies)?

	Yes	No	Uncertain
We do not know this practice/ did not even think about this opportunity.			
We do not know the replacement alternatives, substitution options.			
We do not know about companies with the potential to supply waste/by-product materials in appropriate quantity, quality or composition.			
We do not trust other companies enough to take-over their waste materials.			
Other companies don't want to provide information about their generated waste.			

Other companies are not willing to collaborate in this practice.			
We are uncertain about the profitability of this practice.			
We consider the associated costs and risks too high (equipment, storing, treatment, transportation, etc.).			
We do not want to be dependent on waste materials (operation based on primary materials are more predictable).			
The available waste materials, including their necessary treatments, are more expensive than the primary materials.			
We do not have the necessary technology for this (for example, pre-processing or special treatment).			

4.2. What cost items do you realize related to input materials (from purchase of primary materials to final product)? Material costs (price of the material), Labour costs, Sorting, Storing costs, Handling costs, Treatment costs (necessary before production), Transportation costs, Other:

4.3. If you would have to use waste or by-product materials instead of the usual primary materials, how would these above cost items change (increase/decrease)? What additional costs would occur for your production activities?

Cost item	Increase	Decrease	Uncertain	Complementary note (if any)
Material costs				
Labour costs				
Storing costs				
Handling costs				
Treatment costs				
Transportation costs				
Sorting				
Other:				

Additional costs:

4.4. What potential risks/disadvantages can you imagine/mention for using waste and by-product materials?

4.5. What potential opportunities/advantages can you imagine/mention for the above imagined case of using waste and by-product materials?

4.6. Do you have any production activity where it could be possible to use waste or by-product materials instead of primary (virgin) raw / input materials? No / Yes, for example:

4.7. Would you be willing to replace the primary raw materials with waste or by-product materials? No / Yes, we could replace the following materials waste or by-product materials:

4.8. Under what conditions would you be willing to include waste or by-product materials in your production activity? Please indicate the importance of the conditions in the ranking below from 10 to 1, where 10 is the most important and 1 is the least important for you.

	Condition	**Rank (10-1)**
A	If it is cheaper than the primary input material.	
B	Lower transportation prices.	
C	If the supplier pays for the take-over.	
D	The same quality as the replaced primary input material.	
E	Reliable, constant, guaranteed quality	
F	Permanent, contracted partner.	
G	If it does not require modification of existing technology.	
H	If the necessary modification of the technology and/or product is financially supported.	
I	If we gain a market advantage with this.	
J	If it increases our environmental protection performance and recognition.	

Section 5 – Waste supplier

This section is for respondents/companies who reported that they supply waste materials to other companies.

5.1. Could you estimate what proportion of your generated waste and by-product materials are supplied to another company?

5.2. What is your company's main motivation to supply the waste materials to other companies?

5.3. If it is not confidential, please tell us the exact companies (partners) you supply with waste or by-product materials. (We might include these receiver companies in the research, as well.)

5.4. Do you save landfilling costs/taxes by supplying your waste(s) to this(these) partner(s)? Yes / No

5.5. Do you save the transportation costs to the landfill with this supply? Yes / No

5.6. Do you have any costs related to storing this waste before supplying it? Yes / No

5.7. Does the receiver pay for this waste / by-product material? Yes / No, they get it for free

5.9. Who pays for the transportation of the material? We pay / The receiver pays

5.10. What kind of costs do you realize by supplying waste or by-product materials? (storing cost of waste; pre-processing, treatment, sorting, handling cost, additional labour cost, other:…………..)

5.11. Please put these cost items from the highest to the lowest, including the absolute amount of revenue from waste selling.

Section 6 – No waste supplier

This section is for respondents/companies who reported that they do not supply waste or by-product materials to other companies.

6.1. Are the following statements true as reasons for why your company does not supply its waste to (an)other company(ies)?

	Yes	No	Uncertain
We do not know this practice/ did not even think about this opportunity.			
We do not know for what materials our waste/by-products could be replacement alternatives, substitution options.			
We do not know about companies with the potential to take-over and use our waste/by-product materials in appropriate quantity, quality or composition.			
We do not trust other companies enough to hand-over our waste materials.			
We don't want to provide information about our generated waste.			
Other companies are not willing to collaborate in this practice.			
We are uncertain about the profitability of this practice. (The potential revenue is lower than related costs.)			
We consider the associated costs and risks too high (equipment, storing, treatment, transportation, etc.).			
We cannot supply waste flow in sufficient quantity and quality			
We fear to get involved in such a relationship			
Virgin/primary material prices are low, our waste materials are not considered valuable (for example, because of related necessary treatments, etc.)			
We do not have the necessary technology for this (for example, pre-processing or special treatment).			

6.2. What cost items do you realize in waste management (from waste generation to landfill)? (Storing costs, Sorting, Handling, Pre-processing, Treatment costs (necessary before landfill), Transportation cost, Landfilling costs (disposal fee or taxes), other:__________)

6.3. Please put these cost items from the highest to the lowest.

6.4. Do you generate any waste in your operation of which disposal causes a problem/burden for the company?

- No, the handling of outgoing material flows is in order and we consider it appropriate.
- Yes, we have to take special care of the disposal of the following materials:

6.5. Are you looking for partners who would pay for your waste/by-products? No / Yes, materials we could sell:

Appendix 11: List of respondents for Case study 5

Accra Composting and Recycling Plant
Africa Environmental Sanitation Consult
Agromix Ltd.
Alfie Design
Association of Ghana Industries
CERATH
FibreWealth
Fine Print Gh Ltd.
Ghana National Cleaner Production Centre
Inkumin Foods
Jekora Ventures
KAE Kwabena
Kane-em
Lifestyle Creation
Ministry of Environment, Science, Technology and Innovation
Pioneer Food Cannery
PlangeStar Ltd.
Polytank
Promasidor
Pyramid Upcycling
Sesa Recycling
Sewerage Systems Gh Ltd.
Shinefeel
Shinestar
Universal Plastic Products Recycling
Zaacoal
Zoomlion

Appendix 12: Pictures for Case study 5

Image 46. Prototype at Lifestyle Creation, 7.9.2023; a.p.

Image 48. Interview at Lifestyle Creation, 7.9.2023; a.p.

Image 49. Coconut husk pile at FibreWealth, 28.09.2023; a.p.

Image 47. Visit at Sewarage Systems Gh Ltd., 11.3.2024; a.p.

Image 50. Sewage-based biochar, 11.3.2024; a.p.

Image 51. Waste paper bulks at Fine Print Gh Ltd., 28.9.2023; a.p.

Image 52. Women sorting plastic waste at Sesa Recycling, 29.9.2023; a.p.

Image 53. Shredded sachet plastic waste at UPPR, 12.3.2024; a.p.

Image 56. At the Reception of ACaRP, 12.3.2024; a.p.

Image 57. Receiving bay of ACaRP, 12.3.2024; a.p.

Image 55. Liquid fertilizer, one of ACaRP's final products, 12.3.2024; a.p.

Image 54. Sorting section at ACaRP, 12.3.2024; a.p.