EXPLORING INDUSTRIAL SYMBIOSES: A STEP TOWARDS TURNING BLANTYRE CITY INTO AN ECO-CITY

MASTER OF SCIENCE (ENVIRONMENTAL SCIENCE) THESIS.

By

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DECLARATION

I, Alex Barnet Phiri, hereby declare that the work contained herein, including the organisation and writing of this thesis entitled "Exploring Industrial Symbioses: A Step towards Turning Blantyre City into an Eco-City" is entirely my own work and has been carried out at University of Malawi, School of Natural and Applied Sciences under the supervision of Dr. Ephraim Vunain.

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CERTIFICATE OF APPROVAL

This thesis has been approved as fulfilling part of the requirements for the award of the degree of Master of Science in Environmental Science by the University of Malawi.

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DEDICATION

This thesis is dedicated to my parents (William Barnet Phiri and Harriet Daneck), my sisters, relatives, classmates and workmates for their selfless sacrifices, guidance, love and guidance. You have been an incredible support system through and through.

Above all, I salute God the Almighty, acknowledging His sovereignty and provision. He has been the source of strength, wisdom and knowledge. With His intervention, this work was possible. I am really grateful.

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ABSTRACT

The growing challenges of pollution and unsustainable resource use have prompted a renewed approach to traditional industrial practices. One such strategy is industrial symbiosis and eco-industrial parks. However, despite the waste management challenges in Malawi, no such initiatives have been utilized, and all circular economy projects have only targeted household and market waste. The main aim of this study, therefore, is to investigate the potential waste-sharing pathways among the industries in Blantyre City to optimize resource use, minimize waste, enhance sustainability, and consequently contribute to turning Blantyre into an eco-city through the conversion of the industrial areas into eco-industrial parks. The study involved interviewing fifty-one industry managers from the Chirimba, Makata, and Maone industrial areas to establish solid waste-sharing pathways. It also included Atomic Absorption Spectroscopy analysis of liquid waste from twelve industries to understand water quality and establish its suitability for water symbiosis within the city. The study revealed the existence of few waste-sharing scenarios for both solid and liquid waste among industries, and additional waste-sharing pathways were identified. Liquid waste analyses revealed the presence of heavy metals in the wastewater generated by the industries. However, most metals (except iron, chromium, and cadmium for some industries) were in lower concentrations relative to WHO's limits for both drinking and irrigation water. The maximum concentrations for iron, chromium, and cadmium were 19.99 mg/L, 0.713 mg/L, and 0.008 mg/L, respectively. SWOT analysis of industrial symbiosis revealed a number of notable strengths and opportunities, such as the presence of diverse waste streams and waste/service-sharing relationships among industries, alongside weaknesses and threats, such as insufficient infrastructure and technological shortfalls, just to mention a few. To successfully convert the industrial areas into eco-industrial parks, the study suggested an implementation framework that highlighted the need to develop industrial symbiosis policies, promote stakeholder collaboration, and improve the current infrastructure. Thus, the insights from this research will help policymakers, industry leaders, and community stakeholders in fostering a circular economy and a resilient urban ecosystem in Blantyre.

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LIST OF ABBREVIATIONS AND ACRONYMS

BCA	Blantyre City Assembly
BCC	Blantyre City Council
CE	Circular Economy
CTCN	Climate Technology Centre Network
EIPs	Eco-Industrial Parks
EMF	Ellen MacAther Foundation
EU	European Union
GEF	Global Environment Facility
GoM	Government of Malawi
HMs	Heavy Metals
IA	Industrial Area
IE	Industrial Ecology
IS	Industrial Symbiosis
ISIE	International Society for Industrial Ecology
IWPs	Informal Waste Pickers
NGOs	Non-Governmental Organizations
NSO	National Statistical Office
SDI	Shack/Slum Dwellers International’s
UNCBD	United Nations Convention on Biological Diversity

UNCCD	United Nations Convention to Combat Desertification
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
UNIDO	United Nations Industrial Development Organization
WBCSD	World Business Council for Sustainable Development
WHO	World Health Organisation
WWTPs	Wastewater Treatment Plants

CHAPTER 1

INTRODUCTION

1.1 Background of the study

Waste is unavoidably generated daily in our homes, industries, institutions, markets, and other avenues. The generation levels are amplified today due to high consumption, technological advances, urbanization, and the ever-increasing human population (Madanhire & Mbohwa, 2016; Sharma, 2014). Akhtar et al. (2022) and Sharma (2014) argue that despite industrialization being a requisite for socio-economic development, rapid industrialization is regarded as the greatest challenge faced by towns in the developing world as it results in an overwhelming generation of waste to be disposed of in landfills. Insufficient resources for waste management by the city councils, a common trend in city councils and municipals of developing countries, has resulted in poor and/or uncontrolled industrial waste disposal (Chikukula et al., 2024). According to Truss Group Ltd (2021), most hazardous industrial waste in Malawi is not pre-treated before reuse, recycling, or disposal and is often dumped illegally at municipal dumpsites. Studies conducted by Kandodo (2007), Kumwenda et al. (2012), and Sajidu et al. (2007) revealed that the Nasolo and Mudi rivers of Blantyre City are polluted, by among other pollutants, industrial effluents from industries sandwiching the streams. Nevertheless, Ayres and Ayres (2022) stipulate that recycling and sharing of waste amongst industries can help avoid a greater percentage of waste emanating from industrial processes. The collaborative network of industries where resources, such as materials, energy, and water are shared, to enhance sustainability and reduce waste is called industrial symbiosis (Chertow, Ashton & Espinosa, 2008). Industries are viewed as webs of producers, consumers, and scavengers, and as such, industrial symbiosis ensures that industries mimic the more efficient and sustainable natural systems which do not emit waste into the environment by sharing resources amongst themselves (Desrochers, 2001; Song, Yeo, Kohls & Herrmann, 2017). Thus, as argued by Bain et al. (2010), Gertler (1995), Madanhire and Mbohwa (2016), through the integration of principles of industrial symbiosis, industries achieve one or more of reduction in the use of virgin materials, pollution reduction, increased energy efficiency, reduction in the volume of waste products requiring disposal and increase in the amount and types of process outputs that have market value. This leads to realization of environmental, social and economic benefits (Lowe & Evans, 1995). While industrial symbiosis can lead to these benefits, the adoption rate is still very low and neither is its potential fully exploited (Neves et al., 2019b). Some of the key barriers to the implementation of industrial symbiosis are (i) industries' lack of knowledge about waste exchange mechanisms (Lowe & Evans, 1995) (ii) lack of governments' interest to provide industrial symbiosis policies, framework and resources for identifying, designing and implementing industrial symbiosis among industries (Perrucci, Aktas, Sorentino, Akanib & Gurraba, 2022). In Malawi, there are no industrial symbiosis initiatives and all the circular economy projects have been targeting the household and market waste and shy of the industrial waste (Chinyepe et al., 2022; CTCN, 2022; Montenegro et al., 2022; Waste Advisers, 2018). This study aims to address this gap by investigating the potential waste sharing pathways among the industries in Blantyre City to optimize resource use, minimize waste, and enhance sustainability. The findings of this study are expected to contribute to turning the city's industrial areas into eco-industrial parks, and consequently transitioning the city into an eco-city in the long run.

1.2 Theoretical basis

This study was structured based on the theoretical framework of 5R circular economy, specifically the meso- and macro-circular economy initiatives. According to Camilleri et al. (2023), Geissdoerfer et al. (2017), and Ghisellini et al. (2018), circular economy is a production system that moves away from "take-make-consume and dispose" linear model, to a closed-loop system that allows circulation of materials through strategies such as remanufacturing, compositing, refurbishing, reusing, recycling and repairing to balance economic development with environmental and resource protection. According to Geng and Doberstein (2008), circular economy is implemented in three levels, namely micro, meso and macro levels. Done at an industry level, micro level circular economy is implemented when one industry is engaged in sustainable business models such as cleaner productions, eco-designing, environmental management systems and waste management (Geng & Doberstein, 2008). Meso level circular economy on the other hand involves several industries collaboratively involved in waste, heat, byproducts, water and energy sharing (Geng & Doberstein, 2008). When co-located industries collaborate in sharing of these materials, an eco-industrial park is created. According to Bain et al. (2010); O'carroll, Basson, Lyons, Smout, and Nuwarinda et al. (2017); Song et al. (2017) industrial symbiosis is regarded as the foundation of, and key feature for any eco-industrial park. Thus, eco-industrial parks belong to the meso circular economy level. The last level, the macro level circular economy is implemented at city, municipal or province level. This leads to creation of eco-cities, eco-municipals and eco-provinces (Geng & Doberstein, 2008). This study therefore would like to achieve establishment of an eco-city (macro symbiosis) in Blantyre City through turning the industrial areas into eco-industrial parks (meso symbiosis) through promotion of resource sharing among industries.

The 5R circular economy framework strives to achieve circularity of materials in an economy through strategies, namely, rethink, refuse, reduce, reuse, and recycle. Meshram (2024) argues that these 5Rs can contribute to achieving zero-waste. Rethinking waste is concerned with industries taking responsibility for waste they generate. That is, industries must rethink a waste as resource, so that an industry either reuses it or shares it (redesigned or not) with another industry that would use it as a raw material (Meshram, 2024). Therefore, stakeholder collaborations and meetings on devising on how best a waste can be used as a resource, thereby developing pathways for exchanges would be key in an eco-industrial park and eco-city development. Refusing waste involves stopping or modifying production habits that generate more waste and prohibiting harmful materials. The goal is to use environmental-friendly production practices and generate as less waste as possible using harmless materials (Meshram, 2024). Applying this strategy in industrial symbiosis will ensure that no waste pile up in the environment but instead is taken up by another industry, while safeguarding the people and the environment from harmful effects of pollution and exposure to harmful chemicals. According to Xing et al. (2017), the second 'R' can also stand for recover, which refers to the practice of putting waste products to use by recovering valuable resources from the waste, for example, recovering methane from decomposing garbage. The remaining Rs; reduce, reuse and recycle form the 3R framework. Industrial symbiosis will also strive to reduce the amount of waste generated by an industry by finding pathways for sharing it with other industries and reducing the quantity of natural resources used and consumption of utilities such as energy (Meshram, 2024; Xing et al., 2017). Reusing on the other hand, is when a discarded product that can still perform its original function is used again. The idea is that what is discarded can still be valuable. In this case, with industrial symbiosis, the industries will be required to reuse their waste than discard it or/and let other industries adopt the waste that was supposed to be dumped of as their input. Among other things, reuse diverts more waste from the landfills and resources recovery plants (Meshram, 2024). Recycling of waste involves converting the waste into useable forms. So, with industrial symbiosis, the industries will recycle their waste and use it themselves or sell it to another industry.

Eco-industrial initiatives can be classified using different criteria but the best criterion is the one that categorizes eco-industrial development initiatives based on size and geographical coverage (Agarwal & Strachan, 2006). This criterion was used by Chertow (1998); Chertow (2003); Musnikow and Schlarb (2002); Roberts (2004); Agarwal & Strachan, (2006). According to (Chertow, 1998), the eco-industrial initiatives types are; eco-industrial parks, eco-industrial networks and virtual eco-industrial network / park. An eco-industrial park is a community of co-located industries involved in utility and resource sharing. Eco-industrial networks on the other hand are a group of uncollated industries that are involved in sharing of materials and do not require strict geographical proximity. Lastly, a virtual eco-industrial network / park represents the industries that virtually collaborative and share resources and spread at large distances, for example regional networks. All these types of eco-industrial initiatives can either be greenfield projects, that is, newly developed eco-industrial parks or brownfield projects, which are eco-industrial parks developed from already existing industrial parks (Agarwal & Strachan, 2006).

This study was thus developed basing on the meso and macro circular economy levels to attempt achieve the implementation of the 5Rs and convert the industrial areas into eco-industrial parks (brownfield project). The interaction of the eco-industrial parks is hoped to be able to create eco-industrial networks that would transition Blantyre City into an eco-city. This will help to address various challenges of pollution and waste management facing the city as the industries will be involved in the symbiotic activities.

1.3 Economic activities in Blantyre City

Established by the Scottish Missionaries in the 1870s and declared a planning area in 1897, Blantyre City, the oldest urban center in Malawi, is the country's commercial and industrial capital (Mawenda, Watanabe & Avtar, 2020; Mpoola, 2011). According to Mpoola (2011), the city is characterized by finance, retail trade, construction, transport, food, textile manufacturing, motor vehicle sales and maintenance, and the informal sectors. Within these, retail trade, construction, manufacturing of food products, transport, textile manufacturing, personal care products manufacturing, motor vehicle sales and maintenance, agricultural warehousing complexes, and public administration, are highlighted as some of the important economic activities. These economic activities are concentrated in Blantyre and Limbe central business district (CBD) and the corridor connecting them through industrial areas. These industrial areas are Makata, Ginnery Corner, Chirimba, Maone, Limbe, South Lunzu, Maselema (Mpoola, 2011; Sajidu et al., 2007), and Chitawira. Sajidu et al. (2007) reiterate that the city's major industrial area is bordered by the Nasolo River, the Mudi River, and Makata road, which includes the Makata and Ginnery Corner industrial areas. However, the economic activities in the city have faced several hiccups. Raheem and Sauvant 2009) ranked the challenges as high transport costs of goods to, from, and within the country; high cost and unreliable electricity; security issues such as petty theft; and lastly, unreliable and expensive telecommunication network.

1.4 Challenges faced by Blantyre City

The city faces several intertwining challenges ranging from economic inefficiencies, administrative problems, pollution, resource depletion, high population, poor infrastructure, and poor housing, just to mention a few.

The city is experiencing waste management challenges which have contributed to environmental pollution. High waste generation which is generally associated with high consumption, advances in technology, urbanization, industrialization, and ever-increasing human population (Madanhire & Mbohwa, 2016; Msilimba & Wanda, n.d.; Sharma, 2014), has left the city council overwhelmed when it comes to proper management of the municipal and industrial waste. Khonje, (2022) argues that underbudgeting, lack of staff, insufficient waste collection vehicles, and lack of will by those in power and the general public to push the government on waste management issues have led to poor solid waste management in Blantyre City and Malawi in general. These factors and others have led to irregular waste collection by the Blantyre city council, resulting in waste being heaped on the roads, in open spaces, and on river banks (Kasinja & Tilley, 2018; Mpoola, 2011; SDI, n.d.). Truss Group Ltd (2021) also echoes that most hazardous industrial waste in Malawi is not pre-treated before reuse, recycling, or disposal and is often dumped illegally at municipal dumpsites. In terms of liquid waste management, the city lacks enough wastewater treatment plants, as the majority of these facilities are either not functional or require extensive maintenance (Collet et al., 2016), leading to the dumping of industrial waste such as effluents into the streams without adequate treatment (Kandodo, 2017; Sajidu et al., 2007). In addition, the city council sewerage which transports some of the wastewater generated in the city to the treatment plants is prone to break down and blockages. This is due to poor maintenance, improper design, and lack of public awareness on the use of the sewerage systems. Such issues lead to spillages which are a common sight around the city, eventually discharging the wastewater into the city's rivers (Halle & Burgess, 2006; Kuyeli et al., 2009). Studies conducted by Kumwenda et al., (2012), Sajidu et al. (2007) revealed that the city's Nasolo and Mudi rivers are polluted, by among other pollutants, industrial effluents from industries sandwiching the streams. (Akhtar et al., 2022) notes that industrialization may culminate in wide-ranging implications for resources and the environment. Among other consequences, pollution of the environment leads to depletion of the ozone layer, depletion of soil, air, and water sources, disease outbreaks, and deaths. (Kumwenda et al., 2012)

The city also experiences resource depletion. There are increased anthropogenic-induced urban land use/land cover changes in Blantyre city substantiated by an accelerated increase in built-up area and ecosystem fragmentation and accelerated declining rates for vegetation (Gondwe, Lin & Munthali, 2021; Mawenda et al., 2020; Nazombe & Nambazo, 2023). Most city dwellers especially in the informal settlements rely on firewood and charcoal for fuel. This has led to a depletion of forests. The Malawian cities are characterized by cases of fuel harvesting from the urban peripheries (Kambewa et al., 2007; Ramanathan & Carmichael, 2008; Zulu, 2010), and due to high population, charcoal consumption has been rising with the rise in urbanization (Mugo & Ong, 2006). With unreliable electricity supply trends experienced by the city, coupled with high population, lack of enforcement of laws for protecting forests, and cultural preferences for cooking with charcoal for certain foods, Blantyre city like all the cities in the country has lost most of its forest reserves. GoM (2009) reported that 90% of electrified households still used charcoal for cooking, and this was projected to be the case for the foreseeable future, regardless of whether electricity expansion was realized. In addition, there are also cases of hills and mountains clearance for settlement and agriculture. According to Riley (2012), the city's forest reserves are Kanjedza, Soche, Michiru, Bangwe, and Ndirande. Except for the Kanjedza forest reserve, the rest of the forest reserves are situated in the mountains surrounding the original townships. He argues that the authoritative control during the one-party era led to the protection of these spaces, but with the transition in governance, reduction of forest guards, and poverty, these reserves have been destroyed. The loss of trees and vegetation in the mountains has left people downhill at risk of landslides and other natural disasters. For instance, people below Soche Mountain were badly hit by mudslides and floods due to Cyclone Freddy that hit the country, leading to loss of lives and property. According to Estoque and Murayama (2013), Hirons et al., (2016), Konrad (2003), vegetation loss results in soil degradation, loss of aesthetic values, and declining ecosystem services, such as air and water purification, flood mitigation services, noise reduction and climate regulation, including urban cooling. Another resource that is greatly depleted is water. Generally, water in the rivers of the city such as Naperi, Nasolo, Limbe, and Mudi is polluted due to the increasing urbanization, vehicular, agricultural, and domestic surface runoffs, sewer lines blockages, industrialization and growth of informal settlements. (Kumwenda et al., 2012; Kuyeli et al., 2009; Sajidu et al., 2007). Increasing urbanization and lack of waste management services in the informal settlements have contributed to people dumping their household waste into rivers and other indiscriminate places, which is later washed by storm waters into the rivers, leading to water pollution (Kandodo, 2017; Mpoola, 2011). ICLEI-CBC (2017) reports that in Lilongwe, farming, housing, and informal markets such as Tsoka and Lizulu encroach on the buffer zones of the Lilongwe River, leading to direct and indirect transmission of pollutants into the river, a case which is also true for Blantyre city.

Enough funding is required for city councils to effectively and efficiently be able to provide and manage social infrastructure and basic urban services, such as road provision and maintenance, waste management, sanitation, provision of health services, provision of market outlets, provision of education, maintaining security and safety in the city, and provision of adequate drainage. However, Blantyre city council, just like other city councils in Malawi, experiences inadequate funds due to a shortage of resources, poor planning, and funds mismanagement (Mpoola, 2011; Khonje, 2022). For instance, Blantyre City is experiencing indiscriminate waste disposal on the roadsides and in rivers and littering around picks due to insufficient funds, lack of staff, and insufficient vehicles for waste collection (Chikukula et al., 2024; Montenegro et al., 2022; Zeleza-Manda, 2009).

The city also experiences acute shortages of potable water. Blantyre water board which is responsible for supplying the city residents with water experiences challenges in meeting the high demand for the resource due to the high population which outstrips the supply (Maoulidi, 2012). The problem is worse during the dry season due to the lowering of water levels in the Shire River and Mudi Dam, which are the main sources of water for the city (Maoulidi, 2012; NSO, 2019). In addition, the city's intermittent water supply is also influenced by a lack of funds for maintaining the old supply network, which frequently experiences pipe bursts. Other contributing factors include Blantyre's costly higher geographical location and its long distance from the Shire River, the main source of water (Maoulidi, 2012; Mpoola, 2011). Shortage of potable water in the city forces people to resort to fetching water from unprotected sources such as rivers streams and wells for domestic use. These water bodies are mostly polluted with industrial effluents and other waste that are washed into these waters. Chikukula et al. (2024), Kumwenda et al., (2012), Sajidu et al. (2007) argue that this puts the city dwellers at risk of waterborne diseases. Mkandawire and Banda (2009), Zeleza-Manda (2009) highlight that almost half of all diseases in Blantyre City are associated with waterborne diseases.

Furthermore, the city is experiencing a rapid rise in urban population and informal settlements, leading to increased demand for social infrastructure and basic urban services such as portable water, roads, proper housing waste management, and sanitary services (Spong & Walmsey, 2003). According to Mpoola (2011), the city's population is fast rising, with the majority of the people settling in informal areas, constituting more than 70 percent of the total population of people in the city. According to Mpoola (2011), the majority of people in informal settlements cannot afford a decent house but rather live-in slums and squatters which lack basic amenities such as proper latrines and portable water. SDI (n.d.) reports that people's lack of access to sufficient portable water forces them to trek long distances in search of resources from government or privately-owned kiosks or boreholes, the majority of which are not operational. This insufficiency pushes them to opt for unsanitary water sources such as streams, which are generally polluted. Furthermore, Chikukula et al. (2024), Khonje (2022), Mpoola (2011), and SDI (n.d.) report that, despite constituting the highest percentage of the city's population, waste collection and sanitation services for these informal areas are very inconsistent, if not entirely absent, as compared with the formal settlements, leading to illegal dumping and burning of household waste. Kandodo (2017) asserts that the large populations residing in informal urban settlements with limited access to waste management and sanitation facilities translate to substantial health risks to residents.

Thus, the main of this study, therefore, was to investigate the potential waste-sharing pathways among the industries in Blantyre City, so as to optimize resource use, minimize waste, and enhance sustainability, and thus, consequently contribute to turning Blantyre into an eco-city. This was achieved by identifying raw materials used in the production processes, determining the byproducts and waste produced by the industries, determining the waste management practices used by the industries, identifying the existing and potential industrial symbiotic relationships, and assessing the quality of liquid waste for use in industrial symbiosis. By implementing industrial symbiosis in the industrial areas, that's is, turning the industrial areas into eco-industrial parks, the city will see the pollution due to poor waste management checked.

1.5 Problem statement

In an era marked by increasing environmental concerns and the urgent need for sustainable development, the concept of industrial symbiosis has emerged as a promising strategy for fostering eco-efficiency among industries. Blantyre is one of Malawi's major urban centers and economic hubs, characterized by a diverse array of industries, including agriculture, manufacturing, and services. However, like many urban areas worldwide, Blantyre grapples with a myriad of environmental issues such as waste management, pollution, and resource depletion. The rapid pace of industrialization coupled with inadequate infrastructure and regulatory frameworks exacerbates these challenges, threatening the region's ecological balance and sustainable growth.

In the wake of the daunting task on the shoulders of the city councils to manage waste and deal with the challenges associated with it, such as lack of resources, lack of staff, and lack of institutional will (Khonje, 2022; Mpoola, 2011), various stakeholders including the government through the city councils, have chipped in with various initiatives to rescue the situation. For instance, private waste collectors were introduced to help in the collection of waste from around the cities in reaction to the waste collection challenges the city councils are facing due to insufficient waste collection vehicles, staff, and funds (Kasinja & Tilley, 2018; Montenegro et al., 2022; Zeleza-Manda, 2009). In addition to these strategies, there are several circular economy (CE) initiatives whose main aim is to ensure that waste generation and improper disposal are reduced through turning waste into some useable products or collecting and selling waste to industries for recycling while empowering the people involved financially (Chinyepe et al., 2022; Waste Advisers, 2018).

Malawi's best circular economy potential is in plastic, organic, and agricultural waste, with plastic waste prioritized due to the threat it poses to the environment and its great potential for recycling (CTCN, 2022). However, it has been noted that most of these initiatives have left out industries from the equation of waste management despite contributing to the enormous quantities of waste generated in the cities, day in, and day out. Khonje (2022) reports that according to Monitoring and Evaluation Office of Community Servings Investment Promotion statistics, Blantyre City generates 109 tons of waste every day and more than 15 percent of this waste emanates from industries. It is noted that most of the CE projects in Malawi have targeted waste generated from institutions such as markets and households (Makonombera, 2024; Mpanang'ombe et al., 2021). Projects aimed at promoting industrial waste management amongst industries have been given little or no attention at all.

In this context, the exploration of industrial symbioses in Blantyre is not merely an environmental necessity, it is also a strategic imperative aimed at enhancing the resilience and competitiveness of local industries while promoting ecological sustainability. Waste management at the industry level can take the form of industrial symbiosis and eco-industrial parks (Akrivou et al., 2021; Bain et al., 2010; Desrochers, 2001; Gertler, 1995; Song et al., 2017). These approaches seek to promote the sharing of waste among industries, leading to a reduction in waste generation and exhaustion of resources and services. The industrial symbiotic relationships that exist in the industrial areas of Malawi are not well documented, and let alone no studies have been conducted to explore the potential symbioses that could be generated in addition to the already existing ones. In addition, there are no studies conducted on eco-industrial parks and eco-cities in Malawi. Thus, the lack of this data has potentially contributed to the pollution in the cities of Malawi as most films resort to improper waste disposal due to lack or less sharing of waste and byproducts amongst themselves.

Therefore, this study will propose the potential waste-sharing pathways among the industries in Blantyre City to optimize resource use, minimize waste, and enhance sustainability by mapping the industries and their raw materials and waste and by-products. The symbiosis scenarios that will be revealed are suggested to lay a foundation towards transitioning the industrial areas into eco-industrial parks, and in the long run, converting Blantyre into an eco-city.

1.6 Objectives of the study

1.6.1 Main objective

To investigate the potential waste-sharing pathways among the industries in Blantyre City to optimize resource use, minimize waste, and enhance sustainability

1.6.2 Specific objectives

Specifically, the study aims to:

(i) Analyze the existing industrial landscape in Blantyre, identifying key players, their waste outputs, and resources that can be shared.

(ii) Explore potential symbiotic relationships among local industries in Blantyre City, looking for innovative solutions that could transform waste into valuable resources.

(iii) Propose a strategic framework for implementing industrial symbiosis in Blantyre, outlining steps for regulatory support, infrastructure development, and stakeholder engagement.

(iv) Assess the potential economic, environmental, and social impacts of transitioning to an eco-industrial park model, providing a roadmap for sustainable development in Blantyre.

1.6.3 Research questions

(i) What are the current economic benefits of implementing industrial symbiosis within Blantyre City?

(ii) What are the potential environmental benefits of creating an eco-industrial park in Blantyre through industrial symbiosis?

(iii) How can the implementation of industrial symbiosis reduce waste and emissions in Blantyre's industries?

(iv) How can resource mapping be effectively utilized to identify potential synergies among industries in Blantyre?

(v) Who are the key stakeholders in Blantyre that need to be engaged for the successful implementation of an industrial symbiosis?

1.7 Significance of the study

Waste management services in Blantyre City are insufficient and the city councils are overwhelmed as they cannot collect waste daily. Kasinja and Tilley (2018) reported that a lot of Malawi's waste can enter the environment as only 42% of waste is collected, approximately 12% of waste is thrown on roadsides, 9% thrown on river-sides, and 9% is thrown in dumpsites. They highlighted that Malawi lacks proper landfills, but rather has open dumpsites. Industrial symbiosis could enhance a collaborative exchange of materials, energy, water, and by-products among different industries within a shared context. By fostering these relationships, businesses can optimize resource use, minimize waste generation, and enhance productivity. This approach not only contributes to operational efficiencies but also mitigates environmental impacts, thus aligning with the principles of sustainable development.

In the context of Blantyre City, which has historically been driven by sectors such as agriculture, manufacturing, and trade, the exploration of industrial symbiosis presents a significant opportunity to transform economic practices. By leveraging local resources and promoting waste exchanges among industries (enterprises), the eco-city can help create a more resilient economic structure. The successful establishment of an eco-city modeled on industrial symbiosis would position Blantyre City as a leader in sustainable urban development within the region. It presents a unique opportunity for the city to attract investment and international attention while upholding environmental quality. By exploring industrial symbiosis as a viable pathway, the study highlights a way for a more sustainable future, and how the city can evolve into an integrated ecosystem where industries strive, communities flourish and the planet is protected.

1.8 Study limitations

This study employed a mixed-methods approach, combining qualitative and quantitative methods, to explore the potential for establishing industrial symbioses in Blantyre as a means to transition the industrial areas into eco-industrial parks, and thus turning the city into an eco-city, in long term. It was conducted in Chirimba, Makata, and Maone industrial areas, which were purposively chosen, as they are regarded as some of the city’s most active industrial areas. From these industrial areas, all manufacturing industries were targeted, and 51 industries participated in the study. The study focused on identifying raw materials used in the production processes to exploit input substitution options, determining the byproducts and waste produced by the industries and the waste management practices used to establish symbiotic synergies, identifying the existing and potential industrial symbiotic relationships, and lastly, assessing the quality of liquid waste for use in industrial symbiosis. Data collection involved interviewing the industry managers, supervisors, and/or quality control personnel. It was complemented with onsite observation of production practice and waste management and document review. The study acknowledges and addresses the following limitations in the study's discussion section to enhance the transparency of the research findings and provide valuable guidance for future research work and policy decision-making.

Some challenges that were encountered are:

i. Data availability: The study encountered limited access to comprehensive and reliable data on local industries and environmental impacts. This was observed by the unwillingness of some industry managers/personnel to provide the researcher with comprehensive data on raw materials, waste generation, and waste disposal methods.
ii. The unwillingness of the majority of industries to authorize liquid waste sample collection, limiting the researcher to collecting the samples from drainages, with the exception of one industry.
iii. Lack of records on waste generation rates by most industries, limiting the study to using approximated data.
iv. Reluctance of some industries to participate in the study.
v. Lack of standardized metrics (measurement metrics) for evaluating the success of industrial symbiosis initiatives in specific contexts like Blantyre.
vi. Cultural factors: Resistance to change among local industries, businesses, and communities due to a lack of awareness of industrial symbiosis benefits.

1.9 Structure of the thesis

Chapter One discusses the background of the research, the problem statement, research objectives, the justification, and the dissertation outline, while the literature review and methodology are in chapters two and three respectively. Chapter Four presents the results and discussion sections, while Chapter Five discusses the summary, conclusion and recommendations based on the findings of the study.

1.10 Chapter summary

This chapter discussed the background of the study, by highlighting that Blantyre City is facing waste management challenges, and that promotion of industrial symbiosis which would eventually lead to creation of an eco-industrial park could help in addressing the existing waste management problems. In addition, the chapter gave an overview of economic activities characterizing the city, citing presence of various industries located in industrial areas. Apart from waste management the chapter identified other problems facing the city, including resource depletion, lack of potable water, economic inefficiencies and high population growth. Furthermore, the chapter spelt the problem statement, objectives of the study and the research questions. Last but not least, the chapter discussed the significance and limitations of the study. The chapter concludes by giving the structure of this thesis.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter discusses the literature related to the research topic. This review acted as an eye-opener for the researcher on issues to do with industrial symbioses and eco-industrial parks. You may wish to know that the researcher did not come across literature about Malawi on these themes, and as a result review was delimited to other countries in Africa and beyond.

2.2 Definition and concept of industrial symbiosis

2.2.1 Historical background of industrial symbiosis

Industries and the environment are in interaction all the time. Industries accrue their inputs from the environment and pour their outputs in the form of waste and byproducts back into it. There is, therefore, a need for a sustainable relationship between the two entities. Industries need to operate in such a way that they don’t harm the environment. One of the ways to study the interaction between the industries and the environment is through industrial ecology. Genc and Kurt (2024) explain that industrial ecology, which is the study of the interactions between industrial and ecological systems, ensures that industries mimic the natural systems that do not emit waste into the environment. That is, as according to Desrochers (2001), the principle of industrial ecology is that modern industrial sector should emulate the circulation of materials in ecosystems throughout the processes of raw material accruing, product making and use, and waste disposal. He continues to highlight that in industrial ecology, industries are perceived as networks of producers, consumers, and scavengers, and as such, industrial ecology encourages symbiotic relationships between companies and industries through sharing and exchanges of resources such as waste and byproducts. Through these exchanges industrial systems shift from linear to circular material and energy flows, an ultimate objective of industrial ecology. (Ehrenfeld & Gertler, 1997; Graedel, 1996; Lowe & Evans, 1995; Tibbs, 1993).

The field of industrial ecology was formally introduced in literature in 1989 by Frosch and Gallopoulos, in their article titled "Strategies for Manufacturing", in which the authors proposed that industries were to adopt a production system in which one industry's waste was to be taken up by another industry as a raw material to reduce the negative impacts of pollution caused by industries (Frosch & Gallopoulos, 1989), a concept called industrial symbiosis. According to Turken and Geda (2020), industrial symbiosis collectively puts to task traditionally separate industries to indulge in competitive and advantageous physical exchange of materials, energy, water, and/or by-products. Deutz (2014) defines industrial symbiosis as a movement of underutilised resource(s) (comprising substances and/or objects and/or energy), from an industry which would otherwise discard them, to another industry which uses them as a substitute for new resources. The earliest industrial symbiosis recorded was the Denmark's Kalundborg industrial symbiosis (Ehrenfeld & Gertler, 1997). It began in the 1970s but got worldwide attention the same year Frosch and Gallopoulos wrote their article (Bain et al., 2010). According to Le Tellier et al. (2017), this symbiosis comprises of six processing companies, a waste handling company and the municipality of Kalundborg in bilateral agreements involving sharing of materials and energy, achieving more than thirty exchange loops. These exchanges enabled the industries achieve, social, economic and environmental benefits. Since then, different nations adopted industrial symbiosis as a strategy for sustainable industrial sector, with Kalundborg as the model for industrial symbiosis (Bain et al., 2010).

2.2.2 Key principles of industrial symbiosis

Any industrial symbiosis is built and run on a number of core principles which seek to reduce environmental impacts, improve economic performance, enhance social benefits and foster innovation and competitiveness.

Chertow (2007) cites collaboration and interdependence between or among industries and other stakeholders as one of the key principles of industrial symbiosis. For industrial symbiosis to occur, there is need to identify opportunities for resources and services sharing among industries and make decisions that can sustain the synergies. This requires collaborative effort from different stakeholders such as the industries, city councils and the community. Thus, trust and cooperation among the stakeholders is key for a smooth implementation and running of an industrial symbiosis. Implementing resource sharing among industries ensures environmental, social and economic benefits (Huang et al., 2019). Environmental benefits are achieved when waste is diverted from going into the environment through indiscriminate waste disposal or disposal into the landfills. Social benefits from industrial symbiosis are accrued through promotion of trust and cooperation among the participating industries, among others. By using waste, residues and byproducts as substitute for inputs enables the industries to utilize materials that are cheaper than, leading to economic benefits.

Another principle is resource efficiency. Industrial symbiosis strives to ensure resource efficiency through maximization of the use of materials and energy by recycling and reuse of materials. Lowe and Evans (1995); Neves et al. (2019a, b) assert that with industrial symbiosis, industries shift from using virgin resources to using waste or byproducts, leading to reducing pressure on natural resources. Thus, industrial symbiosis ensures optimal use of resources, waste reduction, sharing of resources such as energy, water, materials and logistics. The resource efficiency is also achieved through closed-loop systems. These systems are achieved through recycling, reusing and material recovery (Ghisellini et al., 2018).

Furthermore, industrial symbiosis seeks to ensure that industries shift from linear production which releases waste into the environment to a closed loop system which ensures that resources circulate within the production processes (Desrochers, 2001). The continuous cycling of resources back into production ensures reduction in waste generation and resource consumption (Camilleri et al., 2023). In other words, industrial symbiosis uses the principles of circular economy, and by implementing these principles, which include material sharing, recycling and reusing (Camilleri et al., 2023; Geissdoerfer et al., 2017; Ghisellini et al., 2018), industries make full use of the intrinsic value of a material even after being initially considered as useless or as waste.

Another key principle of industrial symbiosis is innovation. To come up with synergies, industrial symbiosis involves coming up with innovative solutions and technologies that support sustainability. Therefore, industrial symbiosis invites innovative ideas such as clean technologies and technological advancements that support the sharing of resources among industries and sustainable interaction between man and the environment. Castellet-Viciano et al. (2022) assert that industries in the Kalundborg industrial symbiosis, one of the most successful models in the world, were always in close contact. They held meetings at the Danish Symbiosis Centre in Kalundborg, aimed at generating more partnerships and innovation, contributing to the success story of the symbiosis.

2.2.3 Theoretical framework of industrial symbiosis

Industrial symbiosis is borne from the principles of industrial ecology which study the flow of materials and energy in the industrial systems (Frosch & Gallopoulos, 1989). According to Genc and Kurt (2024), industrial ecology seeks to ensure that industries do not emit waste into the environment and use resources optimally. Thus, in industrial symbiosis, industries collaborate to share resources such as water, energy, water, utilities, waste byproducts and information, by mimicking the natural systems which do not emit waste into the environment. Industrial symbiosis also applies a holistic approach to understanding the complex systems defining industries (Desrochers, 2001). He explains that industries are not viewed as standalone units, but rather as a web of producers, consumers, and scavengers capable of interacting with each other, and this is helpful in designing sustainable industrial systems. By identifying and studying the relationships among the industries, feedback loops are established, and thus industrial symbiotic relationships for sharing resources are implemented. The waste, residues, by-products and other resources produced by one industry are taken up by another industry. Like the natural systems that do not emit waste into the environment, the sharing of waste, residues and byproducts among industries, ensures recycling and reuse of resources, leading to environmental protection attainment through reduction of pollution due to waste accumulation. Apart from the environmental protection, other benefits of industrial symbiosis include social and economic benefits (Sulaiman et al., 2009). Industrial symbiosis generates economic benefits for the industries involved through selling of their resources to other industries and by saving costs on waste management, raw materials, procurement, and utility bills. It is worth noting that waste management is costly due to logistics such as transportation to the landfills and waste handling. On the other hand, virgin raw resources and utilities such as water and energy are generally expensive. Therefore, through industrial symbiosis industries are able to cut their budgets, thereby contributing to economic gains. The other benefit of industrial symbiosis is social benefits. Due to collaborations and interdependence among industries, industries are able to engage in collaborative problem solving, and there is enhanced competitiveness which may result in advances in innovations. In addition, these collaborations also build trust and cooperation among the participating industries (Lowe & Evans, 1995).

Apart from using principles of industrial ecology and holistic systems approach, industrial symbiosis also incorporates the principles of circular economy. According to EMF (2022), CE is a system where no material becomes waste but is kept in circulation through strategies such as maintenance, refurbishment, remanufacture, recycling and composting leading to, biodiversity conservation through natural rejuvenation and tackling waste and pollution. EMF highlight three principles of circular economy, namely; waste and pollution elimination, products and materials circulation and nature regeneration. It explains these principles as follows: Eradication of waste and pollution is achieved through shifting from take-make-waste system, which is an open-loop system to a circulating the resources within an economy. On the other hand, circulation of products and materials through maintenance, refurbishment, remanufacture, recycling and composting, just to mention a few, ensures optimal use of resources by retaining their intrinsic value after being rendered as waste. The circular economy, which encourages optimal use of resources implies that virgin raw materials will not be extracted from the environment at an alarming rate, thereby giving enough time for natural resources to replenish. Thus, it is clear that these principles of CE are part and parcel of industrial symbiosis which seeks to mimic natural systems that do not emit waste into the environment. The Figure 2.1 below illustrates industrial symbiosis and its benefits.

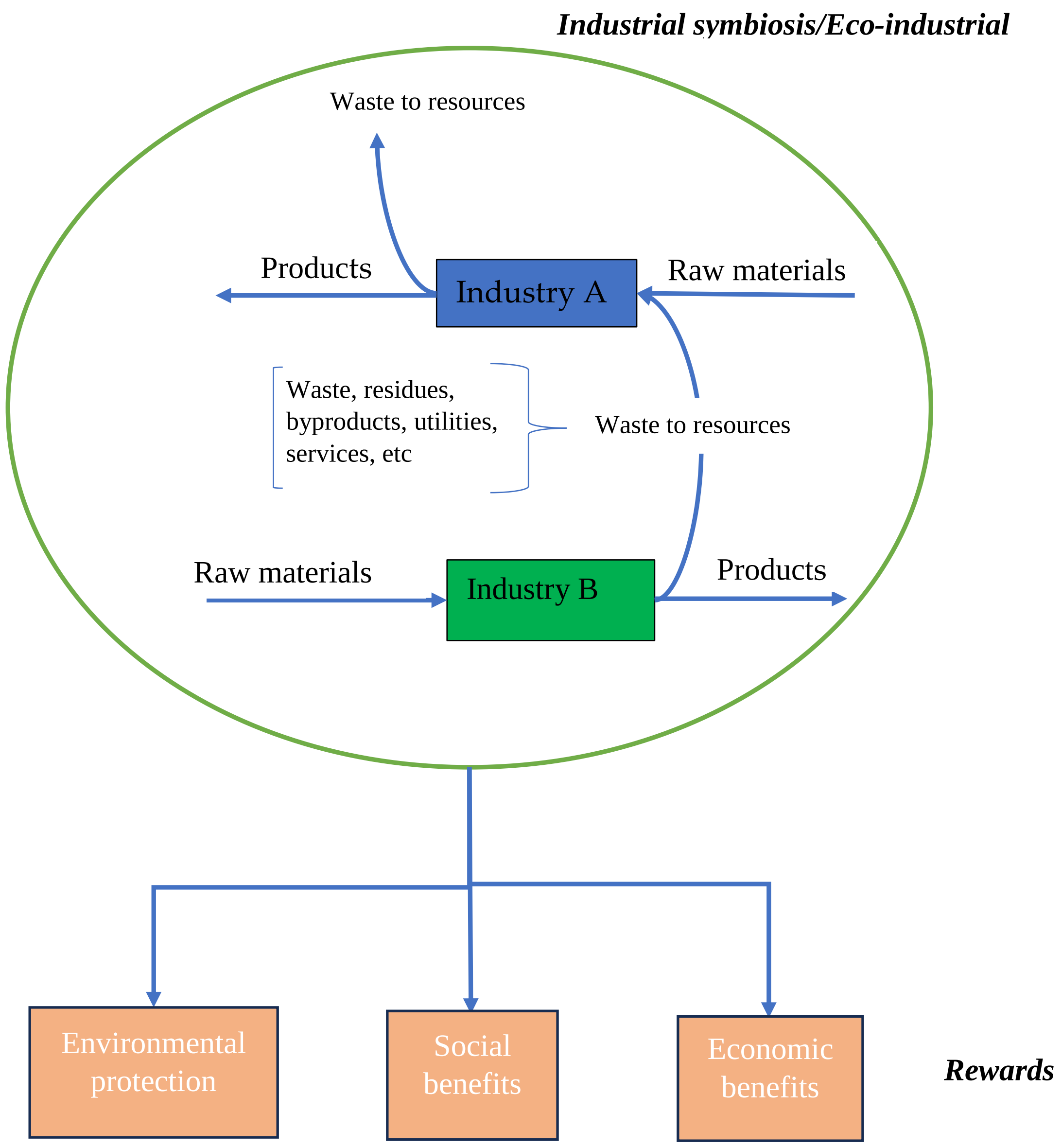

Figure 1: Figure 2.1: Conceptual diagram of industrial symbiosis and its benefits *(Adapted from Lowe and Evans (1995); Sulaiman et al. (2009); Y. Yu et al. (2021)*

2.2.4 Systems theory

As discussed above, industrial symbiosis enacts a holistic approach, in which industries are not perceived as standalone entities, but rather as a web of industries always interacting. This paradigm is known as systems theory. Systems theory which is also known as general systems theory, looks to understand complex systems' structure, behaviour and interactions, which is achieved by studying the interconnected components making up the system, and systems' inputs, throughputs, and outputs, scope and limits, and performance (Whitchurch & Constantine, 1993). The writers concluded by highlighting that, systems theory is a holistic approach, which studies the system as a whole, principle known as holism. According to Kast & Rosenzweig (1972), apart from holism, the other principles of the systems theory include interconnectedness, homeostasis and adaptation. Industrial symbiosis applies systems theory. Interconnectedness principle is evident when companies and industries engage in sharing resources such as utilities, information, waste, byproducts, residues, water and energy. Industrial symbiosis also considers the entire industrial system. As discussed earlier on, industrial symbiosis decisions are made to benefit the entire system not just individual entities. This is holism. One of the key concepts of systems theory, as earlier pointed out, is feedback or information of systems performance. Likewise, in industrial symbiosis there is collaborative relationships and information exchanges among industries and other stakeholders on issues such as collaborative problem solving, creation of resource exchange routes, and sharing of innovative ideas (Al-Saidi, Das & Saadaoui, 2021; Behera et al., 2012; Li Pan, Kim, Linn, & Chiang, 2015). According to Akhtar et al. (2022), development and implementation of industrial symbiotic relationships depends on understanding the raw materials, the manufacturing processes and the waste, byproducts or residues produced and conversion of these materials into useful forms by other industries. This is in tandem with the systems theory, which, as already indicated above, studies inputs, throughputs and outputs of the system. This is also known as Input-Transformation-Output Model (Kast &

Rosenzweig, 1972). This model is, therefore, key in industrial symbiosis as understanding the raw materials, the production process and the waste produced helps in generating waste sharing opportunities among industries. That is, industries are able to share the resources amongst themselves. On the hand, systems theory studies emerging issues by studying the behaviour of the system's components as they interact with each other. This emergence principle is also a key feature in industrial symbiosis. In industrial symbiosis, new opportunities and innovations also arise from interaction of industries and other stakeholders. Besides, one of the key principles of industrial symbioses is encouragement of innovative ideas (Al-Saidi et al., 2021).

2.2.5 Principles of circular economy (CE)

Implemented at industry level (micro CE), among industries (meso CE) and among collocated industries such as in an eco-industrial park (macro CE), circular economy is a production and consumption system that aims at restoring and replenishing nature by using waste and resource consumption reduction strategies (Castellet-Viciano et al., 2022; Geng & Doberstein, 2008). These strategies include, but not limited to maintenance, refurbishment, remanufacture, recycling and composting. (EMF, 2022; Geissdoerfer et al., 2017; Ghisellini et al., 2018). The EMF, who designed circular butterfly diagram, highlight three principles of circular economy, namely "waste and pollution elimination, products and materials circulation, and nature regeneration". It explains these principles as follows: Eradication of waste and pollution is achieved through shifting from take-make-waste system, which is an open-loop system to a system that circulates the resources within a production. On the other hand, circulation of products and materials through maintenance, refurbishment, remanufacture, recycling and composting, just to mention a few, ensures optimal use of resources by retaining their intrinsic value after being rendered as waste. Thus, CE may lead to reduced waste and pollution, biodiversity conservation, economic benefits, competition among industries which may lead to innovations and products' quality improvement. (Meshram, 2024) adds that CE also strives to implement the 5R framework, which help to achieve zero-waste. For successful implementation of circular economy to be realized, circular economy projects success depends on collaborative efforts of different players such as industries, government, private stakeholders and the community (Schraven, Bukvić, Di Maio & Hertogh, 2019; Schut Crielaard & Mesman, et al., 2015). Boons et al. (2017) highlight that among other things, governments must provide a conducive environment for circular economy projects to thrive on, through formulation of economic policies that support the implementation, management and maintenance of the projects.

2.3 Industrial symbiosis in global context

Since its formal introduction by Frosch and Gallopoulos in 1989, industrial symbiosis initiatives have made strides of establishing itself globally as one of the key concepts for achieving sustainable development. This has been evident in the establishment of various international bodies and projects at global, regional, national and city levels. Some of the examples of the global initiatives for industrial symbiosis include the United Nations Industrial Development Organization (UNIDO) and the International Society for Industrial Ecology (ISIE) (UNIDO, n.d.; ISIE, n.d.)

With 172 member states and headquartered in Vienna, United Nations Industrial Development Organization (UNIDO) is as specialized agency of the United Nations whose mandate is to promote industrial development and sustainable development globally. Its activities address all the Sustainable Development goals, but its mandate mainly seeks to respond to the Sustainable Development Goal (SDG) 9: "Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation” (UNIDO, n.d.). UNIDO has seen itself spearheading a number of initiatives in its mandate. An example of such initiatives is transitioning industrial zones into eco-industrial parks, a community of industries practicing industrial symbiosis, in the wake of an increase in industrial zones and the challenges that come along with it, such as pollution and depletion of resources experiencing its member states. With financial aid from Swiss State Secretariat of Economic Affairs (SECO), UNIDO rolled out a five year project (2018-23) called Global Eco-Industrial Park Programme (GEIPP) aimed at transitioning the industrial zones into eco-industrial parks in Colombia, Egypt, Indonesia, Peru, South Africa, Ukraine and Viet Nam, saving enormous quantities of water, energy and material, in addition to pollution control through waste and resource sharing among industries (Ekafitrina & Arthur, 2003; UNIDO, n.d).

Another global initiative on industrial symbiosis is the International Society for Industrial Ecology (ISIE). The idea for its formulation was conceived by a group of industrial ecology scholars who gathered at the New York Academy of Sciences in 2000 and formally subscribing its members in 2001. International Society for Industrial Ecology (ISIE) is an organization that seeks to promote industrial ecology and symbiosis research. Its mission is “to promote the use of industrial ecology in research, education, policy, community development, and industrial practice through seeking to build a community of interest, support cumulative learning, produce high quality research, and promote social change”. Apparently, the society is made up of more than 900 members spread all over the world, with its headquarters in Netherlands as a legally registered non-profit organization. ISIE holds various sessions and provides expertise in “Socio-Economic Metabolism, Life Cycle Sustainability Assessment, Environmentally Extended Input Output, Industrial Symbiosis and Eco-industrial Development, Sustainable Urban Systems [and] Island Industrial Ecology, in addition to granting scholarships and tailored events to students and upcoming researchers (ISIE, n.d,). Other global initiatives that promote industrial symbiosis are the World Business Council for Sustainable Development (WBCSD) which promote sustainable business practices and industrial symbiosis among industries (Idowu, 2013) and the Global Environment Facility (GEF) which provides financial support for projects that promote industrial symbiosis and environmental sustainability across the globe. According to United Nations Environment Programme (UNEP), (n.d.), GEF, which was established on the eve of the 1992 Rio Earth Summit, works with 183 countries to try to find solutions to different environmental issues. UNEP continues to explain that the GEF's financial assistance responds to the Minamata Convention on Mercury, the Stockholm Convention on Persistent Organic Pollutants (POPs), the United Nations Convention on Biological Diversity (UNCBD), the United Nations Convention to Combat Desertification (UNCCD) and the United Nations Framework Convention on Climate Change (UNFCCC).

Regardless of these and other instituted initiatives aimed at promoting industrial symbiosis globally, the implementation of industrial symbiosis model has not been even, with Africa seeing the least interventions. Boom-Cárcamo & Peñabaena-Niebles, 2022) cite a number of factors that have affected the participation of industries from emerging and frontier countries in industrial symbiosis initiatives, including financial barriers, lack of awareness of industrial symbiosis, lack of favourable policies, absence of landfill fees, fears of bleach of confidentiality which leads to lack of trust among industries, lack of infrastructure, social barriers and imbalance between availability and demand which affect continuity of resource flow.

2.3.1 Industrial symbiosis in Africa

Most African countries have policies and legislations aimed at protecting the environment and ensuring proper waste management, including CE strategies to ensure minimization of waste generation, recycling and reuse of waste (Oni, Nevo, Hampo, Ozobodo, Olajide, Ibidokun, Ugwuanyi, Nwoha, … Ikpae, 2022). Oni et al. (2022), however, laments that employment of these strategies has proved to be a problem across the continent. Boom-Cárcamo and Peñabaena-Niebles, 2022) also report that despite showing great potential owing to the type of economic activities and her waste streams, industrial symbiosis in Africa is still in infancy and facing a number of challenges. Akhtar et al., (2022) added that, unlike in the developed countries, proclivities for industrial symbiosis and eco-industrial development are less observable among the developing economies. They continue to highlight that these developing nations are rather mostly characterized by resource sharing information and assessment missing links. There is, therefore, a need to identify and facilitate such productive exchanges for robust industrial and economic growth (Chattopadhyay, Kumar, Fine, & Olivetti et al, 2016). According to Oni et al. (2022), notable examples of industrial symbiosis and eco-industrial parks are prevalent in Ghana (Nukpezah et al., 2019), Tanzania (Rweyendela & Mwegoha, 2021), Zimbabwe (Kasese, Smout, O'Carroll & Basson, 2016; O'carroll et al., 2017), South Africa (Brent et al., 2008); Cape Town, 2020; Mann 2018; Sedibeng District Municipality (DC42), 2021;), Egypt (ElMassah, 2018), Kenya (Damgaard, Takou, Ramin, & Andersen, 2019; Ramin, Bestuzheva, Gargalo, Ramin, Schneider, Ramin, Flores-Alsina, Andersen & Gernaey et al., 2021), Liberia (Alfaro & Miller, 2014). Oni reports that these initiatives are facing a number of challenges such as unviable resource amount, poor resource quality, absence of industries to utilize waste streams, legislative, economic and logistical constraints, concern about information confidentiality, passive government support, outdated technology, poor infrastructure, limited of information on quality and quantity of waste and byproducts.

Bacudio, Benjamin, Eusebio, Holaysan, Promentilla, Yu and Aviso (2016), Illsley, Jackson and Lynch (2007), Neves et al. (2019a) acknowledge financial and technological shortfalls as some of the hiccups of industrial symbiosis development. Mauthoor (2017), Neves et al. (2019) and Oni et al. (2022) stress the importance of funding and subsidies in establishment of industrial symbiosis, by arguing that it is of paramount importance that local or national governments should provide financial incentives that promote industries to create resource sharing partnerships. Furthermore, there is a need to formulate and enforce implementation of appropriate policies and efficient regulatory frameworks and concise action plan that spearhead industrial symbiosis (Neves, et al., 2019a, b; Oni et al., 2022). Other proposed solutions to a successful industrial symbiosis in Africa as proposed by Oni include the need to embrace a coordinated multisectoral national approach to industrial symbiosis, unstiffen the process of by-product classification, providing tax relief, sensitizing and supporting industries and other stakeholders to address lack of awareness on industrial symbiosis, and encouraging industries that can act as anchor tenants.

2.3.2 Industrial symbiosis in Europe

Europe has been the leading continent in the implementation of industrial symbiosis, with plentiful eco-industrial parks and initiatives (Neves et al, 2019a). One of the most renowned examples of industrial symbiosis in Europe is the Kalundborg industrial symbiosis in Denmark, where multiple industries collaborate to utilize each other's byproducts and waste (Ehrenfeld & Gertler, 1997). Beginning in the 1960s and often hailed as the world's first eco-industrial park, this model showcases material and energy sharing among companies, significantly reducing waste and costs. Initially, the reason behind its establishment was to minimize waste by reusing and recycling, but later the managers and city dwellers discovered that the model was yielding environmental benefits. The industrial symbiosis involved five core industries plus other smaller industries. The main industries are coal-fired Asnaes Power Station, Statoil Refinery, Gyproc Plasterboard Factory, Novo Nordisk Biotechnological Company, producing pharmaceuticals and lastly City of Kalundborg. These industries are involved in both energy and material sharing. For instance, Asnaes now supplies steam to Novo Nordisk, thereby eliminating the need for new boilers; to Kalundborg City for district heating; and to the Statoil Refinery for energy for the refinery process. In terms of material flows, the model does the following: fly ash produced by the power plants is used by a cement company, gypsum produced by the desulfurization unit at Asnaes is taken up by Gyproc for wallboard making; pure sulfur produced by the refinery's desulfurization process goes to Kemira for sulfuric acid production; sludge produced by pharmaceutical processes by Novo Nordisk Biotechnological Company and other companies and from the fish farm's water treatment plant is used as fertilizer on nearby farms; and finally, the surplus yeast proceeds from Novo Nordisk’s insulin production is used as animal feed by the farmers. This network of recycling and reuse has resulted into accruing economic and environmental benefits (Lowe & Evans, 1995).

According to Neves et al. (2019a) the success story behind the implementation of industrial symbiosis in Europe is centered on governments’ commitment through the European Commission, to establishing and providing funds for programs that support the model, mainly focusing on reducing greenhouse gas emissions and sustainable use of resources. “Roadmap to a Resource Efficient Europe” sought to provide a framework for sustainable use of all resources while achieving economic development (European Commission, 2011). “Closing the Loop—An EU Action Plan for the Circular

Economy" which sought to emphasize the significance of industrial symbiosis, facilitate it through cooperation with the Member States and provide financial support for its implementation (European Commission, 2015). "Directive 2018/851 on Waste" which acknowledged waste as a resource and encouraged Member States to participate in and facilitate industrial symbiosis (European Parliament, Council of the European Union, 2018). Other European countries involved in industrial symbiosis include Czech Republic, Slovenia, Greece, Croatia, Russia and Poland (Boom-Cárcamo & Peñabaena-Niebles, 2022).

2.3.3 Industrial symbiosis in Asia

Asian countries, China and Japan in particular, have also made significant strides in industrial symbiosis. Their industrial practices have been designed in such a way that they promote industrial symbiosis. (Shi & Chertow, 2017) cites an example of arguably one of the best examples of sugar industry industrial symbiosis network in China, belonging to Guitang Group. The sugar industry exhibits five symbioses, namely pulp and paper manufacturing from bagasse from sugar mills, a powering a plant using bagasse from sugar mills, an alcohol distillery producing alcohol from molasses from sugar mills, cement manufacturing from ash from venture scrubber and electrostatic precipitator, and finally, compound fertilizer plant utilizing filter mud from sugar mills and alcohol plant. In 2020, China launched a program called "The China National Eco-Industrial Demonstration Programmed" Shi, Chertow & Song, 2010 et al., 2010). This led to a rise in industrial symbiosis initiatives in the country. Apparently, as reported by Huang et al. (2019); Liu and Côté (2017), the initiative has contributed to commissioning of a large web of eco-industrial parks in the country which promote industrial symbiosis, leading to pollution reduction and resource efficiency. Other Asian countries involved in industrial symbiosis include Taiwan, India, Malysia, Singapore, Turkey, Vietnam, Indonesia, South Korea, Philippines, Thailand and Bangladesh (Boom-Cárcamo & Peñabaena-Niebles, 2022).

2.3.4 Industrial symbiosis in America

Industrial symbiosis in form of eco-industrial parks and regional initiatives in United States of America and Canada is less applied as compared to Europe and China (Neves et al. 2019a). According to Cimren, Fiksel, Posner and Sikdar (2011), implementation of the model in the United States of America is only occasional and lacks proper follow ups. In addition, most industries are not willing to share information about their production processes and waste generated (Fraccascia & Yazan, 2018). Akrivou et al., (2021) argue that one of the main barriers hindering the achievement of IS actions is the informational gap among industries regardless of the geographic proximity between them regarding how they can utilize each other's waste. Şenlđer and Albayrak (2011) proposed that there is a need to come up with flexible and comprehensive database of industries to aid in matching the industries that could be involved in symbiotic relationships; and establish more recycling facilities. There are also fears of unstable supply of waste to be taken up by an industry, which discourages industries to participate in industrial symbiosis for the fear of affecting their supply (Bansal & Mcknight, 2009).

To expedite industrial symbiosis in USA, the government implemented a national initiative across the country through the President's Council on Sustainable Development and the US Environmental Protection Agency to aid in the development of eco-industrial parks in the country (Neves et al., 2019a). However, despite these incentives, eco-industrial parks are still underdeveloped. Among other things, this is due to the fact that industries do not freely participate in the symbioses, as the government initiate and heavily control these projects, as these projects are deemed by the government as a means for improving regional economy (Heeres, Vermeulen and de Walle, 2004). Lowe & Evans (1995) warned that for industrial symbiosis to be effective, industries should voluntarily participate in the projects. Furthermore, Gibbs and Deutz (2007) add that the presence of regulations unfavourable for industrial symbiosis such as, the US Resource Conservation and Recovery Act which characterize many waste streams as hazardous waste has also impeded the development of industrial symbiosis in the USA, as industries are confined from engaging in sharing of such waste. Other American countries involved in industrial symbiosis include Argentina, Brazil, Mexico and Columbia (Boom-Cárcamo & Peñabaena-Niebles, 2022).

2.4 Types of industrial symbiosis

Industrial symbiosis can be categorized into three main types, namely material symbiosis, energy symbiosis and water symbiosis (Chertow, 2007; Lowe & Evans, 1995; Neves et al., 2019b). Material symbiosis involves the sharing or exchange of waste, residues and byproducts among industries. While energy symbiosis involves the sharing of energy resources, such as waste heat or renewable energy sources, while water symbiosis are collaborative initiatives to manage water resources efficiently, such as sharing of wastewater between industries. Lowe and Evans highlight benefits of symbiosis, which include; contributing to lowering of operational costs and promoting environmental and social sustainability. On the other hand, Akrivou et al. (2021) highlight four levels of industrial symbiosis in terms of geographical orientation, namely local, regional, national and international symbioses. Unlike regional symbiosis which involves industries from a larger geographical area, local symbiosis is a network of co-located industries involved in the sharing of waste and byproducts. Akrivou et al. (2021) points out that eco-industrial parks fall into this category of local symbiosis.

2.5 Framework for Eco-Industrial Parks

2.5.1 Resource efficiency

By practicing industrial symbiosis, eco-industrial parks are designed to ensure optimal use of resources, waste reduction and sharing resources such as energy, water, materials and logistics (Le Tellier et al., 2017). They aim to achieve closed-loop systems through recycling, reusing and material recovery. This industries' deliberate shift from linear production which releases waste into the environment to a closed loop systems which ensures that resources circulate within the production processes, thereby ensuring reduction in waste generation and resource consumption.

2.5.2 Collaborative governance

This involves engagement of different stakeholders in decision making processes. Chertow (2007) cites collaboration and interdependence between or among industries and other stakeholders as one of the key principles of industrial symbiosis, and hence for eco-industrial parks also. For industrial symbiosis to occur, there is need to identify opportunities for resources and services sharing among industries and make decisions that can sustain the synergies. This requires collaborative effort from different stakeholders such as the industries, city councils and the community (Neves et al., 2019b). Thus, trust and cooperation among the stakeholders is key for a smooth implementation and running of an eco-industrial park. According Baas and Boons (2004), Baas (2005), Heeres et al. (2004), Hein, Jankovic, Feng, Farel, Yune and Yannou (2017), Paquin and Howard-Grenville (2009); (2012), Spekkink and Boons (2016) these actors fall into two main categories, namely symbiosis partners, which include stakeholders directly or planning to be involved in material exchange(s) and lastly the non-symbiosis partners such as; industry or business associations, anchor tenants, regional or local government or nationwide symbiosis programs. The industrial associations will be responsible for tabling discussions towards exploring more opportunities for material sharing amongst themselves and other issues key in the sustenance of the symbiotic relationships (EU, 2020). The government's role will be to make sure that it rolls out industrial symbiosis programs and put in place policies and financial and research incentives (Mauthoor, 2017; Neves et al., 2019a, b) that are pertinent to the smooth running and monitoring of the industrial symbiosis initiatives, which are currently no-existent and/or clearly spelt. Thus, collaborative governance is crucial for any eco-industrial park.

2.5.3 Innovation

Eco-industrial parks strive to encourage innovative practices that support sustainability. According to Al-Saidi and Saadaoui (2021), industrial symbiosis, and thus, eco-industrial parks, involve restructuring of consumption and production trends using innovative designs and business models that allow efficient use of resources through the principles of the circular economy. In addition, innovative practices in eco-industrial parks may take the form of energy conservation technologies, the cleaner production of energy, water, and materials in industrial manufacturing processes, and the adoption of efficient technologies (Behera et al., 2012; Li et al., 2015).

2.6 Case studies of industrial symbiosis

2.6.1 Kalundborg, Denmark

Beginning in 1960s and often hailed as the world's first eco-industrial park, this model showcases material and energy sharing among companies, significantly reducing waste and costs. Initially, the reason behind its establishment was to minimize waste by reusing and recycling, but later the managers and city dwellers discovered that the model was yielding environmental benefits. The industrial symbiosis involved five core industries plus other smaller industries. The main industries were coal-fired Asnaes Power Station, Statoil Refinery, Gyproc Plasterboard Factory, Novo Nordisk Biotechnological Company, producing pharmaceuticals and lastly City of Kalundborg. These industries are involved in both energy and material sharing. For instance, Asnaes conduits steam to Novo Nordisk, thereby eliminating the need for new boilers, to Kalundborg City for district heating, and to the Statoil Refinery. In terms of material flows, the model does the following: fly ash produced by the power plants is used by a cement company; gypsum produced by the desulfurization unit at Asnaes is taken up by Gyproc for wallboard making, pure sulfur produced by the refinery's desulfurization process goes to Kemira for sulfuric acid production; sludge produced by pharmaceutical processes by Novo Nordisk Biotechnological Company and other companies and from the fish farm's water treatment plant is used as fertilizer on nearby farms; and finally, the surplus yeast proceeds from Novo Nordisk’s insulin production is used as animal feed by the farmers. This network of recycling and reuse has resulted into accruing economic and environmental benefits (Desrochers, 2001; Lowe & Evans, 1995).

2.6.2 Cincinnati, USA

The Cincinnati industrial symbiosis program facilitated exchanges between local industries, yielding substantial economic and environmental benefits. According to Lee (2003), Cincinnati industrial district has a diverse type of industries which fall into eight main categories, namely food, machinery, metal manufacturing, wood and furniture, electrical equipment, chemicals, glass and stone, and metal products. Lee continues to explain that these industries form input-output production linkages, which involves sharing of materials, in addition to service linkages, information linkages, and marketing linkages. Sharing of resources such as waste and byproducts among industries resulted to economic, social and environmental benefits.

These cases illustrate the potential benefits and practical applications of industrial symbiosis.

2.7 Benefits of industrial symbiosis and eco-industrial parks

The application of industrial symbiosis can yield numerous benefits, including economic savings, environmental protection and social benefits (Sulaiman et al., 2009).

2.7.1 Economic benefits

Industrial symbiosis and eco-industrial parks help industries to cut costs. This is achieved through; increased efficient use of resources and energy, waste recycling, evading of penalties related waste generation and management and sharing of costs on thing such as infrastructure, research and maintenance costs among the industries involved (Lowe & Evans, 1995). Huang et al. (2019) added by highlighting those economic benefits are also acquired through selling of waste and byproducts and services to other firms and cutting costs for waste management and for virgin raw materials and for utilities such as water and energy. Aside the economic benefits to the industries, the models contribute to economic empowerment of the communities. According to De Gobbi (2022), due to collaborative governance which may contribute to innovation as the stakeholders engage, there is creation of job opportunities for the people from the surrounding communities in avenues such as waste management, recycling, and green technologies. Thus, it is worthwhile noting that industrial symbiosis and eco-industrial symbiosis contribute to industries' profit making.

2.7.2 Environmental benefits

Chertow (2007), Ghisellini et al. (2018) explain the waste minimization principle of industrial symbiosis as the practice of turning waste products into valuable inputs for other industries. This is achieved through shifting from open loop systems which release waste into the environment to a closed system which encourages circulation of materials within the industrial systems (De Gobbi, 2022; Sulaiman et al., 2009). Some of the strategies for implementing closed loop systems include recycling, reuse and sharing of materials among industries (Chertow, 2007; Geissdoerfer et al., 2017; EMF, 2022). Thus, Industrial symbiosis and eco-industrial park models lead to environmental protection through reduced waste and pollution as industries indulge in sharing of waste, byproducts and residues.

2.7.3 Social benefits

Lastly, industrial symbiosis and eco-industrial parks strive to achieve social benefits. This is achieved through collaborative activities among industrial actors, communities and other stakeholders involved, which leads to cooperation and trust building among industries (Chertow, 2007; Sulaiman et al., 2009). In addition, Lowe and Evans (1995) highlight that the enhanced environmental quality achieved through industrial symbiosis leads to better health outcomes for people in the surrounding communities, as the models ensure reduction of waste and pollution.

2.8 Challenges to industrial symbiosis

Despite the potential advantages, several challenges impede widespread adoption of industrial symbiosis. Some of these barriers include lack of awareness, regulatory issues and cultural resistance (Boom-Cárcamo & Peñabaena-Niebles, 2022; Oni et al., 2022).

2.8.1 Lack of awareness

Many businesses lack understanding of symbiosis opportunities, let alone, the concept of industrial symbiosis itself. This leads to improper waste management, as industries do not share waste among themselves. As argued by Akrivou et al. (2021), to achieve industrial symbiosis action, there is a need to address this information gap among industries on how they can utilize each other's waste. Among other ways to achieve this, it is paramount that municipals or governments should come up with flexible and comprehensive database of industries and incorporate an electronic waste registration system to aid in matching the industries that could be involved in symbiotic relationships; and establish more recycling facilities (Oni et al., 2022; Şenlđer & Albayrak, 2011). The case for Malawi is that, there are no industrial symbiosis policies and programs in the country, and as a result, most industries do not know about the model. Boom-Cárcamo and Peñabaena-Niebles (2022) argue that the lack of knowledge of industrial symbiosis in top-level management significantly impedes its development, as such, there is a need for decision makers to fully incorporate industrial symbiosis into their management and planning decisions. Furthermore, Oni et al. (2022) suggests that involving industrial symbiosis advocates to be sensitizing industries on the importance of industrial symbiosis could also help.

2.8.2 Regulatory issues

Some existing regulations and/or absence of industrial symbiosis friendly regulatory frameworks may hinder collaborative exchanges. Gibbs & Deutz (2007) highlight that most regulations related to waste generation condemn most waste streams as being hazardous. As a result, industries are discouraged to participate in industrial symbiosis. These researchers cited the "US Resource Conservation and Recovery Act" as one of the factors that impeded the development of industrial symbiosis in the USA. On the other hand, lack of industrial symbiosis frameworks, policies, and concise action plan that spearhead industrial symbiosis programs has been seen to be one of the challenges to implementation of the model (Neves et al., 2019a; Oni et al., 2022). Mauthoor (2017), Neves et al. (2019) highlight that governments should make sure that it rolls out industrial symbiosis programs and put in place policies and financial and research incentives. The success story behind the implementation of industrial symbiosis in Europe is centered around governments' commitment through the European Commission to establishing and providing funds for programs that support the model, mainly focusing on reducing greenhouse gas emissions and sustainable use of resources. "Roadmap to a Resource Efficient Europe" sought to provide a framework for sustainable use of all resources while achieving economic development (European Commission, 2011). "Closing the Loop—An EU Action Plan for the Circular Economy" which sought to emphasize the significance of industrial symbiosis, facilitate it through cooperation with the Member States and provide financial support for its implementation (European Commission, 2015). "Directive 2018/851 on Waste" which acknowledged waste as a resource and encouraged Member States to participate in and facilitate industrial symbiosis (European Parliament, Council of the European Union, 2018). China also has seen a rise in industrial symbiosis initiatives in the wake of a 2020 launched program called "The China National Eco-Industrial Demonstration Programmed" (Shi et al., 2010). This initiative has contributed to commissioning of a large web of eco-industrial parks in the country, which promote industrial symbiosis (Huang et al., 2019; Liu & Côté, 2017). Guan, et al. (2019), Neves et al. (2019a) highlighted that aside the industrial symbiosis policies and plans, the success of China's industrial symbiosis initiatives could also be attributed to financial incentives, and research incentives towards industrial the initiatives. Conversion of waste into useful products may require equipment and advanced technology, for instance, and the financial incentives offered to such industries can help them in procurement of necessary equipment for this. Neves et al. (2019b) also acknowledges that apart from financial incentives, there is need for industrial symbiosis research incentives, and it's the government's role to provide evidence-based data helpful in the meaningful establishment and thriving of industrial symbiosis interventions through industrial symbiosis research programs by coordinating with the academia and researchers. This data collected will help in decision making regarding the projects, among other things providing solutions for different innovative application of waste.

2.8.3 Cultural resistance

Every industry guards its business confidentiality with jealousy, by sealing perforations capable of leaking its sensitive information. However, industrial symbiosis involves sharing of confidential information such as production processes, inputs and waste generated. Concerns about leakage of this secretive information thus spells serious barriers to implementation of industrial symbiosis as industries may resort to being reluctant to share sensitive information regarding operational practice (Bacudio et al., 2016; Walls & Paquin, 2015). It is clear therefore that, for industries to freely share this information, there is need to build trust and enhance communication among themselves. Neves et al. (2019b) highlights that lack of trust and unwillingness on the part of industries to provide data on production processes and waste generation are some of the barriers to realization and application of industrial symbiosis. Ji et al. (2020) assert that trust is a prerequisite for achieving partnerships among industries. Thus, unless trust is built, and communication among the collaborating industries is enhanced, industries will not be willing to share their confidential information, hence industrial symbiosis development will be a daunting task.

2.9 Context of Blantyre City

Blantyre, the second-largest city in Malawi, confronts various socio-economic and environmental challenges, including waste management, high unemployment rate due to rapid population growth mainly in the informal settlements, and depletion and scarcity of resources (Gondwe et al., 2021; Kambewa et al., 2007; Maoulidi, 2012; Mawenda et al., 2020; Mpoola, 2011; Nazombe & Nambazo, 2023; Ramanathan & Carmichael, 2008; SDI, n.d.; Spong Jane & Walmsey Bryony, 2003; Zulu, 2010)

Blantyre City is experiencing high waste generation, and limited waste management infrastructure which has contributed to environmental degradation. High waste generation which is generally associated with high consumption, advances in technology, urbanization, industrialization and ever-increasing human population (Madanhire & Mbohwa, 2016; Msilimba & Wanda, n.d.; Sharma, 2014), have left the city council overwhelmed when it comes to proper management of the municipal and industrial waste. Chikukula et al. (2024), Khonje (2022), Montenegro et al. (2022) and Zeleza-Manda (2009) argue that underbudgeting, lack of staff, insufficient waste collection vehicles and lack of will by those in power and the general public to push the government on waste management issues has led to poor solid waste management in Blantyre City and Malawi in general. These factors and others have led to irregular waste collection by the Blantyre City Council, resulting into waste being heaped on roadsides, in open spaces and on river banks (Kasinja & Tilley, 2018; Mpoola, 2011; SDI, n.d.). Truss Group Ltd (2021) also echoed that, most hazardous industrial waste in Malawi is not pre-treated before reuse, recycling or disposal and is often dumped illegally at municipal dumpsites. Khonje reports that 15 percent of solid waste generated in Blantyre City proceeds from industries. In terms of liquid waste management, the city lacks enough wastewater treatment plants, as majority of these facilities are either not functional or requiring extensive maintenance (Collet et al., 2016), leading to dumping of industrial waste such as effluents into the streams with little or no treatment (Sajidu et al., 2007; Kandodo, 2017). In addition, city council's sewerage which transports some of the wastewater generated in the city to the treatment plants is prone to break down and blockages due to poor maintenance, improper design, and also lack of public awareness on use of the sewerage systems, leading to spillages which are a common sight around the city, eventually discharging the wastewater into the city's rivers (Halle & Burgess, 2006; Kuyeli et al., 2009). Akhtar et al. (2022) notes that industrialization may culminates to wide-ranging implications for resources and the environment. Among other consequences, environmental pollution leads to depletion of ozone layer, depletion of soil, air and water sources, diseases outbreaks and deaths (Kumwenda al., 2012).

City councils are mandated to manage waste in the cities and towns of Malawi. However, the above highlighted challenges and others make it difficult for the councils to render their services effectively and efficiently. In response to the waste management challenges faced in the country, there are a number of strategies that have been proposed and/or implemented. Chikukula et al. (2024) argues that a multi-faceted approach to waste management involving enforcement of legal laws, civic education and awareness campaigns, community engagement, involvement of private operators, conversion of waste to energy, promotion of recycling activities, composting, and provision of public bins/trash containers can be key in moving Malawi towards sustainable municipal solid waste management, mitigate environmental risks, and improve public health.

To improve collection of waste in the city of Blantyre, which is a very daunting task for the city council alone, Informal Waste Pickers (IWPs) which are also known as scavengers are involved (Kasinja & Tilley, 2018). Their job is to collect, sort, process and transform recyclable materials such as metals and plastics (Aparcana, 2017), thereby reducing the amount of waste disposed of at dumpsites and reduce the use of virgin materials needed for manufacturing (Colombijn & Morbidini, 2017; Ghisolfi, Chaves, Ribeiro & Xavier 2017).

On the other hand, the country has relied much on circular economy initiatives to help in addressing waste management issues. According to (CTCN, 2022), circular economy is a regenerative, restorative, economic and industrial model that seeks to use materials that have already been processed and can be recovered and reused, thus protecting the natural resources from overexploitation. However, CE initiatives are not fully implemented in Africa (Oni et al., 2022). According to Barré (2015); CTCN (2022), waste market activities for Malawi are trade of compost produced from organic waste, trade of plastic waste for industry and residential waste collection by small local companies. Barré argues that the compost market has a huge potential for development due to the large quantity of organic waste produced, minimum competition for organic waste and the simplicity of the process to compost waste. However, plastic waste is the most prioritized due to the threat it poses to the environment and great reusability (CTCN, 2022). For instance, people from the surrounding townships of Blantyre City are seen collecting plastic from different avenues such as markets and homes, and selling them to plastic manufacturing industries for recycling. On the hand, regarding organic waste, literature shows that Blantyre city council has only two compost facilities. These facilities collect organic waste from the markets within the city. One facility is in Limbe, which gets organic waste from Limbe market (Chinyepe et al., 2022), and the second facility from other four markets (Waste Advisers, 2018). This indicates that there is a huge opportunity for scaling up organic fertilizer production as a huge amount of municipal organic solid waste is not tapped.

This literature about Malawi shows a lack of strategies for waste generated among industries. That is, there are no well-known deliberate initiatives that promote deliberate sharing of waste among industries. Such initiatives take the form of industrial symbiosis and eco-industrial parks. The potential for transforming Blantyre into an eco-industrial park through industrial symbiosis thus presents a strategic avenue for sustainable development. Factors to consider in this context include; understanding the prevalent industries and their waste streams, stakeholder engagement and coming up with supportive policies that encourage collaborative practices.

2.9.1 Local industry composition

Understanding the local industry composition will be key for transforming Blantyre into an eco-industrial park through industrial symbiosis. This involves identifying and comprehending the prevalent industries and the type of waste generated. This will aid in identifying and analyzing resources sharable by industries. According to Akhtar et al. (2022), this process is called resource mapping and assessment, and takes understanding the types of industries available, their inputs and outputs such energy, water and waste and byproducts. In addition, it also involves generating waste sharing opportunities among the industries and the challenges that may be encountered. One of the challenges facing the implementation of industrial symbiosis is unreliability of resource stock which fails to meet the production demands (Neves et al., 2019b). So, resource mapping and assessment will determine resource flow and ensure that the waste and byproducts targeted by another industry are in stable supply. According to Mpoola (2011), Blantyre City is characterized by finance, retail trade, construction, transport, food, textile manufacturing, motor vehicles sales and maintenance, and the informal sectors, with retail trade, construction, manufacturing of food products, transport, textile manufacturing, personal care products manufacturing, motor vehicle sales and maintenance, agricultural warehousing complexes and public administration, as some of the important economic activities in the city. Understanding these industries, their inputs, throughputs and outputs, will therefore be one of the crucial things worth pondering in the quest to transition the Malawi's commercial city into an eco-industrial park through industrial symbiosis.

2.9.2 Stakeholder engagement

Apart from defining the local industry composition, another important factor to consider is building of relationships with local businesses, government entities, and communities. Formulation and sustenance of any industrial symbiosis depends on identifying and engaging various actors that have an enthusiasm in the symbiosis and the possibility to influence it (Hein et al., 2017). These actors fall into two main categories, namely symbiosis partners, which include stakeholders directly or planning to be involved in material exchange(s) and lastly the non-symbiosis partners such as industry or business associations, anchor tenants, regional or local government or nationwide symbiosis (L. Baas & Boons, 2004; L. Willem. Baas, 2005; Heeres et al., 2004; Hein et al., 2017; R. Paquin & Howard-Grenville, 2009; R. L. Paquin & Howard-Grenville, 2012; Spekkink & Boons, 2016). Thus, to implement industrial symbiosis in Blantyre City, there is a need to engage the symbiosis partners-the industries, which in the case of the city include, but not limited to plastic industries, food industries, construction industries, textile industries, home and personal products industries, food/beverage/brewery industries, transport and maintenance industries, metal/steel industries, decorative industries and packaging industries. This would involve exploring their resources such waste and byproducts, and how best they can be exchanged among themselves. The non-symbiosis partners that are considered key in the implementation of industrial symbiosis in the city may include the industries associations, the community, the Blantyre City Council and the government. The industrial associations will be responsible for tabling discussions towards exploring more opportunities for material sharing amongst themselves and other issues key in the sustenance of the symbiotic relationships (EU, 2020). The government's role will be to make sure that it rolls out industrial symbiosis programs and put in place policies and financial and research incentives Mauthoor, (2017), Neves et al., (2019a, b) that are pertinent to the smooth running and monitoring of the industrial symbiosis initiatives, which are currently no-existent and/or clearly spelt. Through the city councils, the government will strive to provide a conducive environment for the symbiosis partners through provision of appropriate infrastructure onto which the symbioses to thrive on. The communities surrounding the industrial areas should also be take on board. By being involved in the industrial symbiosis and understanding and its benefits, the communities will, among other things, jealously guard it, and work towards its sustenance, while enjoying the rewards of the model. Raheem and Sauvant (2009) ranks security issues such as petty theft as the second worst challenge faced by the industries in Blantyre City.

2.9.3 Policy framework

Lastly, there is going to be a need to develop supportive policies that encourage collaborative practices. A conducive policy framework is key in industrial symbiosis (European Commission, 2011; Mauthoor, 2017; Neves et al., 2019b), and apparently, the country lacks industrial symbiosis policies, and no programs and action plan of the model have been instituted thus far. Therefore, for a successful transition to eco-industrial park, the country has to start to take industrial symbiosis initiatives seriously. Well defined policies for the model will help in turning the city of Blantyre into an eco-industrial park. It is worth acknowledging that the constitution of Malawi recognizes environmental protection as a right and thus waste management is crucial if this right is to be upheld. Consequently, the constitution led to formulation of different policies and legislations aimed at protecting the environment and ensuring proper waste management, which Blantyre City subscribes to. Some of these legislations include Environmental Management Act (2017), Local Government Act (1998) and Environment Management (Waste Management and Sanitation) Regulations (2008) for guarding against waste generation and poor infrastructure, National Environmental Policy (NEP) (2004) which seeks to promote waste segregation at the source, recycling, and proper waste disposal using appropriate technology. In addition, there is Environmental Management (Plastics) Regulation (2015) which promotes circular economy interventions for plastic waste, The National Waste Management Strategy (2019-2013) which spells strategies and budget allocation for reducing, reusing, recycling, and recovering energy from waste, and lastly, The National Climate Change Management Policy (2016) which seeks to address climate change through addressing emissions of greenhouse gases by different economic sectors.

The country also has a policy regarding manufacturing sector development and waste management and environmental protection. This policy is National Industrial Policy (NIP), which was formulated in 2016, with a goal is to "increase the proportion of manufacturing in GDP through structural transformation of the Malawian economy". The policy was thought to achieve the following outcomes: increased productivity of the industrial sector, increased diversification of industrial products, increased value addition of primary products and reduced trade deficit. Blantyre City, like all the other cities, is obliged to commit to these policies, so as to provide environmentally friendly, high quality, effective and efficient municipal services. Despite these policies being in place, service delivery in realms of waste management and pollution prevention is still poor. The current policy framework however is short of industrial symbiosis policies. Infusing the industrial symbiosis into the framework thus can provide an alternative solution to achieving a sustainable city, and also would facilitate the running and monitoring of the symbiosis initiative. However, current policies can act as the foundation for development of a comprehensive policy on industrial symbiosis.

2.10 Chapter summary

This literature review highlights the definition and concept of industrial symbiosis, industrial symbiosis in global context, types of industrial symbiosis, the framework for eco-industrial parks, case studies of industrial symbiosis, benefits of industrial symbiosis and eco-industrial parks, challenges to industrial symbiosis and lastly the context of Blantyre City. Among other things, the review has revealed the important role played by industrial networking in waste management. Practiced and promoted in Africa and beyond, implementing initiatives that promote industrial symbioses and establishing eco-industrial parks are playing a key role in addressing pollution and waste management challenges faced by governments. However, gaps regarding lack of industrial symbiosis and eco-industrial parks studies in Malawi have been unearthed despite the enormous waste management challenges in the country. This literature review thus gave some ideas and theoretical thoughts useful further in the discussion of this paper to understand what is happening in Malawi in as far as industrial symbiosis is concerned, thereby laying a foundation for turning the cities into eco-industrial parks, ultimately achieving a sustainable industrial sector.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter discusses the methodology used in data collection and analysis. It sheds more light on the study area, study design used, sample size and sampling techniques, data collection tools and techniques and data analysis and presentation. It concludes with the ethical considerations applied in the study and a summary of the chapter.

3.2 Study area

With an area of 240km^2 and lying at 35^o east of Greenwich Meridian and 15^o 42' south of the Equator, Blantyre City is located in the Shire highlands, in the southern part of Malawi. The city was established by the Scottish Missionaries in the 1870s and declared a planning area in 1897. The city is the country's commercial and industrial capital (Mawenda et al., 2020; Mpoola, 2011) and her population as according to the 2018's population and housing census was 800 264 (NSO, 2019). This study was conducted in three industrial areas found in the city, namely Chirimba, Matata and Maone (Figure 3.1).

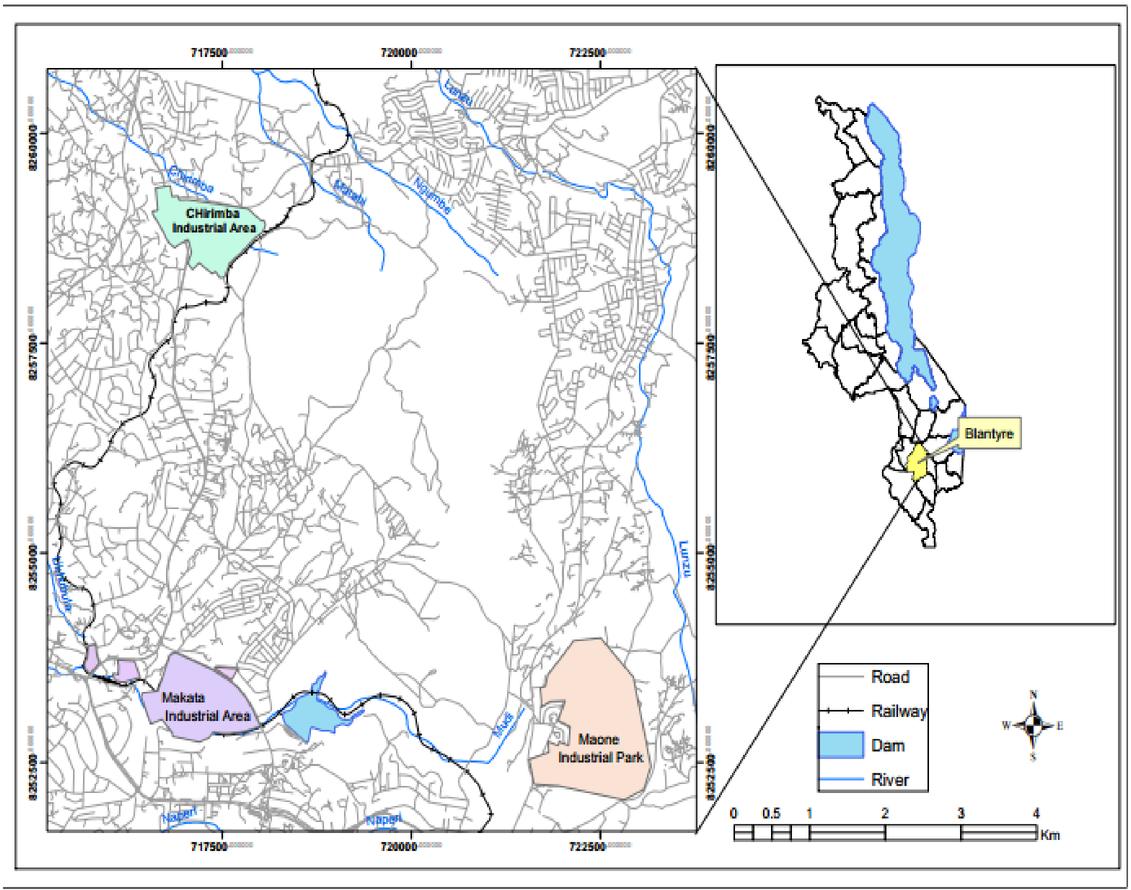

Figure 2: Figure 3.1: Industrial areas that participated in the study

3.3 Research design

The study was descriptive in nature adopting both qualitative and quantitative designs. This design was preferred because the research was meant to handle both numerical and non-numerical data. According to Leavy (2017) mixed-methods research approach involves collecting and integrating quantitative and qualitative data in research to promote comprehensive understanding of the phenomenon under investigation. Creswell (2003) highlight that combining the designs helps in addressing the drawbacks of employing a single design.

The qualitative design enabled the researcher to get an in-depth understanding of the production processes applied by the industries, raw materials involved, waste products and byproducts produced and their waste management practices. In addition, the design also helped the researcher to capture information on the sharing of resources that occur among the industries, which in turn enabled the researcher to come up with additional symbiotic relationships that could occur. According to Enosh, Tzafrir and Stolovy, (2015), qualitative research design ensures a thorough and deeper understanding of the topic being investigated and take on board the input of the participants.

The quantitative design on the other hand helped the researcher to determine the concentration of heavy metals in the liquid waste samples. Troy (2021) explains that quantitative research is associated with the aspects of measurement, quantity, and extent.

3.4 Data collection tools and techniques

3.4.1 Interviews, field study and grab sampling

This section discusses the data collection tools and techniques for objectives (i) and (ii).

The relevant data and information were collected through in-depth semi-structured interviews of fifty-one industry managers or supervisors. This solicited information about the type of industries, raw materials and their sources, waste and byproducts generated and their annual generation rates, waste management practices and waste sharing relationships currently available among the industries.

The industry managers were subjected to a semi-structured interview on the following themes: types of raw materials used in the production process, byproducts and waste produced, waste management practices employed and how their industries relate with other neighboring industries in as far as waste and resources sharing is concerned. In addition, phone calls were involved for clarification purposes on the themes. To identify the raw materials involved in the production processes, the interview asked the responsible managers on the type of the industry (for instance, construction, food and beverage, textile etc), the raw materials they use and their source (whether imported or locally sourced).

To determine the waste and byproducts for each industry, the interview solicited information from the responsible personnel on the type of waste and byproducts generated by their industry and their generation rates per year. When the waste was not homologous, the researcher segregated and classified it into different classes such as metal, glass, textile, biodegradable, non-biodegradable, hazardous, non-hazardous, etc. To determine a waste hazardous nature, both a description and list of hazardous from Malawi's 8th Schedule of the Environment Management (Waste Management and Sanitation) Regulations (2008) and waste composition expertise from the responsible respondents, were consulted.

To determine the waste management practices employed within the industrial areas, responsible officers were asked to provide the researcher with information about the waste management practices and collaborative waste management practices such as any form of waste and byproducts sharing employed by their industry. In addition, the researcher was given an opportunity to observe the waste management practices. The identification of the inputs, determination of the waste and byproducts and identification of the waste management practices and how industries relate with their neighboring industries in waste management helped the researcher to get comprehensive data on industrial symbioses present within and among the industrial areas. Madanhire and Mbohwa (2016) argue that analysis of industries' raw materials and waste products and byproducts is paramount as it provides an informative basis to assess the potential for input substitution or output exchange between processes.

On-site observation complemented the interviews findings by enabling the researcher observe the waste management practices and production processes of industries.

For liquid waste, samples were collected from twelve industries using clean 250ml bottles. Four samples were collected from each sampling site (industry) using grab sampling technique. According to Simpson (2013), grab sampling is a collection of wastewater samples which consists of either a single or discreet sample or individual samples collected over a period not exceeding fifteen minutes. The liquid waste samples were packed in a cooler box and taken to University of Malawi Chemistry Laboratory for standard laboratory tests to establish the concentration of heavy metals and their potential adverse impacts on the environment.

3.4.2 Document review

Apart from consulting documents related to industrial symbiosis and eco-industrial parks across the globe to help in the establishment of potential industrial symbioses for Blantyre City, relevant government legal policy and strategy documents and projects that were/are being used by deferent countries in the quest to establish and maintain industrial symbiosis were consulted. The review of the experiences of the countries includes the specific context of countries at their early stage of industrial symbiosis development, historical patterns of industrial symbioses, policies and institutional aspects of industrial symbioses, prospects, and challenges faced during implementations in the respective countries. These documents helped the researcher to achieve objectives (ii), (iii) and (iv).

3.5 Sample size and sampling techniques

The study was conducted in Blantyre city because of its vast heterogeneity in industries. Makata, Maone and Chirimba industrial areas were purposively targeted industrial areas (Figure 3.1). Makata industrial area is one of the big and most active industrial areas, while Chirimba industrial area is designated as the heavy industrial area (Mpoola, 2011; BCA, 1999; Sajidu et al., 2007). On the other hand, Maone industrial area is one of the fast-growing industrial areas. The choice of these industrial areas for this research thus provided the researcher with a bigger sample of heterogenous industries to work with. All industries except service industries were targeted and 51 industries participated in this study. The industry managers or supervisors were purposively identified for the interviews.

On the other hand, the liquid waste collection points which mainly were convenient and easy to access open drains channeling effluents from the industries were randomly sampled.

3.6 Data analysis and presentation

The data from the interviews was synthesized into various thematic areas of the study namely raw materials used in the production processes, the byproducts and waste produced and their quantities and industrial waste management for analyses and discussion. In addition, the data on the concentrations of heavy metals in the liquid waste samples was also analysed.

3.6.1 Thematic analysis for qualitative responses

Qualitative data collected by note taking during the interviews with the industry managers was thematically analysed, a process which involved manual analysis and categorization according to the developed themes. "Themes are codes, categories, concepts, or words that occur frequently in your data and help summarize the findings" (Johnson & Christensen, 2019, p. 1458). The qualitative data for this study was synthesized into the following themes: type of industry, raw materials used in the production processes, the source of the raw materials, the byproducts and waste produced, the industrial waste management practices and existing symbioses. According to Caulfield (2019), thematic analysis which is a method of analyzing qualitative data is applied to interview or transcript texts, whereby the researcher comprehensively identifies themes in form of repeated ideas, topics, ideas and patterns of meaning. He continues to give six steps involved in thematic analysis, namely data familiarization, coding, themes generation, themes review, theme definition and naming and writing up. Consistent with Leedy and Ormrod (2001), this approach enabled the researcher to organize and severally scrutinize, identify themes and integrate or summarise the data.

Depending on the products produced, the industries were characterized into different types, including plastic, packaging, metal, brewery/beverage, food, construction, meat or abattoir and textile industries, among others.

Establishment of the industrial symbioses currently available within and among the industrial areas took four formats. The first way the researcher obtained the information about the industrial symbioses present within or among industrial areas was through a question on particular industry’s involvement in waste sharing with other industries. Secondly, there was a question that asked the respondents to explain how their industry related with other industries, apart from waste sharing. This also helped the researcher to establish the symbioses among the industries other than those to do with waste sharing. Furthermore, by responding to questions pertaining how a particular industry managed its waste, the respondent could explain how other industries or people from the surrounding communities came to collect such waste for other uses, such as for recycling, for instance. The last but one way through a question from which the researcher obtained information about the existing waste sharing relationships among industries was from the participants' responses on the type and sources of the raw materials needed for their production processes. Unlike the imported raw materials, the attention was given to the locally sourced raw materials. The respondents could indicate a raw material(s) which was a byproduct or waste product from another industry. In so doing, a mapping of industrial symbiosis was established among the involved industries.

The data collected in this study was then entered and categorized in Microsoft Excel and later analyzed and presented in tables and charts. In addition, the established patterns and trends in waste and byproducts exchanges among the industries identified using the four formats outlined earlier on were aggregated and mapped using the shapes tool of Microsoft Word software.

To generate potential symbioses within and among the industrial areas, the researcher analyzed the various production processes and components of inputs and waste and byproducts to come up with substitution and sharing relationship instances. With the help of studies conducted on various applications of diverse waste and byproducts, these instances were generated. In addition, the researcher referred to the already existing industrial symbioses and in eco-industrial parks in Africa and beyond. Hein et al. (2017) argues that if an industrial symbiosis has already been established somewhere, there is a higher probability that such a symbiosis can be recreated as it is considered in principle feasible. Like the already existing symbioses, these potential symbioses generated were also aggregated and mapped using the shapes tool of Microsoft Word software.

3.6.2 Analysis of quantitative data

The EPA vigorous digestion method described by Gregg (1989) was adopted. 100 mL of each representative water sample were transferred into Pyrex beakers containing 10 mL of concentrated HNO3. The samples were boiled slowly and then evaporated on a hot plate to the lowest possible volume (about 20 mL). The beakers were allowed to cool, and another 5 mL of Conc. HNO3 was added. Heating was continued with the addition of Conc. HNO3 as necessary until digestion was complete. The samples were evaporated again to dryness (but not baked), and the beakers were cooled, followed by adding 5 mL of HCl solution (1:1 v/v). The solutions were warmed, 5 mL of 5M NaOH was added, and then filtered. The filtrates were transferred to 100 mL volumetric flasks and diluted to the mark with distilled water. These solutions were then used for the elemental analysis using a flame atomic absorption spectrophotometer (Agilent Technologies, USA) after calibrating the equipment with respective standard solutions according to the standard calibration methods. The sample solutions were analyzed for heavy metal concentrations. Numerical data on the concentrations of heavy metals in liquid waste was collected, which was then entered in Microsoft Excel and mean concentrations were computed. These findings were compared against the World Health Organization (WHO) guidelines for drinking and irrigation water to determine the quality of the liquid waste generated by the industries. Furthermore, data on approximated annual generation rates for industries was entered in excel and presented in charts.

3.7 Ethical consideration

The researcher made sure that participants or respondents voluntarily entered into the research project after being given full information concerning the study to be conducted. The researcher also ensured that neither individuals nor industries were harmed or exploited as a result of the research. Information about the participants was highly kept confidential and accessible by the researcher only. Lastly, the data obtained was used for the purposes of this study only.

3.8 Limitations of the study

As outlined in Section 1.7, the study acknowledged and addresses the following limitations in the study's discussion section to enhance the transparency of the research findings and provide valuable guidance for future research work and policy decision-making.

Some challenges that were encountered are data unavailability, unwillingness of the majority of industries to authorize liquid waste sample collection, limiting the researcher to collecting the samples from drainages, with the exception of one industry, reluctance of some industries to participate in the study, lack of standardized metrics (measurement metrics) for evaluating the success of industrial symbiosis initiatives in specific contexts like Blantyre, and last but not least, cultural factors such as resistance to change among local industries, businesses, and communities due to a lack of awareness of industrial symbiosis concept. The unavailability of data on waste generation rate limited the researcher to approximate the waste generation rates for most of the industries. As such the waste generation rates in this study are generally approximated rates.

3.9 Chapter summary

The chapter has presented research design and methodology which comprised research design, data collection tools and techniques, sample size and sampling techniques, data analysis and presentation, ethical consideration and limitations of the study.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

This chapter discusses the findings and implications of the study.

4.2 Current industrial practices in Blantyre City

4.2.1 Overview of industries in Blantyre City

Conducted in the Chirimba, Makata, and Maone industrial areas, fifty-one industries, excluding service industries, participated in this study (Table 1). The study revealed that the types of industries present in these industrial areas included plastic industries, metal/steel industries, decorative industries, food/processing/beverage/brewery/dairy industries, construction industries, packaging industries, textile industries, manufacturing industries, meat industries, and pharmaceutical industries. The study found that the production processes employed by these industries involved a wide range of raw materials, both imported and locally sourced. Some of the imported raw materials reported included yarn, chemicals, flavors, iron sheet rolls, paper rolls, and metals, to mention a few. Grain and legume crops, scrap metals, waste paper/cartons, plastic waste, and others constituted the locally sourced raw materials. Among the local raw materials, some were seasonal, such as crops, which determined an industry's production duration per year. In addition, some industries, especially the packaging and recycling industries, used waste materials such as paper, carton waste, plastic waste, and tyre waste as raw materials.

Table 4. 1 Industries that participated in the study

Type of industry	**Industrial area**			**Grand total**
	Chirimba	**Makata**	**Maone**	
Construction	2		1	**3**
Decorative		1		**1**
Food/processing/ brewery/beverage	4	3	8	**15**
Home/ personal consumer goods		1		**1**
Meat		1		**1**
Metal/steel	3	5	5	**13**
Packaging	2	2	2	**6**
Plastic	5		2	**7**
Recycling		1		**1**
Textile/home furnishing		1	2	**3**
Grand total	**16**	**15**	**20**	**51**

4.2.2 Key industries in Blantyre City

Aside from the informal sector, the study revealed that the manufacturing and service industries are some of the key industries present in the city of Blantyre. According to this study, manufacturing industries from Chirimba, Makata, and Maone industrial parks participated in the research. The 2013 JICA report states that Malawi's main industries are agriculture, manufacturing, retail and wholesale, information and communication, mining, and service industries (JICA, 2013). The manufacturing industry includes food and beverages such as bakeries, breweries, and agro-food processing; textiles and apparel; the tobacco industry; and other manufacturing sectors such as boiler, tank, and shipping container manufacturing, electrical equipment manufacturing, glass and glass product manufacturing, construction, and consumer goods, to mention a few (Dun & Bradstreet, n.d.; Etherege & Rodriguez, 2018; Wikipedia contributors, January 26, 2025; March 13). The service industry, on the other hand, consists of sectors such as tourism, retail, transport, financial services like banks, and other services such as education, healthcare, and telecommunications. The service sector contributes 51.7% to the nation's GDP (Wikipedia contributors, January 26, 2025). This makes the industry the highest employer. According to Martincova (2015), GDP is considered one of the factors that affect employment, as higher GDP translates to high production, which implies a high demand for the workforce. As a result, the industry absorbs more employees. Malawi's Report on Employment Statistics by the Ministry of Labour (2022) supports this by highlighting that during the first part of the 2022/23 year, the country's service industry created more jobs compared to the manufacturing industry. According to the report, jobs created in the public sector, which comprises ministries, departments, and agencies, were recorded to be the highest (more than 80 percent), while the manufacturing industry contributed only 0.05 percent of jobs. However, the manufacturing industry has seen a slight rise in annual growth rates from 2020 to 2023 (from 4.2 percent to 5.0 percent), following a decline from 7.6 percent attained in 2020 to 4.2 percent in 2021 (Ministry of Finance and Economic Affairs, 2022).

4.2.3 Current environmental challenges

The study revealed that Blantyre city is facing a number of environmental challenges, mainly due to improper waste disposal, which has led to pollution of land, air and water.

4.2.3.1 Improper solid waste management

Despite the waste management practices revealed in this study, it was established that waste management is still a problem in the city. It was discovered that most of the industrial solid waste awaiting collection by the city councils for landfill dumping is left piling up. This could contribute to improper disposal by the industries. Madanhire and Mbohwa (2016); Msilimba and Wanda (n.d.); Sharma (2014) highlight that the city council is overwhelmed when it comes to the proper management of municipal and industrial waste. Chikukula et al., (2024), Khonje (2022), Montenegro et al. (2022); Zeleza-Manda (2009) cited a lack of staff, insufficient waste collection vehicles, and a lack of will by those in power and the general public to push the government on waste management issues as some of the contributing factors. In other words, the rate at which solid waste is being generated does not match the available resources needed for proper disposal.

Apart from the irregular collection of waste by the city council, it was suggestively established that there is a lack of enforcement of the laws that seek to promote proper waste disposal, as evidenced by the improper disposal practices observed among some industries. Among other things, it was discovered that some waste was being dumped in drains and on roadsides. These findings concur with (Kasinja & Tilley, 2018; Mpoola, 2011; SDI, n.d.; Truss Group Ltd, 2021), who lamented that there is a high rate of indiscriminate disposal of waste on the city's roadsides, open spaces, drains, and riverbanks in Malawi. The improper disposal contributes to the pollution of the environment: the land, air, and water.

4.2.3.2 Improper liquid waste management

Apart from the improper solid waste disposal, the researcher discovered that most industries were dumping their effluents into open drains and spaces, and some directly into in the rivers of the city. After a thorough chemical analysis of the liquid waste discharged from twelve industries (from home and personal products industry, beverage/brewery, packaging (egg tray) industry, and plastic industry, metal/steel, food/food processing, meat/abattoir industries) in the three industrial areas of Chirimba, Makata, and Maone, heavy metals were detected. The results of the analyses for heavy metals, namely manganese, zinc, copper, chromium, cadmium, lead, iron, potassium, magnesium, calcium, and sodium, along with their corresponding World Health Organization drinking and irrigation water guidelines, (Orosun, et al., 2023; WHO, 2004, 2022). The results are shown in Table 4.2.

Table 4. 2 Concentration of heavy metals in liquid waste

Concentration of Iron, Manganese, Sodium, Potassium, Calcium, Magnesium, Copper, Zinc, Lead, Cadmium, Chromium, and Mercury

Sample site	Parameter											
	Fe (mg/L)	Mn (mg/L)	Na (mg/L)	K (mg/L)	Ca (mg/L)	Mg (mg/L)	Cu (mg/L)	Zn (mg/L)	Pb (mg/L)	Cd (mg/L)	Cr (mg/L)	Hg (mg/L)
A	<0.006	<0.002	7.431	0.565	5.368	0.697	0.006	<0.0010	<0.0100	<0.002	0.588	<0.200
B	<0.006	<0.002	10.859	0.598	5.618	0.711	0.004	<0.0010	<0.0100	<0.002	0.617	<0.200
C	<0.006	<0.002	9.7814	0.543	5.669	0.728	<0.003	<0.0010	<0.0100	<0.002	0.664	<0.200
D	<0.006	<0.002	11.937	0.622	5.858	0.780	0.011	<0.0010	<0.0100	<0.002	0.688	<0.200
E	0.208	<0.002	13.499	0.855	8.947	1.226	<0.003	<0.0010	<0.0100	<0.002	0.713	<0.200
F	0.900	0.100	201.262	0.6745	233.53	289.243	1.090	0.0536	<0.0100	0.004	0.014	<0.200
G	19.99	0.530	251.436	0.5678	296.54	211.800	1.020	<0.0010	<0.0100	0.006	0.012	<0.200
H	10.78	0.340	294.524	0.6421	401.79	277.388	1.080	<0.0010	<0.0100	0.005	<0.006	<0.200
I	5.710	0.510	303.696	0.6789	418.57	285.623	0.590	<0.0010	<0.0100	<0.002	<0.006	<0.200
J	2.860	0.120	404.855	0.8967	445.24	285.844	0.860	<0.0010	<0.0100	0.007	<0.006	<0.200
K	2.090	0.140	416.235	0.5645	437.63	282.766	1.330	<0.0010	<0.0100	0.008	0.007	<0.200
L	0.640	0.180	425.692	0.6345	446.64	286.706	0.870	<0.0010	<0.0100	0.006	<0.006	<0.200
WHO drinking water standards	1-3[a]	0.4	ND	ND	ND	ND	2	3[a]	0.01	0.003	0.05	0.006
WHO irrigation water standards									5.0	0.01	0.10	

ND= not defined

[a] Suggested but not approved guidelines

Samples: A= Candlex Ltd, B= Castel Malawi Ltd, C= Bowler Beverage, D= Flexible Packaging, E= OG Plastics, F= ETG, G= Mothers Foods, H= Euro Alliance, I=Kris Offset, J= Adla Confectioneries, K= Haroon Steel Industry, L= CK Cold Storage

The study revealed that liquid waste discharged by the industries contain heavy metals such as Iron, Manganese, Sodium, Potassium, Calcium, Magnesium, Copper, Zinc, Lead, Cadmium, Chromium, and Mercury. However, majority of these metals were within the set limits of WHO for drinking water and irrigation water (Orosun et al., 2023; WHO, 2004; 2022), with only iron, cadmium and chromium being the metals with concentrations above the set standards. The presence of heavy metals in the samples recorded in this study concurs with the studies conducted by Halle and Burgess (2006), Kandodo (2017), Kuyeli et al. (2009; Sajidu et al. (2007). Sajidu et al. (2007) attributed the presence of heavy metals in the Mudi, Limbe, and Nasolo Rivers to the dumping of untreated industrial effluents into the water bodies. This indicates that the presence of these metals in such high concentrations, surpassing the WHO limits, renders the water unfit for both drinking and irrigation.

42 percent of the twelve industries recorded high concentrations of iron above the WHO standards of 1-3[a], with Mothers Foods and Euro Alliance registering the highest concentrations (19.99 mg/L and 10.78 mg/L respectively) (Table 4.2). This may be attributed to the presence of heavy metals such as iron in scrap aluminium metals and match production process for Euro alliance and presence of heavy metals from the cleaning water used at Mothers Foods industry which is involved in food processing and producing beverages.

On chromium, 42 percent of the 12 industries recorded concentrations higher than the WHO set standards for drinking water and irrigation water of 0.05 mg/L (WHO, 2004) and 0.10 mg/L, respectively (Orosun et al., 2023). These industries are; Candlex Ltd, Castel Malawi Ltd, Bowler Beverage, Flexible Packaging, and OG Plastics (used oil). The maximum value of chromium, 0.713 mg/L was recorded from samples collected from liquid waste (used oil) generated by a OG Plastics, a plastic-producing industry.

Its minimum value was 0.588 mg/L, recorded from samples from Candlex Limited, a home and personal products industry (Table 4.2). This indicates that the presence of these metals in such high concentrations, surpassing the WHO limits, renders the water unfit for both drinking and irrigation.

According to Tan, Avasarala and Liu (2020), presence of high levels of chromium in water from a water distributing system could probably be attributed to reactions between scales from corroded cast iron pipes which build up in the pipes, with water which normally contains disinfectants. It is suggested by Tan that use of less-reactive disinfectants and exercising care when using cast iron pipes could mitigate chromium levels. In this study, the residual water from Bowler Beverage was collected from a water tap within the premises. The presence of the chromium in the residual water (Table 4.2), could be attributed to presence of chemicals in the water, including disinfectants which were reacting with pipes and steel water storage tank. It was reported that this water was being used by farmers whose fields are nearby the industry to irrigate their crops. This suggests that the plants irrigated with this water can be contaminated with the metal, and over time can cause serious problems to people. High intake of chromium (III) is said to be responsible for cardiovascular problems, liver and kidney damage from acute toxicity of chromium (VI) ranging from 50 to 70 mg/kg body weight, in addition to other health problems such as skin rashes, circulatory system issues, respiratory tract problems, and gastrointestinal tract problems are other health complications resulting from chromium exposure (Dianyi, 2008; Oliveira, 2012; Shrivastava et al., 2002).

The presence of heavy metals in plastics and waste oils from machinery has been analyzed by several researchers. For instance, Zali et al. (2015) explain that, in addition to the heavy metals used as additives, other contaminants such as dirt found in oil may also contain heavy metals. As machines run, they wear down, thereby releasing heavy metals into the oils as well. Turner and Filella (2021) concur by explaining that some additives involved in plastic manufacturing contain heavy metals, and thus plastic dirt in contact with used oil might contaminate it. Like any other machinery, it is not surprising to find heavy metals in used oils from the plastic manufacturing industry's machines. Therefore, the presence of the heavy metal chromium in the used oils from the OG Plastics in this study (Table 4.2) can be attributed to these factors. Zali et al. (2015) cite chromium as a wear metal found in the used oils of machinery. As discussed earlier, this metal has detrimental effects on organisms, including humans. Therefore, there is a need to find sustainable ways to dispose of used oils, rather than the current practice of dumping them in open spaces such as drains. This mode of disposal may lead to the leaching of metals into the soil or runoff into water bodies. Contamination of these resources can pose a great danger to plants and aquatic life. Consequently, humans can be exposed through ingestion, leading to various health problems associated with chromium exposure.

Akhtar and Mannan (2020), Jakovljević and Vrvić (2017) suggest that the home and personal products industry, particularly those involved in the manufacturing of detergents, generates wastewater that contains high levels of oil and grease, biochemical oxygen demand (BOD), chemical oxygen demand (COD), suspended solids (SS), and various heavy metals that can be harmful to aquatic organisms. In this study, wastewater samples from the Candlex Limited which manufactures detergents and other home and personal products were collected from an open drain. Worrisomely, maize fields were observed along the drain, and farmers were using the water to irrigate their crops. This poses a risk to consumers who may be exposed to heavy metals. As established by this study (Table 4.2), the wastewater flowing in this drain contained high levels of chromium at 0.588mg/L, which is higher than the WHO standard for drinking water, 0.006mg/L for copper, 0.565mg/L for potassium, 0.697mg/L for magnesium, 5.368mg/L for calcium, and 7.431mg/L for sodium (Table 4.2). These heavy metals can accumulate and magnify in crops, consequently causing serious health problems in humans (Atta et al., 2023; Dayan & Paine, 2001; Oladimeji et al., 2024). Maleki et al. (2013), Orosun et al. (2023) highlight that irrigating crops with heavy metal-contaminated water increases heavy metal concentration in the soil, thereby increasing plants' uptake rate, which in turn leads to an increase in concentration and bioaccumulation in the plants. Kinuthia et al. (2020) argued that soils along wastewater in open drains are contaminated by the pollutants found in the wastewater, especially when the drains overflow with stormwater.

Wastewater from egg tray production using paper and recycled paper can contain heavy metals (Zabaniotou & Kassidi, 2003). This may be attributable to the presence of heavy metals in the paper used in the manufacturing of the trays. Unlike papers made from virgin pulp, fiber suspension made from recycled pulp contains, among other things, chemical additives, pigments, dyes, and filler agents, all aimed at improving the quality of the paper (Elmas & Çınar, 2018). One of the functions of the fillers is to act as paper colorants. Elmas and Çınar (2018) report that due to their chemical makeup, the colorants contain impurities, including heavy metals such as Pb, Hg, Cd, and Cr. The presence of high levels of chromium in the wastewater (0.688 mg/L) from Flexible Packaging responsible in egg tray manufacturing (Table 4.2), is thus attributable to these factors. The current disposal method of wastewater from the industry therefore introduces heavy metals into the environment.

Apart from solid waste such as spent grain, the brewery industry generates liquid waste, mainly liquor that comes from pressed wet grains and wash water from various departments within the factory (Arimieari & Akari, 2020). The effluent is detrimental to ecosystems, as among other things it might contain heavy metals. Thus, disposing of untreated wastewater from a brewery into water bodies or on land causes serious pollution problems, while discharging it into open drains creates obnoxious odors due to anaerobic decomposition (Arimieari & Akari, 2020; Ninnekar, 1992; Obasi & Agwu, 2017). In this study, as shown in Table 4.2, the samples collected from Castel Malawi Limited, a brewery industry revealed chromium levels higher (0.617mg/L) than the recommended standards of WHO for drinking water (0.05 mg/L).

On the other hand, 50 percent of the twelve industries recorded high concentrations of cadmium above the WHO standards for drinking water of 0.003 mg/L. These industries are ETG, Mothers Foods, Euro Alliance, Adla, Haroon Steel Industry and CK Cold Storage with a range of 0.004 mg/L to 0.008 mg/L. The presence of cadmium in wastewater generated by Haroon Steel Industry, which is involved in metal recycling can be attributed to presence of heavy metals in the scraps used in the steel production. This wastewater is mainly generated from its metal cooling process.

Despite establishing the presence of heavy metals in the liquid waste samples, the study revealed improper disposal of liquid waste by some industries. This is the case despite the stringent rules and regulations stipulated by the Local Government Act (1982) and Blantyre City Assembly (1999). The study found that most industries dump their untreated liquid waste into open drains and on surfaces. These effluents are then washed into the rivers and fields, leading to pollution. This aligns with what Sajidu et al. (2007) found in their study, which indicated that most industries dumped their untreated effluents directly into the rivers, contributing to water contamination. Additionally, the study revealed that most industries do not have treatment plants, with only two industries reporting that they have such facilities. This implies that most industries in the city dump their raw effluents either into sewer lines or into drains and open spaces. According to Collet et al. (2016), Blantyre City lacks sufficient wastewater treatment plants and faces maintenance challenges, leading to the dumping of liquid industrial waste into streams without any treatment or with ineffective treatment (Halle & Burgess, 2006; Kandodo, 2017; Kuyeli et al., 2009; Sajidu et al., 2007). This has contributed to the pollution of the rivers in the city (Kumwenda et al., 2012), a phenomenon that poses health and environmental risks.

The effluents from industries have the potential to contaminate the environment; therefore, their proper handling before being discharged is a crucial issue. Among other contaminants, liquid waste contains heavy metals, whose presence in higher concentrations in water, air, and soil is detrimental to plants, animals, and humans. This is because heavy metals are generally toxic, persistent, bioaccumulative, unbiodegradable, and tend to biomagnify up the trophic levels (Boahen, 2024; Malikula, Kaonga, Mapoma, Chiipa, et al., 2022; Mussa et al., 2020). Although these metals can occur naturally, anthropogenic activities such as industrialization have contributed to their widespread presence in the environment (Tchounwou et al., 2012). When released into the environment, they tend to accumulate in the food chain, causing great harm to ecosystems and human health, even at their lowest concentrations, such as cadmium, lead, and chromium (Malikula, Kaonga, Mapoma, Chiipa, et al., 2022). Other examples of heavy metals include mercury, arsenic, nickel, zinc, copper, iron, and manganese. Ali et al. (2019) stipulates that rapid human population growth is regarded as the primary anthropogenic contributor to the spread of heavy metals in the environment.

Accumulation of heavy metals in the environment leads to pollution of natural resources such as air, water, and soil. Additionally, Boahen, (2024) suggests that the three main pathways through which heavy metals enter the environment are air discharges from industrial combustion and vehicle exhaust, water bodies, and soil. The pollution caused by these metals has serious implications for both flora and fauna. Wastewater that contains heavy metals, when absorbed by plants or consumed by animals, disrupts complex biochemical cycles, which may threaten their survival (Kayira & Wanda, 2021). Although plants need these metals to survive, excessive concentrations in the soil can have the following effects on plants: inhibition of important plant enzymes and damage to cell organelles due to oxidative stress (Assche & Clijsters, 1990; Jadia & Fulekar, 2009), replacement of essential nutrients ready for absorption (Taiz & Zeiger, 2002), and negative impacts on plant growth and development (Asati et al., 2015). For instance, lead (Pb) reduces the number of leaves, suppresses growth, decreases plant protein content, reduces plant biomass, and affects carbon dioxide fixation by inhibiting enzyme activity in maize (Zea mays), Portia tree (Thespesia populnea), and oat (Avena sativa) (Demirevska-Kepova et al., 2004; Hussain et al., 2013; Kabir et al., 2009). Contamination of agricultural soil by heavy metals is a critical environmental concern. Once absorbed, heavy metals compromise the biochemical processes of plants and tend to accumulate in them. Since heavy metals cannot be disintegrated, they consequently accumulate in the human body (Morais et al., 2012). In addition to impacting terrestrial life, heavy metals have also been reported to cause significant damage to aquatic life. When heavy metals contaminate the soil and are washed into water bodies along with wastewater from industries and other anthropogenic activities, they can disrupt aquatic ecosystems, ultimately leading to a loss of aquatic biodiversity (Abdel Salam et al., 2011; Mushtaq et al., 2020). For instance, according to Olojo et al. (2005); Shah (2017), heavy metals in water bodies lead to high mortality rates in juvenile fish and reduced breeding potential in adult fish.

Additionally, lead oxide from old paints releases lead into water bodies when it reacts with stormwater, resulting in water depletion and consequently disrupting the central nervous system and membrane structure.

Furthermore, contamination of the environment by heavy metals is also a public health issue. When exposed to heavy metals, either directly or indirectly through oral ingestion, food and diet, drinking water, dermal contact, and inhalation from occupational sources (Boahen, 2024), they can cause serious health problems. Wastewater is a direct source of heavy metals. After industries generate wastewater that contains heavy metals, it finds its way into water bodies, and drinking from such sources exposes people to these metals (Boahen, 2024). On the other hand, wastewater can also be a means of indirect exposure to heavy metals for humans through dietary exposure. When plants absorb this contaminated water, the heavy metals may accumulate in the edible parts of the plants, such as fruits and leaves. In addition, aquatic animals, such as fish, absorb heavy metals into their tissues, where they accumulate (Shah, 2017). Consuming these foods exposes people to heavy metals. Dietary exposure is regarded as the major means of exposure to heavy metals for people (Yang et al., 2022). It is worth noting that depending on the dose, the age of the individual exposed, gender, the route of exposure, the duration of exposure, the type of heavy metals, and individual susceptibility, the extent of toxicity of heavy metals on humans can differ (Tchounwou et al., 2012). The author continues to highlight that to arsenic, cadmium, chromium, lead, and mercury are categorized as probable or known heavy metals that are carcinogenic according to experimental and epidemiological studies by the United States Environmental Protection Agency.

4.2.4 Existing infrastructure and resource availability

A city requires a range of well-maintained, reliable, and efficient infrastructure and resources to support industrial symbiosis and the general well-being of its inhabitants. Infrastructure disruptions affect people both directly and indirectly (Lenz et al., 2017). Among other things, they can pose serious health problems, lead to pollution, and cut people off from transportation or communication (Jeandron et al., 2015; Ni et al., 2016). Blantyre City has a number of these amenities, including waste management services, roads, and water and electricity.

4.2.4.1 Waste management: Wastewater treatment plants, landfill and waste collection services

The study acknowledged the insufficient waste management infrastructure in the city. One manager reiterated that the city lacks a proper industrial liquid waste treatment plant which makes it difficult for their industry to achieve proper liquid waste management. This concurs with what Collet et al. (2016) found out in their study. They reported that the Blantyre City's water treatment plants are inadequate, with most of them nonfunctional or poorly maintained. Furthermore, the study noted the insufficient waste collection services and the presence of a poorly engineered landfill. Some industries reported that their solid waste tends to accumulate due to inefficient waste collection services by the BCC. When the solid waste is collected by the city council, it is taken to a landfill located in the outskirts of the city, in the Kachere area. However, the landfill is in poor condition and lacks the appropriate engineering of a modern landfill. Several researchers have condemned it as a mere open dumping site. This leads to pollution of the land, air, and nearby water resources. However, with industrial symbiosis and the transition of industrial areas into eco-industrial parks, the city could benefit significantly. The city would divert solid waste from the landfill as industries would share the waste. In addition, this would relieve the pressure on the BCC related to waste management. Industrial symbiosis would also encourage the sharing of wastewater treatment plants that a few industries have. The treated water would be shared, thereby reducing utility bills. In return, the industries would be able to make profits.

4.2.4.2 Road networks

Blantyre City has road networks connecting various places of importance, including the townships and industrial areas. For effective service delivery, a vibrant and efficient road infrastructure is paramount. Among other things, it enables the timely execution of business activities. For instance, it ensures easy transportation of goods and services between suppliers or industries and consumers. Like the other three cities in Malawi, Blantyre faces a number of challenges regarding road infrastructure. According to the Ministry of Transport and Public Works' 2017-2037 Malawi National Transport Master Plan, the urban transport system is characterized by high congestion during peak hours due to a lack of sufficient road capacity, poor road maintenance, and inadequate design standards for roads and junctions, as well as the absence of an appropriate institution for coordination, management, and policy direction for Malawi's cities. One of the motivating factors behind participating in an industrial symbiosis project is to achieve economic benefits. Therefore, the availability of a vibrant road infrastructure in a city to connect industries and industrial areas is key. Thus, there is a need to improve the existing road networks connecting the industrial areas for a smooth exchange of resources among industries.

4.2.4.3 Electricity and Water

Portable water is a very important resource for both domestic and industrial use. A shortage of water spells a catastrophic series of health and sanitation problems. Kalulu et al. (2012) argued that at most half of all illnesses recorded in Malawi are related to waterborne diseases. On the other hand, the industrial sector requires vast volumes of water for production, cleaning purposes, and the cooling or heating of production machines, among other uses (Refalo et al., 2013). Blantyre's only water utility is the Blantyre Water Board. However, due to the high population, the supplier is unable to meet the increased demand for the resource (Maoulidi, 2012). The shortage of water is more pronounced during the dry season (NSO, 2019). Furthermore, a lack of funds for maintenance of the supply network, in addition to Blantyre's costly higher geographical location and the long distance from the main source of water, the Shire River also contributes to the intermittent water supply in the city (Maoulidi, 2012; Mpoola, 2011). Magombo et al. (2016) reiterated that poor governance and low tariffs compared to production costs, coupled with a higher rate of urbanization, are the main causes of water shortage in the city of Blantyre. To avert these challenges, (Magombo et al., 2016) recommended that the government should: "increase budgetary support to urban water utilities; privatize water services and operations; enact an urban water and sanitation act to guide urban water supply; make water utilities autonomous to avoid political meddling; and institute a regulator for urban water utilities." Furthermore, the country faces enormous electricity challenges. Hettinger et al. (2020) state that the country's electricity is unreliable. They explicitly mention that electricity and water service delivery in Malawi is poor, and among other things, Malawi has the lowest electricity access at 11 percent, compared to 42 percent and 48 percent access recorded in Low-Income Countries (LICs) and Sub-Saharan Africa, respectively. Additionally, electricity generation is insufficient to meet current and foreseeable demand. The reliance on hydroelectricity means that the country's generation capacity drops to at most 50 percent of its maximum capacity. In terms of access to water, 67 percent have access to basic water supply, and 26.2 percent have access to basic sanitation. The report highlighted that the “limited access and reliability of energy and water services have constrained economic growth prospects, aggravated poverty levels, and negatively affected the health of Malawians” (p. 20). These assertions imply that poor water and electricity infrastructure negatively affects the industrial sector. Given the water shortage problems facing the city, it is imperative to explore strategies that promote water recycling and reuse, such as industrial symbiosis. In this regard, with industrial symbiosis, industries in the city of Blantyre could share wastewater treatment facilities and the treated water for their production processes. Sharing water utilities will not only help industries address water shortage challenges but will also enable them to cut costs related to water utility bills, thereby achieving the economic benefits that industrial symbiosis offers. Eco-cities and eco-industrial parks, which are also involved in promoting green energy innovations, would enhance the energy sector by addressing the electricity problems facing the city, which negatively affects the industrial sector.

4.2.5 Opportunities for symbiosis

4.2.5.1 Industrial characterization, waste generation and waste management practices for Chirimba industrial area

The study revealed that Chirimba IA was comprised of the plastic, food processing, metal, construction, packaging, and textile/home furnishing industries. This excluded service industries such as warehousing, distribution, and security service companies. However, 16 industries from the plastic, food processing, metal, construction, and packaging sectors participated in the study (Table 4.1). It is worth noting that a textile/home furnishing industry responsible for mattress manufacturing and one food processing industry did not take part in the study. In terms of the quantity of waste/byproducts generated per year, it was revealed that the construction industry produced the most waste (approximately 1,117 tons/year), followed by plastic waste (approximately 240 tons/year), which includes waste generated by plastic industries and packaging waste from non-plastic producing industries. The least produced waste was ash waste (approximately 12 tons/year). Other common wastes generated in the area include metal/steel and food waste (Figure 4.1). However, the most dominant waste in this IA was plastic waste, with 10 out of the 16 industries that participated in the study reporting the generation of this waste. The study also revealed that the most commonly employed waste management practice was onsite dumping. It was observed that this was done prior to collection by the city council or private waste collectors for dumping at the city council's landfill, or before being sold or collected by other industries or individuals within and outside the industrial area for various uses, or prepared for open space incineration. This uncontrolled incineration is hazardous to the environment, as it releases harmful volatiles into the atmosphere, leading to air pollution. Other waste management practices in the industrial area, in addition to onsite dumping, incineration, and landfill dumping, included recycling, sorting, and reuse. However, it was discovered that the majority of the industries do not sort their waste before disposal (Figure 4.2).

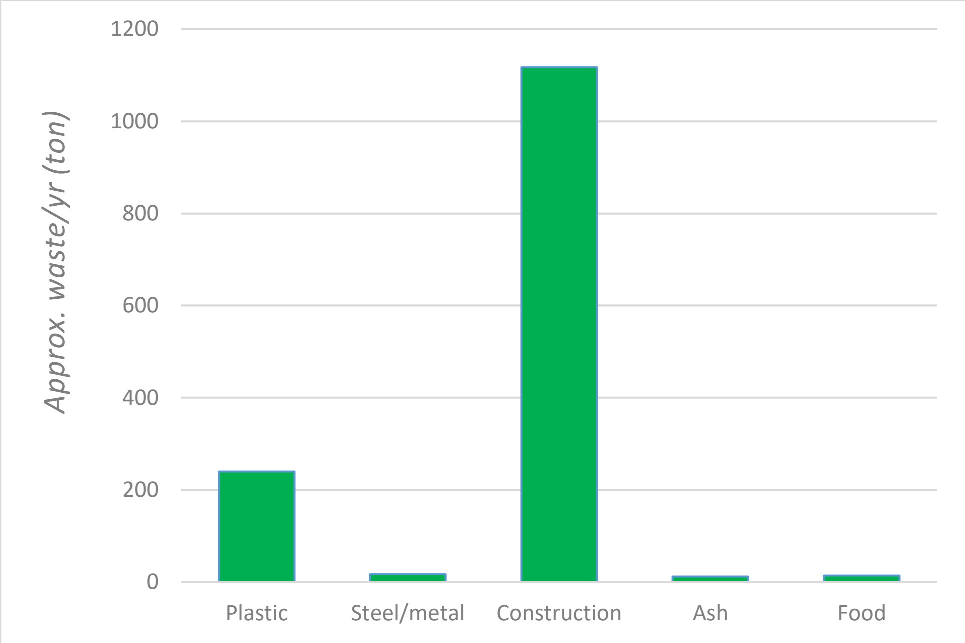

Figure 3: Figure 4.1:Waste generation in Chirimba industrial area

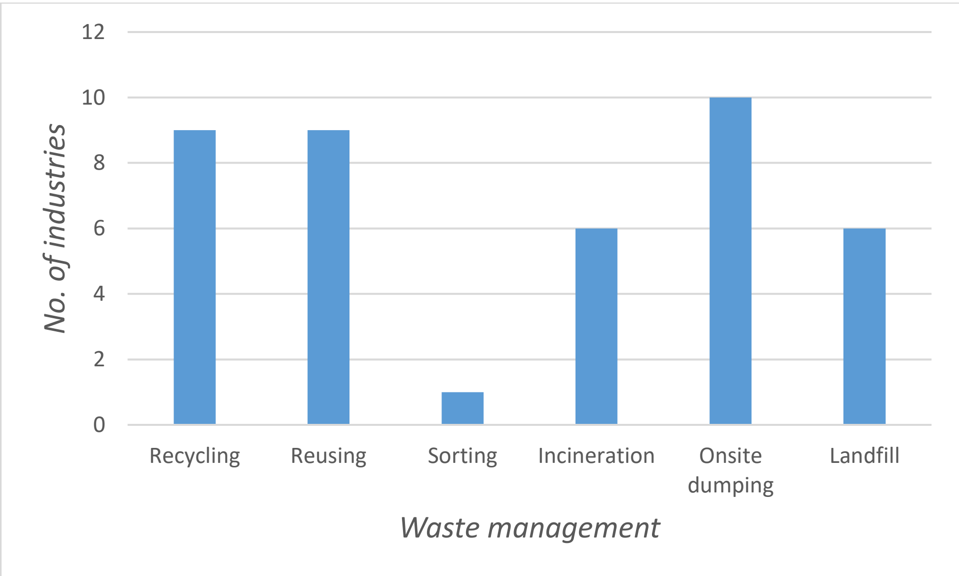

Figure 4: Figure 4.2: Waste management practices in Chirimba industrial area

4.2.5.2 Industrial characterization, waste generation and waste management for Makata industrial area

The study revealed that, apart from service industries, Makata IA comprises textile, decorative,food/confectionery/beverage, metal/steel/roofing, construction/construction materials, recycling, packaging, home and personal consumer goods, and meat/animal slaughtering industries. However, 15 industries from the food/processing/brewery/beverage, metal, meat/animal slaughtering, recycling, decorative, textile, and packaging sectors participated in the study (Table 4.1). Thus, this IA has a wide variety of industries. Mpoola, (2011); BCA (1999); Sajidu et al. (2007) assert that Makata IA is one of the largest and most active industrial areas in the city of Blantyre. In terms of the quantity of waste/byproducts generated per year, the meat industry generated the highest amount (approximately 1,200 tons/year) in the form of solid slaughterhouse waste, followed by food waste (approximately 570 tons/year), and slag and ash waste (approximately 400 and 300 tons/year, respectively). It was also discovered that fiber and medical waste were the least produced wastes from the industrial area. Other common wastes generated in the area include metal/steel, plastic, paper/carton, glass, spent grain, and textile waste (Figure 4.3). It was observed that the plastic and paper/carton waste were mainly packaging wastes. This scenario for plastic waste is attributed to the lack of more plastic-producing industries in this industrial area. The study revealed that the most dominant waste generated in this industrial area was plastic and metal/steel waste. Out of the 15 industries that participated in the study, 7 generated plastic waste and 5 generated metal/steel waste, respectively. The least dominant waste was glass waste.

In terms of waste management, it was observed that the most commonly employed practices were onsite dumping, reuse, recycling, and incineration. Similar to Chirimba IA, onsite dumping was practiced prior to collection by the city council or private waste collectors for disposal at the city council's landfill or before being sold or collected by other industries or individuals within and outside the industrial area for various uses or for incineration. Another waste management practice observed was treatment (Figure

4.4). The meat and animal slaughtering and textile industries have wastewater treatment plants for treating their liquid waste. The textile industry reuses the water it recycles from the plant, whereas the slaughterhouse liquid waste from the meat industry is treated before being emptied into the city's sewer lines. However, it was observed that some industries did not treat their wastewaters and instead emptied these effluents either into the city's sewer lines or into nearby streams and open drains. Kumwenda et al., (2012); Sajidu et al. (2007) confirm this by stating that the Nasolo and Mudi rivers, which are surrounded by industries in the city, are polluted by, among other pollutants, industrial effluents from the surrounding industries. On the other hand, it is worth reporting that industries that generate liquid waste in the form of used oils were selling it to other industries, such as metal and steel recycling industries, both within and outside Makata for heating. However, some oils were being dumped in open spaces and drains.

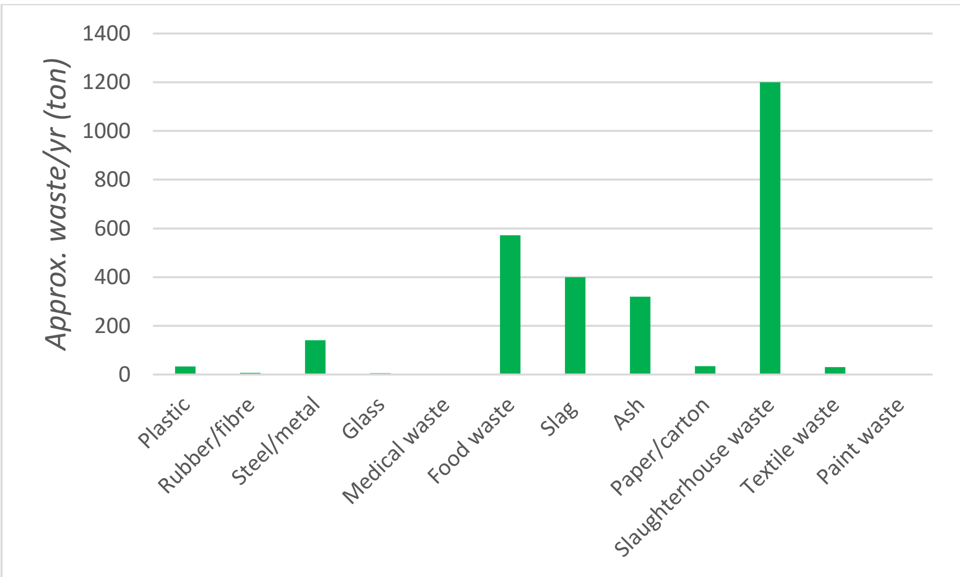

Figure 5: Figure 4.3: Waste generation in Makata industrial area

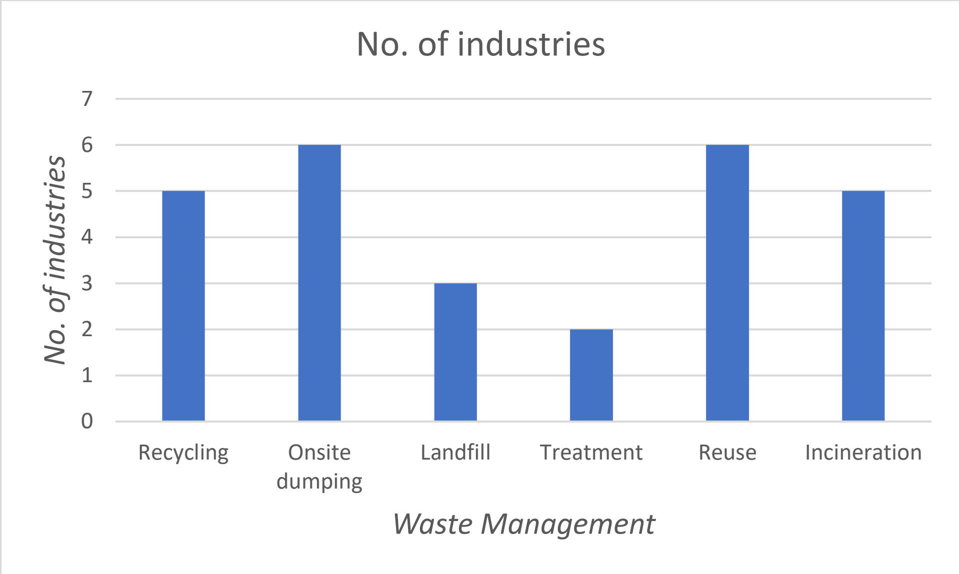

Figure 6: Figure 4.4: Waste management practices in Makata industrial area

4.2.5.3 Industrial characterization, waste generation and waste management for Maone industrial area

The study revealed that Maone industrial park is characterized by plastic, packaging, food/processing/beverage, construction, textile/home furnishing, dairy, metal/steel and pharmaceutical industries. This excludes service industries such as warehouses. However, dairy, pharmaceutical and some plastic industries did not participate in the study. As observed in Chirimba and Makata industrial areas, plastic waste was also the most dominating waste in this area. Out of 20 industries that participated in the study from this IA (Table 1.1), 11 industries reported to generate plastic waste. However, most of this waste was being generated as packaging waste as only two industries from the ten industries were plastic producing industries. The other common waste/byproducts generated in this IA were slag from metal/steel industries and food waste from food/processing/beverage. In terms of quantity of waste/byproducts generated per year, paper/carton, food and plastic waste were the highly generated wastes (approximately 865, 280 and 250 ton/year respectively) (Figure 4.5). Excluding being produced as packaging waste, the huge quantities of paper waste in this industrial was largely attributed to the presence of a carton manufacturing company. However, most of this waste is recycled into egg trays onsite. Apart from recycling, other waste management practices common in Maone industrial areas include onsite dumping, reuse, recycling, incineration and landfill (Figure 4.6). Like in Chirimba and Makata industrial areas, onsite dumping is done waiting for the waste to be collected for landfill dumping or sold or incinerated.

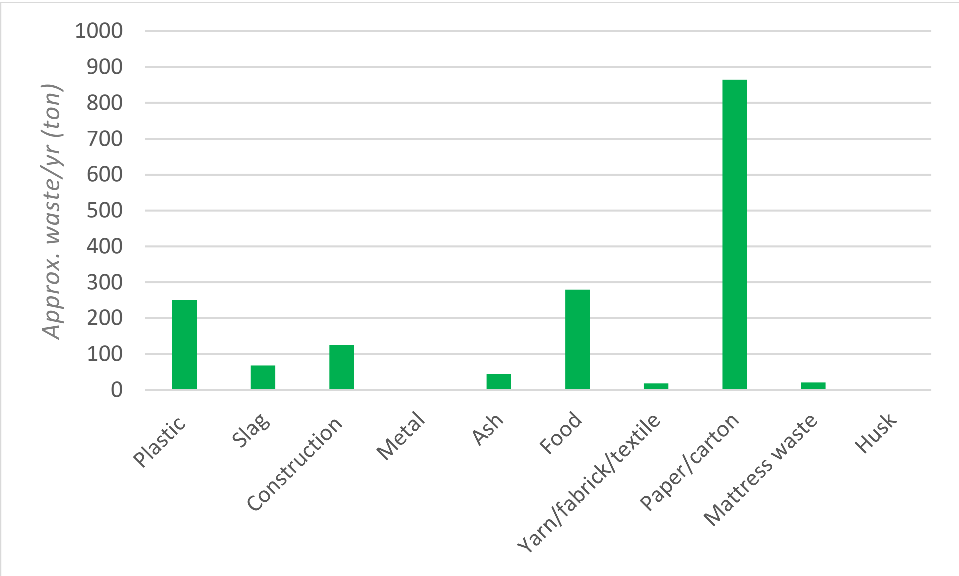

Figure 7: Figure 4.5: Waste generation in Maone industrial area

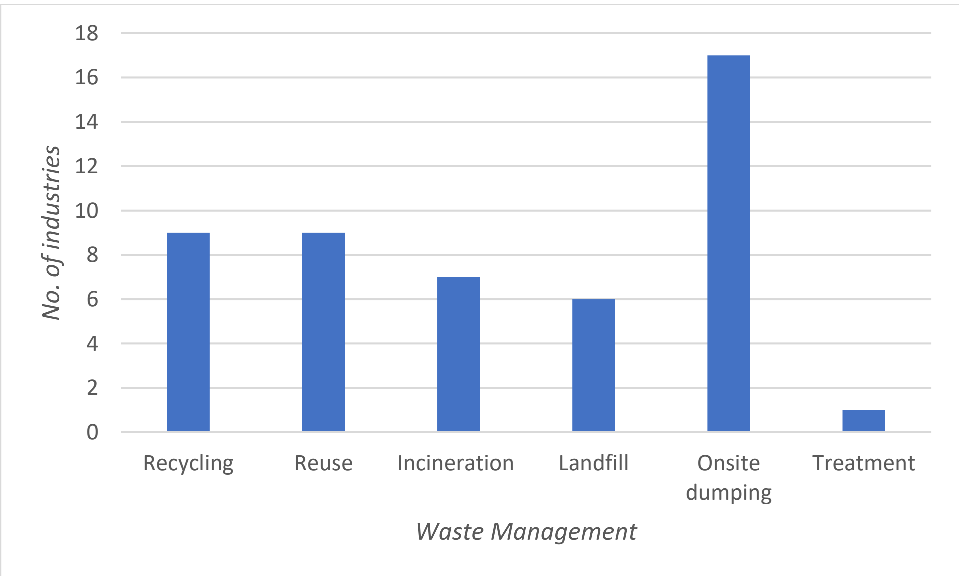

Figure 8: Figure 4.6: Waste management practices in Maone industrial area

The data obtained from these three industrial areas revealed a number opportunities for transitioning the city's industrial areas into eco-industrial parks, which could eventually contribute to turning the city into an eco-city.

Firstly, the study revealed that the city has diverse industries, which include construction, home and personal products, plastics, packaging, metal/steel, decorative items, food processing/beverages, breweries, meat/abattoirs, pharmaceuticals, and textiles, just to mention a few. This indicates the presence of different and steady waste streams for industrial symbiosis. Neves et al., 2019b; Patnaik & Poyyamoli, 2015; Ribeiro et al., 2018; Watkins et al., 2010) explicitly suggest that the presence of diverse industries is important for the establishment of industrial symbiosis, as it provides multiple opportunities for waste sharing.

There is already some presence of interrelationships among industries on matters beyond waste sharing, which can be beneficial in terms of the creation of eco-industrial parks. Blantyre City is composed of industries involved in similar production processes, such as clusters of food processing industries, plastic-producing industries, metal industries, and others. Neves et al. (2019b) argue that this phenomenon is responsible for the creation of infrastructure and service sharing among these industries, relationships that can aid in the development of industrial symbiosis. Some of the services shared and collaborative relationships among the industries include buying or borrowing raw materials among related industries, selling products to other industries (for instance, sacks from Propack are purchased by other industries for packaging their products), warehousing services among industries, collaboratively addressing safety and theft issues, and providing consultancy services among industries. Liu and Côté (2017) argue that the presence of already existing relationships among industries is a prerequisite for industrial symbiosis.

Furthermore, despite needing some renovations, there is a good road network connecting the industrial areas, which makes the transportation of waste between industries easy. This is in addition to the fact that most of the industries are situated near each other. The proximity of industries is thought to facilitate industrial symbiosis (Mouzakitis et al., 2017; Simboli et al., 2019). Long distances between industries involved in the sharing of waste can be detrimental to achieving economic benefits. Thus, the proximity of industries in the city would ensure that they make profits by using waste, which is significantly cheaper compared to virgin raw materials, and transportation costs are very low. In addition, engaging in waste-sharing relationships among nearby industries also promotes trust among the involved industrial actors (Neves, et al., 2019b).

Lastly, the city already experiences some degree of recycling and reuse, as well as some form of waste sharing among its industries. Patnaik and Poyyamoli (2015) highlight that the presence of existing industrial symbiosis helps in the expansion and addition of more synergistic relationships. This is because some of the prerequisites for establishing industrial symbiosis, such as communication channels, trust, and cooperation among industries, are already present (Liu & Côté, 2017; Neves et al., 2019b). However, it was also noted that some of the industries' waste was being taken up by the informal sector, including tinsmiths, farmers, and people from the surrounding industrial areas.

4.3 The potential for industrial symbiosis in Blantyre

4.3.1 Industrial symbiosis in Chirimba IA

The study revealed that there was little sharing of waste among the industries located within the industrial area. Of the sixteen industries that participated in the study, the only registered symbiosis was between Propack and Aero Plastics, in which Propack reported selling its plastic waste to Aero Plastics for recycling. On the other hand, it was observed that some industries shared their waste and byproducts with industries outside Chirimba, with Natpack selling its crude oil to an oil refining industry being the only established case. The findings thus showed that industrial symbiosis in this area was in its infancy.

However, the study established that the majority of the industries share their waste and byproducts with the informal industry (Table 4.3). Steel waste is mostly collected by tinsmiths and other casual steel recyclers. Food waste and other biodegradable waste are mainly collected by farmers and surrounding communities for food, animal feed, and manure production. Construction waste, such as dust, waste cement blocks, and waste bricks, is collected by people for construction purposes.

Table 4. 3 Waste sharing in Chirimba industrial area

Name of industry	Symbiosis
Flexible packaging	Carton manufacturing industry sends its waste carton to the egg tray manufacturing industry within the premises
Patson produce	Residues are collected by farmers for animal feed and manure production
Natpack	-Sells crude oil to cooking oil refining companies -Soya pieces waste is collected by farmers for animal feed and manure production
Automotive truck bodies	Sells metal scraps to informal metal recyclers
VAZA	Sells maize bran to people and farmers for food and animal feed
Parklane industries	Casual business groups collect plastic wastes for free
Propack	-Waste sack and mesh weighed and sold to other plastic manufacturing companies for production of recycled plastic containers -Waste sacks sold to people for various domestic uses
Terrastone and Ceramic company	-Ash collected for free by people from the surrounding communities for manure production -Empty cement bags collected by workers and people from the surrounding communities for various domestic uses

	-Brick rejects collected by other construction industries and people from the surrounding communities for construction purposes -Dust from recycling of cement blocks and pipes is sold to other construction companies and the people from the surrounding communities for road construction
Durabrick	Concrete block rejects are crushed and reprocessed or sold to the other construction companies and the surrounding communities
Aero plastics	Casual business groups collect plastic waste for free
Cable Manufacturers	Copper and aluminium waste is sold to mines
Mkango Allied Ltd	-Waste steel is sold to casual business people such as tin smiths -Sold to people for roofing

4.3.1.1 Onsite symbioses

Flexible Packaging, which makes cartons (though it was not operational during the time of data collection), had another subsidiary company on its premises that manufactured egg trays from waste cartons. This ensured that no waste paper was generated by the packaging industry. In addition, at Natpack, soya cake generated from soya pieces production was being recycled into animal feed and sold to farmers. Shi & Chertow, (2017) acknowledged the importance of onsite symbiosis in their study of a sugar industry in China—the Guitang Sugar Company—which, through onsite symbiosis, was able to reuse its waste in other production processes, thereby achieving, among other things, environmental benefits through the reduction of waste generation and pollution. For instance, it was discovered that the molasses from sugar production were being used in alcohol production, and sugarcane's fibrous byproducts were used in pulp and paper production, just to mention a few.

4.3.1.2 Other forms of symbioses

These are interrelationships among industries apart from those related to waste or by-product sharing. The study revealed the following symbioses: the buying or borrowing of raw materials among related industries, the selling of products to other industries (for instance, sacks from Propack were being purchased by other industries for packaging their products), the sharing of warehousing facilities among industries, and lastly, the collaborative tackling of safety and theft issues. According to (Liu & Côté, 2017; Neves, et al., 2019b), the presence of already existing relationships among industries is crucial in the implementation and promotion of industrial symbiosis.

4.3.1.3 Suggested symbioses within and outside Chirimba IA

The data obtained from this IA exhibited opportunities for additional industrial symbioses. Wood ash could be used as a cement replacement material. The Terrastone and Ceramic Industries generate wood ash, which could be used to partially replace the cement in their concrete block manufacturing. The Durabic Industry could also obtain the ash from the Terrastone and Ceramic Industries for its concrete block manufacturing. According to (Chowdhury et al., 2015; Elahi et al., 2015; Ramos et al., 2013), by correctly blending wood ash with cement, concrete blocks with acceptable strength properties can be achieved. (Martínez-García et al., 2022) thus recommend that waste wood ash can be utilized as a cement-substitute construction material, thereby reducing the demand for cement, which will consequently reduce the pressure on natural limestone reserves and also decrease greenhouse gas emissions from cement production.

Plastic waste produced by Aero Plastics, Parklane, Pipeco, Flowtech, Yangtse, Bakeman's and Propack could be utilized by Durabric, Terrastone, and Ceramic Limited for the production of construction materials. According to Maitlo et al., 2022), this can be achieved in two ways. Firstly, the crushed plastic can be used as a binder. This involves mixing the shredded plastic with fillers such as sand, fly ash, rubber, and wood particles. The mixture is then melted, molded, and cooled into tiles, paver blocks, or bricks. Secondly, the shredded plastic can be used as a filler, whereby the plastic materials are mixed with water, cement, and admixtures before being pressed and cured into cement or concrete. Maitlo et al. (2022) summarized different studies on the application of plastic waste in various construction activities, which can be useful in creating sharing routes for plastic waste with the construction industry. In this study, he compiled different proportions of plastic waste that can be applied in construction (pg. 12-13). This can be useful in implementing the industrial symbiosis involving the use of plastic waste in the construction industry.

Kumi-Larbi Jnr et al. (2023) also suggest another application of plastic waste in the construction industry. They reported that shredded plastic waste could be melted and mixed with sand to be molded into light and durable interlocking blocks. In a similar project, Harem and Lugenthram (2023) found that adding coarse aggregate to a molten polypropylene (PP) plastic-fine sand aggregate mixture in the ratio of 2:1:1 (plastic: coarse aggregate: fine aggregate) achieved the strongest interlocking blocks. Thus, Malawi's construction industry can fully utilize these discoveries, thereby addressing the environmental and waste management problems caused by plastic waste. However, Harem and Lugenthram stressed the need for proper plastic melting technologies, as melting plastic emits harmful gases into the atmosphere.

The study revealed that Encor Products, located in the Makata industrial area, sold its scrap steel to Agrimal within the industrial area for the production of bolts, nuts, and hoes. Therefore, apart from selling their scrap metals to informal metal recyclers, Automotive Track Bodies in the Chirimba industrial area could also sell their heavy steel waste to the Agrimal Industry.

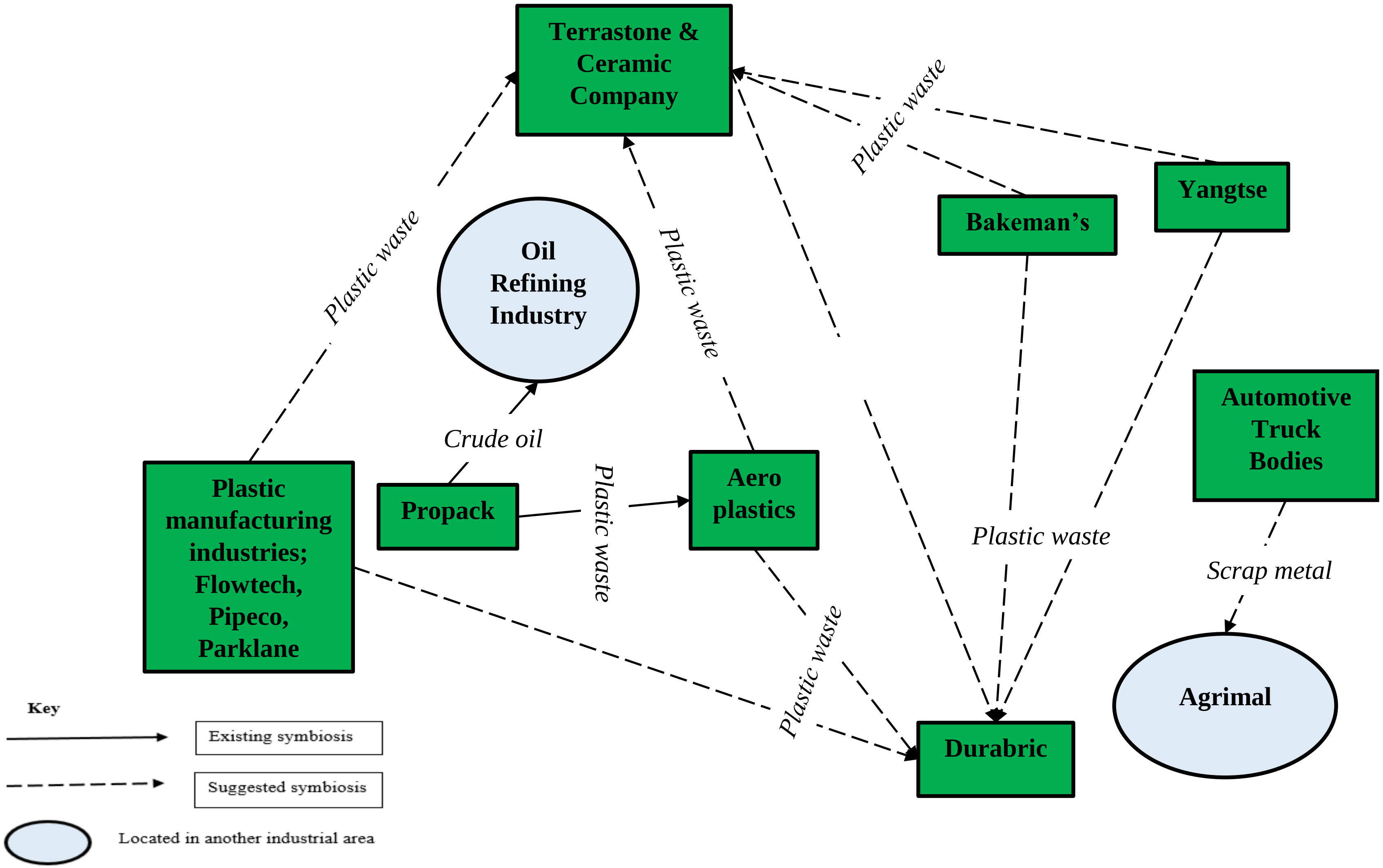

Figure 9: Figure 4.7 Industrial symbioses for Chirimba industrial area

4.3.2 Industrial symbiosis in Makata IA

The study revealed that there is sharing of waste both among industries and with informal industry such as recyclers. Similar to the Chirimba IA, most industries in Makata IA share their waste and by-products with informal industry such as farmers and metal and plastic recyclers (Table 4.4).

Table 4. 4 Waste sharing in Makata industrial area

Name of industry	Symbiosis
Safintra	Metal scraps sold to informal recyclers eg tinsmiths
BNC Packaging	Waste plastic eg polypropylene ropes and brush bristles are sold to local people for various uses
King Steel Malata	Metal scraps sold to informal recyclers eg tinsmiths
General Tinsmith	Metal scraps sold to informal recyclers eg tinsmiths
Encor Products	Steel off cuts is sold to Miscor (Agrimal) industry within the industrial area for bots, nuts and hoe blade manufacturing
Plascon Paints Company	-Damaged plastic tins are sent to Arkay Plastics and OG Plastics for recycling -Waste paper is collected by people from the surrounding communities for various uses -Waste tins collected by people for various uses
Miscor	Apart from dumping into one of its farms in Chileka, some of the slag is collected onsite for roads maintenance by people or road construction companies
CK Cold storage	-Animal parts such as head skin are sold to people for food -Sediments from the treatment plant and all organic waste including excreta from the kraals is sold to people for manure production
Castel Malawi Limited	-Glass waste is occasionally collected by a Kenyan company for recycling. Most of the glass waste is dumped into the landfill -Medical waste from the industry’s clinic incinerated at Queen Elizabeth Central Hospital -Spent grain collected by farmers for animal feed -Used oil sold to steel companies eg Agrimal for heating metals -Waste tyres are sent to their supplier for retreading

	-Broken crates are sent to Arkay Plastics for recycling -Coal ash is collected by people and road construction companies for road filling
Candlex	-Plastic waste is collected by informal waste recyclers eg Achewa Investments -Used oil is sold to metal industries Euro Alliance Aluminium -Papers and pieces of carton are sold to Flexible packaging for egg tray manufacturing
Mapeto (DWSM) Ltd	-Cotton waste collected by egg manufacturing industries. -Waste yarn collected by people for mops making, -Fabric off cuts collected by people for handbag sewing

However, a few industrial symbiosis cases between formal industries were also recorded. Castel Malawi Limited shares its waste with industries such as Arkay Plastics, Mapeto Tyres, and Agrimal. It was reported that Castel Malawi Limited has an agreement with Arkay Plastics regarding plastic waste. Apart from sending used oils to Agrimal for heating, it was reported that the broken plastic crates generated by Castel Malawi Limited were being taken by Arkay Plastics for the production of various recycled plastic products, including crates. The recycled crates were then sent back to Castel Malawi Limited for use. In this way, Castel Malawi Limited gets its broken plastic crates recycled, while Arkay Plastics obtains raw materials for the production of assorted recycled plastic products. In addition, waste tyres produced by Castel Malawi Limited were being sent to their supplier, Mapeto Tyres, for retreading. Conversely, the brewery industry lamented the inability to send back glass waste to their supplier for recycling, leaving them with no alternative but to dump it into the city's landfill, despite how dangerous and hazardous this practice is. It was, therefore, noted that more research needs to be done to explore how glass waste can be a useful material, as apparently, no glass recycling is done in the country. However, it was revealed that a certain cement-producing company in the country once collected glass waste from the brewery for cement production. Nevertheless, there has been no feedback since then. This indicates that lobbying the cement production industries to explore the usefulness of such waste can play a significant role in the management of glass waste in the city and in the country of Malawi as a whole. Xie and Xi (2002) assert that glass waste can be used in cement production. Furthermore, Castel Malawi Limited lamented that the city's industrial waste treatment plant is in poor condition, which puts both the people and the environment at risk, considering that their hazardous wastewater enters the city council's sewer system. This aligns with what (Collet et al., 2016) highlighted in their study: that Blantyre City lacks sufficient wastewater treatment plants, as the majority of these facilities are either not functional or require extensive maintenance.

Other notable industrial symbioses that were discovered were between Encor Products and Miscor (Agrimal). It was found that the former was selling its steel waste to the latter for bolt, nut, and hoe blade manufacturing. In addition, waste paper and cartons generated by Candlex were being sold to Flexible Packaging of Chirimba IA.

4.3.2.1 Other forms of symbioses

Aside from the industrial relationships involving the sharing of waste and byproducts, the following symbioses were discovered: purchasing packaging materials from other industries within the industrial area. For instance, Lai Lai reported that they were obtaining their packaging materials from Blantyre Netting Company (BNC); consultancy services between steel/roofing companies and building contractors and engineering companies; and lastly industries reported engaging each other in security and emergency preparedness.

4.3.2.2 Suggested symbioses within and outside Makata IA

Paint waste can be used as a source of polymers for concrete and mortar production (Noruzman & Mohd Apandi, 2020). Polymers are added to paints during their manufacturing process to enhance film continuity, adhesion to surfaces, quick drying, and discoloration prevention. Polymer waste, along with expired or waste paints, can be utilized in the construction industry to add value to concrete and bricks as admixtures (Avci et al., 2017; M. Ismail et al., 2011; Z. Z. Ismail & Al-Hashmi, 2011; Nehdi & Sumner, 2003; Noruzman et al., 2013). These studies reported that paint waste increases the durability of concrete and its resistance to water and chemical penetration. Mostafa and Peters (2017) add that paint waste can also be used in brick and tile-making. This not only improves the strength of the bricks but also makes transportation easier, as they tend to be lighter than normal bricks. From these studies, it can be established that waste paint and wastewater generated by Plascon Paints Company and other paint industries in the city could be shared with construction companies such as Durabrick and Terrastone and Ceramic Company Limited in Chirimba IA, instead of being dumped into the city's landfill and sewage lines.

Despite glass containing a higher concentration of alkalis, which leads to the expansion of concrete blocks made from glass waste (Matos & Sousa-Coutinho, 2012), they affirmed that if finely ground to less than 300 μm, the expansion issue can be addressed, thus making glass waste a viable option in the construction industry. The two researchers also reported that alternatively, the expansion could be mitigated by incorporating other pozzolanic materials into the mixture, such as coal fly ash. In a literature review conducted by Mohajerani et al. (2017), it was confirmed that fine glass powder can be used as a cement replacement in concrete production. Specifically, the optimum cement replacement was found to be 10%. Therefore, the glass waste and coal ash waste produced by the Castel Malawi Limited could be utilized by construction companies such as Durabrick and Terrastone and Ceramic Company Ltd in Chirimba IA.

According to Xie and Xi (2002), glass waste can also be used in cement production by substituting a portion of clay in the cement manufacturing process. In their experiment, Xie and Xi found that adding glass to the cement raw materials altered the clinker properties, resulting in the formation of a more liquid phase between 950 and 1250 degrees Celsius compared to conventional raw meals, and the product was fast-setting cement. However, it was discovered that this issue could be addressed by increasing the specific gravity value of the clinker, leading to the production of cement from glass waste that is similar to ordinary cement. Therefore, the glass waste generated by industries such as Castel Malawi Limited can be utilized by any cement-producing company within or outside Blantyre city.

Castel Malawi Limited also produces large quantities of spent grain. This could be utilized by CK Cold Storage and other meat industries for animal feed purposes. In a study conducted by Madanhire and Mbohwa (2016), it was suggested that the waste grain produced by the GMB food processing company could be used as stock feed by Feedmix Company. This aligns with Mussatto et al. (2006) who highlights that the main application of brewery spent grain is as animal feed due to its high content of protein and fiber, which leads to increased milk production and improved fertility. Furthermore, Mussatto et al. (2006) also suggests that the spent grain can be milled into baking flour and used in bakery products such as bread, biscuits, and flakes. Therefore, the spent grain produced by Castel Malawi Limited could be utilized by the baking and confectionery industries in the city, such as Bakeman's Confectioneries and Universal Industries.

Coal ash and slag produced by Castel Malawi Limited and Agrimal industries can be utilized by the construction industry, including cement-producing industries, Terrastone and Ceramics Company, and Durabric Company, for concrete block manufacturing. In addition, the road construction industry can also take advantage of the opportunity to incorporate the ash into their projects. Madanhire and Mbohwa (2016)) argue that fly ash improves road quality by enhancing the properties of hardened concrete through hydraulic activity.

Waste tyres and tyre shreds from Castel Malawi Limited and Mapeto Tyres could be sent to construction companies such as Terrastone, Ceramic Company Limited, and Durabric Company to be used as aggregate for making concrete blocks. In a comprehensive review of waste tyre applications in concrete/mortar as a fine aggregate replacement, Hasan et al. (2024) reported that when used in correct concentrations, crumb rubber could be a useful fine aggregate substitute in concrete or mortar, leading to the production of mechanically strong concrete with high resistance to water, acid, chlorides, abrasion, and low temperatures.

(Briga-Sá et al. 2013) acknowledged studies conducted by various authors on the application of textile waste in the construction industry. They reported that textile wastes could be used in the production of lightweight concretes and cement bricks by combining the textile wastes with materials such as limestone powder, fly ash, barite, and paper (Algin & Turgut, 2008; Aspiras & Manalo, 1995; Binici et al., 2012; Rajput et al., 2012). Thus, textile waste generated by textile industries such as Mapeto DWSM can be utilized by construction industries such as Terrastone, Ceramic Company, Durabric in Chirimba IA, and Global Concrete in Maone IA.

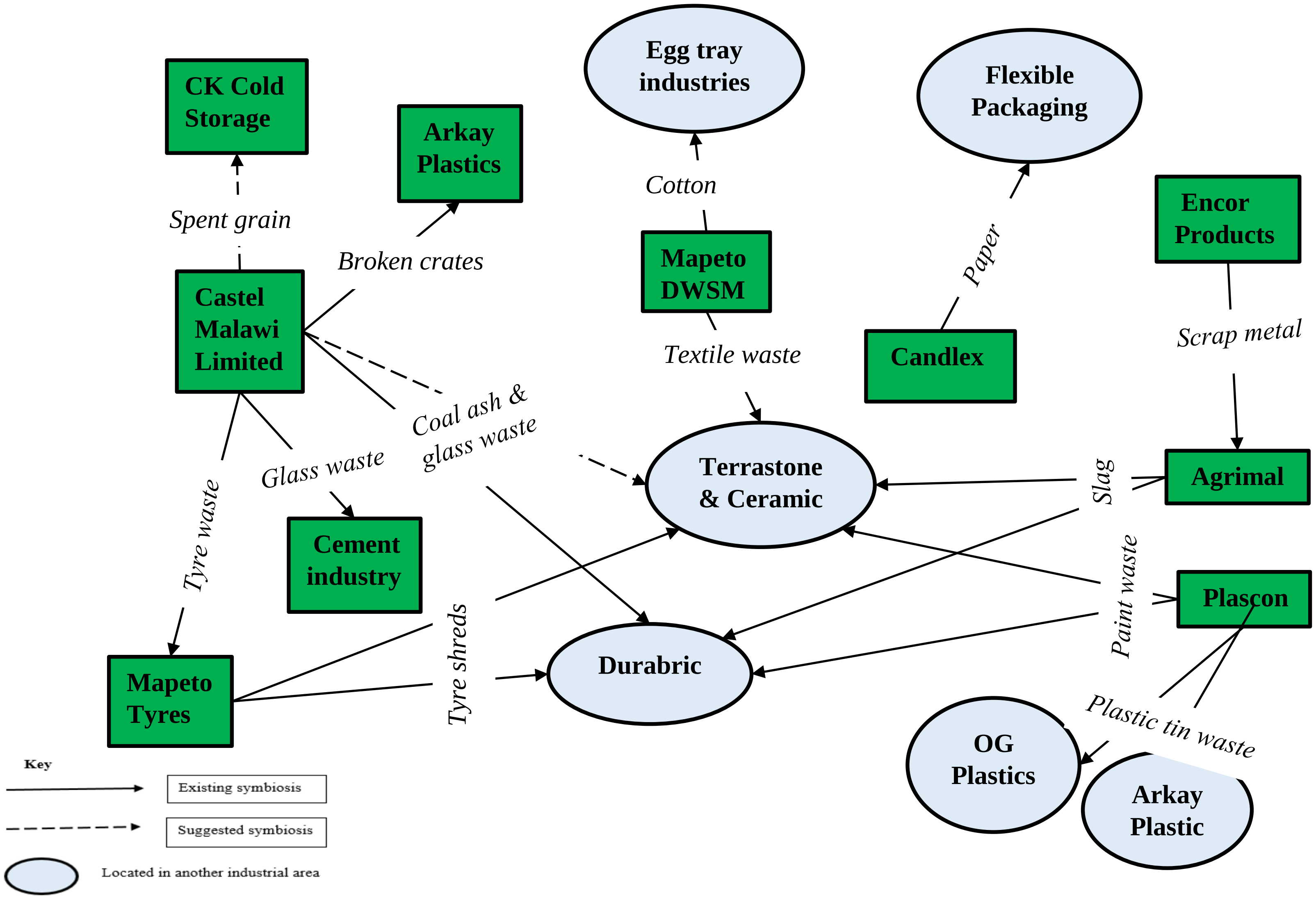

Figure 10: Figure 4.8 Industrial symbioses for Makata industrial area

4.3.3 Industrial symbiosis in Maone IA

The study revealed that there is sharing of waste both among industries and with informal sectors such as recyclers. However, sharing of waste and byproducts with the informal industry is a dominant practice. Amani Industries and Mellet Enterprises sell their plastic waste to GM Plastics, located within Maone IA, which recycles it into various plastic items. Crude oil produced by Rab Processors is sold to Capital Oil Refining Industries, located outside the industrial area. Waste cartons from Kris Offset are sold to Flexible Packaging in Chirimba IA, and lastly, waste plastic bottles generated by Mother Foods are sold to plastic manufacturing industries in Chirimba IA.

The majority of the industries, however, share their waste and by-products with the informal sector (Table 4.5). For instance, plastic waste generated by some industries in this industrial area is collected by individuals who, in turn, sell it to plastic recycling companies located both within and outside the Maone industrial area. The food waste and other biodegradable waste are mainly collected by farmers and surrounding communities for sale and/or for use as food, animal feed, bedding, and manure production. Crude oil produced by Rab Processors industry is sold to vendors who refine it before it is sold for consumption, while yarn waste is sold to sofa and mop makers. However, heaps of ash waste and slag were seen in various metal industries.

Table 4. 5 Waste sharing in Maone industrial area

Name of industry	Symbiosis
Alif	People collect slag for road filling
Vitafoam	-Decontaminated plastic drums sold to people -Excess plastic sheets are cleaned and sold to people who sell to plastic recycling industries
Mellet Enterprise	-Plastic bottles collected by GM Plastics industry within the industrial area for recycling -Plastic sheets and carton waste collected by people for sale and other uses
Sheet Metal	Copper waste sold to companies for pallet manufacturing
Global Concrete	-Collected by people for road filling and construction -Empty cement sacks collected by people for various uses
Premium Foods	People collect broken snacks and plastics sheets for sale
Rab Processors	-Crude oil sold to Capital Oil Refining Industry in Chirimba IA -Rejects sold to people for animal feed
Exports Trading	-Husks sold to Issa in Ngabu for animal feed -Dal powder and rejects sold to people for food/sale
Kris Offset	-Waste carton is sold to Flexible Packaging egg tray manufacturing company in Chirimba IA -Buys waste cartons from other shops eg Sana when they've a higher demand for egg trays
Mother Foods	-Waste plastic bottles sold in Chirimba IA for recycling by plastic manufacturing companies -Cartons and plastic sheets bought by people -Crude oil sold to vendors for refining
Fadamz	-People buy bran for baking and husk for poultry feed, beds and manure production
Bowler Beverage	Plastic sheets are collected by workers on the industry for sale to plastic recycling industries Residual water used by farmers for irrigation
Amani	Waste plastic jars are sold to plastic recycling companies eg GM which is found within the industrial area
Nu-Line	Yarn waste sold to sofa and mop makers
Simba	Buying waste cartons from other shops and local people when they've a higher demand for egg trays
OG Plastics	-Receiving empty plastic bottles from hotels from within the city -Used oils sent to other industries for heating

4.3.3.1 Onsite symbioses

Kris Offset and Simba Packaging Industry reported that they recycle the carton waste from the carton-making process into egg trays onsite. Another example of onsite symbiosis was recorded at Rab Processors, which reported processing the soya pieces residues into animal feed.

4.3.3.2 Other forms of symbioses

These are interrelationships among industries apart from those to do with waste or by-products sharing. The study revealed the following symbioses:

- Buying or borrowing raw materials from a related industry
- Warehousing

4.3.3.3 Suggested symbioses within and outside Maone IA

Plastic waste produced by plastic-producing industries and by all the industries that generate it as packaging waste can be sold to construction industries (Maitlo et al., 2022) within the city, such as Durabric, Terrastone, and Ceramic Limited in Chirimba IA, or Global Concrete in the same industrial area, for the production of construction materials like concrete, paver blocks, bricks, or tiles.

Likewise, slag and coal ash produced by metal industries such as Alif, Haroon, and Auhad can be sold to these construction industries for concrete manufacturing. It was also noted that some metal recycling industries co-combust coal and waste tyres when melting scrap metals. This was evident through heaps of tyre ash waste, tyre wires, and coal waste on-site. It is worth noting that due to the chemical composition complexity of tyre rubber, tyre combustion leads to the emission of toxic compounds, including carbon monoxide, sulfur oxides, and volatile organic compounds (Czajczyńska et al., 2020; Giere et al., 2006) report that co-combusting coal with tyre rubber results in an increase in metal emissions, especially zinc and hydrochloric acid, with a slight decrease in carbon monoxide concentration. (Z. Zhang et al., 2021) warn that the zinc that volatilizes during combustion is less compared to the concentration that binds to the ash, which can lead to soil and water contamination if the ash is not properly managed. Another drawback of this ash is that it cannot be used as a replacement or reduction of cement in concrete block making, as it results in the production of thin blocks with reduced compressive strength (Harmiyati et al., 2021). However, Shahidan et al. (2021) argue that when river sand is replaced by up to nine percent during concrete making, tyre crumb and ash can achieve desirable concrete characteristics.

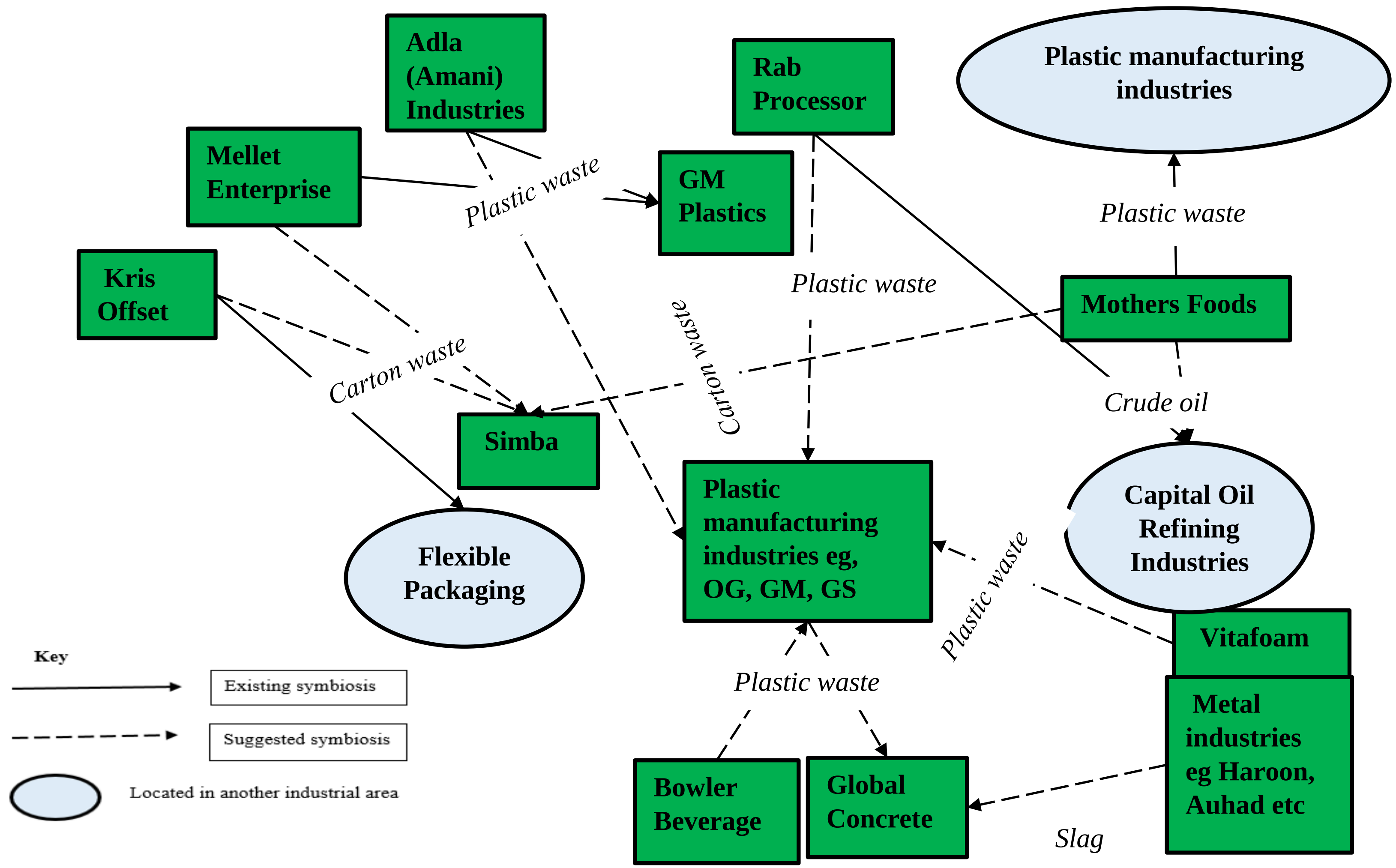

Figure 11: Figure 4.9 Industrial symbioses for Maone industrial area

4.3.4 The suggested solid waste sharing pathways for Blantyre City

The symbiotic relationships revealed in the three industrial areas show that there is potential for turning Blantyre City's industrial areas into eco-industrial parks. As discussed in section 4.1.5, the presence of already established relationships among the industries regarding the sharing of materials, services, and waste or byproducts, coupled with the presence of road networks connecting the industrial areas, recycling and reusing practices, and the existence of diverse waste streams, could be key in promoting more industrial symbiotic relationships and thus aid in transitioning the industrial areas into eco-industrial parks.

The study showed that there are a number of waste-sharing pathways for the city of Blantyre that can be implemented. Some of these pathways have been suggested and summarized in Figure 4.10. Some of these symbioses include; more options for sharing of plastic wastes among plastic manufacturing themselves and the construction industry, sharing of slag, fibre/rubber waste, paint waste and ash to the construction industry for concrete, roads, ceramics, and cement blocks/bricks, sharing glass waste to the cement manufacturing industries and the construction industry for cement and concrete blocks production, spent waste to meat industry for animal feed. These symbiosis scenarios are in addition to other forms of industrial symbioses that were revealed include; warehousing, consultancy, buying/borrowing of raw materials and collaborative efforts on matters such as theft and safety, among others.

On the other hand, aside the plastic, construction, glass, metal and slag waste, the rest is organic waste, which is generated in large quantities. In addition to that, Malawian cities' wastes composition is generally dominated by organic wastes (Chinyepe et al., 2022). This indicates that there is a huge opportunity for scaling up organic fertilizer production as a huge amount of municipal organic solid waste is not tapped. Spent grain from the breweries, sludge, manure and livestock waste from the meat industry, paper/carton, fly ash, textile and food waste together with all the industrial and municipal organic wastes generated all over the city of Blantyre thus can be composted and/or vermicomposted to produce fertilizers that can help in addressing problems farmers in Malawi face to access the expensive chemical fertilizers and prevent pollution due to heavy use of chemical fertilizer.

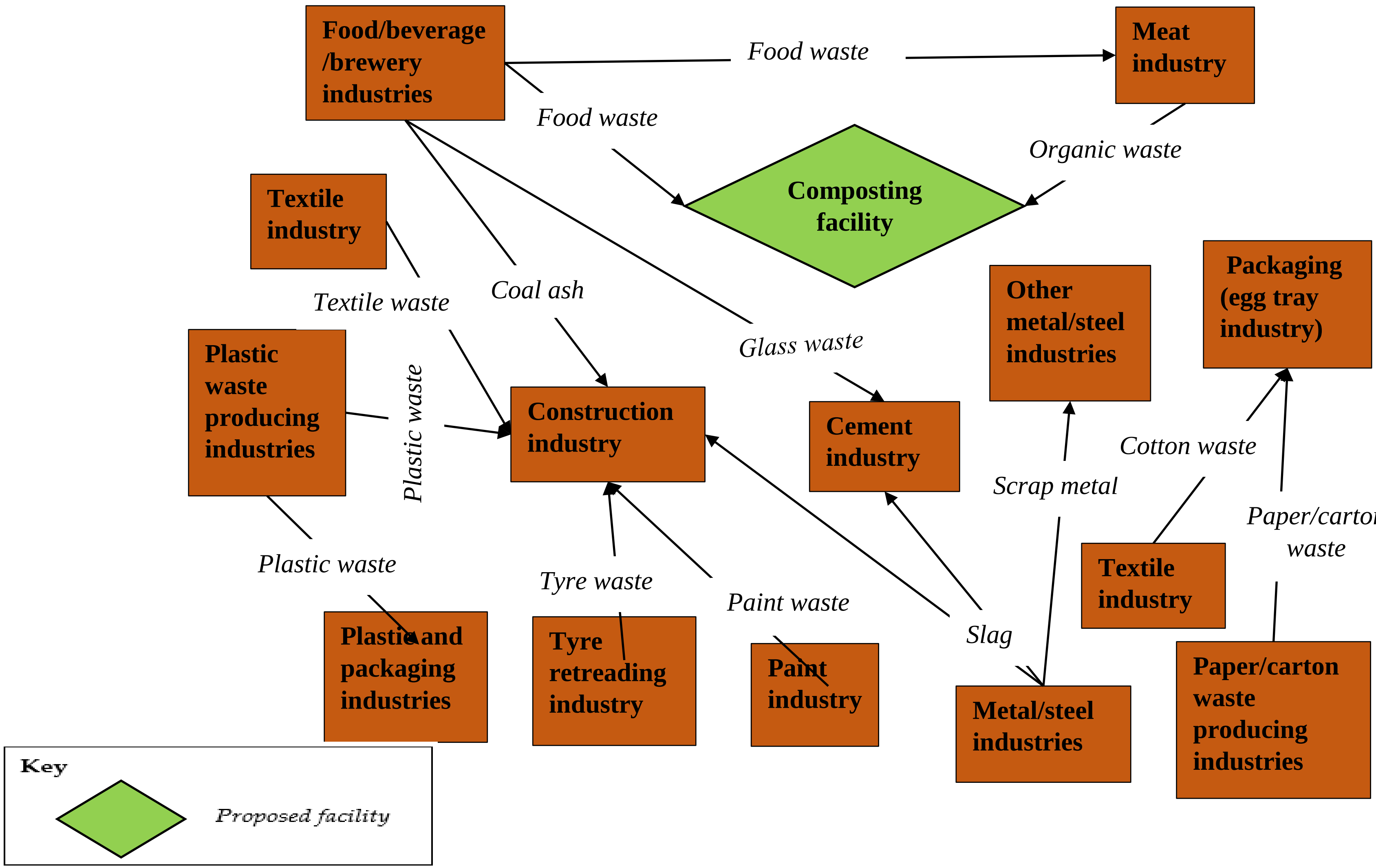

Figure 12: Figure 4.10 Proposed waste/byproducts pathways for Blantyre City

4.3.4.1 Proposed facility: Organic fertilizer industry

This study revealed that, aside from plastic, construction, glass, metal, and slag waste, the rest of the solid waste was organic waste. Adeyemi and Adeyemo (2007) reiterate that slaughterhouses/abattoirs generate enormous quantities of organic waste. Mozhiarasi and Natarajan (2025) concur with Adeyemi and Adeyemo, highlighting that slaughterhouse waste is primarily composed of rumen, which accounts for 80 percent of animal weight, and dung/manure, which constitutes 12 percent, while other wastes make up 5 and 3 percent of the animal weight, respectively. The study revealed that at most 41 animals were slaughtered per day, which translates to considerable tons of organic waste in this regard. Additionally, Chinyepe et al. (2022) assert that the waste composition of Malawian cities is generally dominated by organic waste, with Blantyre City's waste composition as follows: 79 percent organic waste (which aligns with the findings of this study, which showed that the most overall dominating waste is organic in nature), 7 percent plastic waste, 5 percent paper waste, 1.5 percent metal waste, 0.5 percent glass waste, and 7 percent for other forms of waste. However, literature shows that the Blantyre City Council has only two compost facilities. These facilities collect organic waste from the markets within the city. One facility is in Limbe, which receives organic waste from Limbe Market (Chinyepe et al., 2022), and the second facility collects waste from four other markets (Waste Advisers, 2018). This indicates that there is a significant opportunity for scaling up organic fertilizer production, as a large amount of municipal organic solid waste is not being utilized. Therefore, the spent grain from breweries, sludge, manure, and livestock waste from the meat industry and the WWTPs, as well as paper, cardboard, fly ash, textiles, and food waste, along with all the industrial and municipal organic waste generated throughout the city of Blantyre, can be composted and/or vermicomposted to produce fertilizers. These fertilizers can help address the challenges that farmers in Malawi face in accessing expensive chemical fertilizers. Additionally, the organic fertilizers produced from this biodegradable waste are environmentally friendly, as they do not release hazardous chemicals into the environment, thereby contributing to environmental conservation. According to Jack (2024), composting is a form of green technology, which is an environmentally friendly initiative to address the ecological consequences of chemical fertilizers. In addition to the environmental benefits, if implemented in the city through industrial symbiosis initiatives, the composting facility will create employment opportunities for people within the city, especially in informal settlements, where the majority are unemployed (SDI, n.d.). (De Gobbi, 2022) cites the Grangemouth and Dunkirk symbiosis initiatives in Scotland and France, respectively, as industrial symbiosis initiatives that were implemented for job creation for the local communities.

4.3.5 The suggested water symbiosis for Blantyre City

The presence of heavy metals in the liquid waste samples analyzed in this study indicates a need for proper management if pollution of the environment due to heavy metal contamination and other contaminants is to be addressed. Among other strategies, industrial symbiosis could be considered. In response to the water stress that the Kalandborg and Kwinana industrial areas were facing, they turned to implementing water synergies among the industries. This helped address the water shortage challenges and led to the realization of economic and environmental benefits (Domenech & Davies, 2011; Ramin et al., 2024a). However, like solid waste industrial symbiosis, Malawi’s literature lacks any information on water symbiosis practices despite being a country facing an unreliable water supply for both domestic and industrial use and significant liquid waste management challenges. According to van Beers et al. (2007), water symbiosis innovations fall into two main types: utility sharing and byproduct exchange (Ramin et al., 2024a) highlights that utility sharing is practiced when industries are involved in (i) sharing utilities that act as alternative sources of water to address water shortage challenges. Such facilities may include those used for extracting, reclaiming, cooling, desalination, and treating surface water, and (ii) sharing facilities aimed at preventing wastewater pollution, such as water treatment plants. On the other hand, byproduct exchange, as the name suggests, involves the sharing of byproducts from or to be used in wastewater treatment. This is practiced through (i) water recovery from wastewater for reuse by the industries and (ii) energy recovery, for example, biogas and biofuel production from water treatment plant sludge. (iii) Material recovery, such as fertilizer from wastewater treatment plant sludge, and (iv) material exchanges aimed at enhancing the performance of a wastewater treatment plant, such as spent acid from chemical industries taken up by the wastewater treatment plant for wastewater neutralization. Reflecting on these categories of water symbiosis innovations can be of great help in suggesting the water symbiosis pathways for Blantyre City.

The study revealed a few scenarios involving water symbiosis that are already in practice. These include industries emptying their wastewater into the city's WWTPs via the sewer lines, farmers obtaining wastewater for irrigation from the city's WWTPs and/or directly from the industries that generate the wastewater, and farmers obtaining sludge from CK Cold Storage for manure. However, there were no cases of utility sharing among the industries.

According to this study, two industries, CK Cold Storage and Mapeto DWSM Limited, reported having water treatment plants that treat their wastewater. After treatment, the water is then emptied into a sewer line leading to the Blantyre WWTP for conventional wastewater treatment processes (Chipofya et al., 2010). Nearby these industries are Castel Malawi and Candlex Limited. These industries do not have water treatment plants, which poses a number of challenges for liquid waste management. The presence of wastewater treatment plants at CK Cold Storage and Mapeto DWSM thus provides an opportunity for facility sharing and symbiosis among these four industries, a phenomenon that could contribute to the release of pretreated effluents into the sewer line leading to the city's WWTPs. The study revealed that the treated wastewater collected from CK Cold Storage registered concentrations of heavy metals below WHO guidelines, with cadmium being the only heavy metal present at a slightly high concentration of 0.006 mg/L (Table 4.2). This signifies the importance of having a wastewater treatment plant in terms of preventing effluent pollution. Thus, Candlex Malawi Limited and Castel Malawi Limited can benefit from these facilities, while the owners of the facility can reap economic benefits.

Another suggested water symbiotic relationship could be between Bowler Beverage and Kris Offset, which makes cartons and egg trays. According to Ramin et al. (2024b), the pulp, paper, and paper products industry is one of the most water-intensive industries; as such, the residual water generated by Bowler Beverages can be shared with the Kris Offset industry, considering their proximity as well. This would help the receiver industry to cut on water bill costs, while the sender industry will reap economic benefits. However, there is a need to establish the suitability and usability of the residual water generated by the beverage industry in the process of carton and egg tray manufacturing.

Sewerage is considered the greatest industry in water symbiosis, as it is regarded as a water recovery facility, the main receiver of material exchange for enhancing treatment, and an energy recovery exchange facility (Ramin et al., 2024b). According to Blantyre City, the two treatment plants at CK Cold Storage and Mapeto DWSM Limited, along with the city’s wastewater treatment plants and other wastewater treatment plants in industrial areas that did not participate in this study, can be considered sources of sludge that can be collected and used in biofuel/biogas generation and fertilizer manufacturing. This symbiosis falls under the category of byproduct exchange in water industrial symbiosis (Ramin et al., 2024b). The current situation is that the city's wastewater treatment plants generate considerable amounts of sludge. Tapping into this byproduct thus provides an opportunity for implementing energy generation innovations through the production of methane gas for electricity or sludge compost for organic fertilizer production. This could potentially help to ease the electricity challenges facing the city and the industrial sector and provide a lasting solution to the ever expensive and environmental unfriendly chemical fertilizers.

However, the study revealed two challenges to the implementation of water symbiosis. Firstly, there is a lack of WWTPs at both industry and city level. The city's WWTPs are insufficient and inefficient. This implies that the water that leaves the plants is partially treated, which makes it not a viable option for industries to get its water for production from the WWTPs. On the other hand, lack of these facilities at industry level implies that industries will not be able share the treatment plants with their nearby counterparts. In addition, the current status quo of lacking wastewater treatment plants at the industry level means that most industries in the city discharge their wastewater into the sewer system untreated. This leads to hydraulic overloading and corrosion of the sewer pipe system (Ikhu-Omoregbe et al., 2005). With the current situation of insufficient, inefficient, and poorly maintained wastewater treatment plants that BCA has, it suffices to say that the water leaving the city's wastewater treatment plants is only partially treated, thereby releasing heavy metals into the environment. The release of contaminated wastewater from the city's wastewater treatment plants has been reported by many researchers. Therefore, wastewater management at both industrial and city wastewater treatment plant levels is crucial. This calls for financial incentives and the enforcement of laws and regulations against the release of hazardous effluents directly into the environment. In addition, the city assembly should intensify efforts toward maintaining and building additional wastewater treatment plants. According to Vunain et al. (2019), Blantyre has three main wastewater treatment plants, namely Limbe, Soche, and Manase. Others include Maone, Zingwangwa, and Chirimba wastewater treatment plants. However, these plants are old, non-functional, and mostly inefficient (Malikula, Kaonga, Mapoma, Thulu, et al., 2022). This contributes to water pollution, as the partially treated water is released into the environment (Ngoma et al., 2020). It is evidently clear that water recovery from the wastewater treatment plants is not practical in Blantyre City, as the effluents are only partially treated. For instance, in a study conducted by (Malikula, Kaonga, Mapoma, Chiipa, et al., 2022), it was established that the wastewater being released by Manase wastewater treatment plant, which receives effluents from the Makata industrial area, released partially treated water, evidenced by the presence of heavy metals above the WHO permissible limits in crops that were being irrigated using this water. This signifies a challenge in the implementation of water symbiosis involving the reuse of treated wastewater from the city's treatment plants due to the WWTPs' poor conditions. However, Bassi et al. (2023), argued that "if treated (to the desired quality standard) and reused, (wastewater) offers tremendous potential in addressing the water supply and demand gap on one hand and reducing the pressure on freshwater resources on the other" (pg. 4). Ramin et al. (2024b) concurs with Bassi et al. (2023) that treated water can be used in a symbiosis involving wastewater treatment plants (WWTPs) and the agricultural sector, which could consequently reduce pressure on groundwater, a major resource for irrigation, and also reduce fertilizer use since treated wastewater inherently contains nutrients such as nitrogen, potassium, and phosphorus. According to this study, it was discovered that farmers in the catchment areas of the WWTPs and near the industries that release wastewater were using this water for crop irrigation. This practice has been criticized by several researchers as it leads to exposing the people to heavy metals and other pollutants. In addition, recovering water for reuse by industries could also be challenging to implement, as it is difficult to consider the treated water suitable for reuse in industrial processes.

The second challenge to the implementation of water symbiosis is lack of proximity of complementary industries that could be involved in the sharing of utilities such as WWTPs. Proximity of industries has been reported by several researchers as one of the enablers of industrial symbiosis. Therefore, there is a need for the city council to improve the planning of the industrial areas so that industries capable of engaging in waste or utility sharing are co-located.

It can be established from the findings of this study that unless the WWTPs infrastructure is improved and that complementary industries are co-located, a sustainable water symbiosis is very difficult to implement.

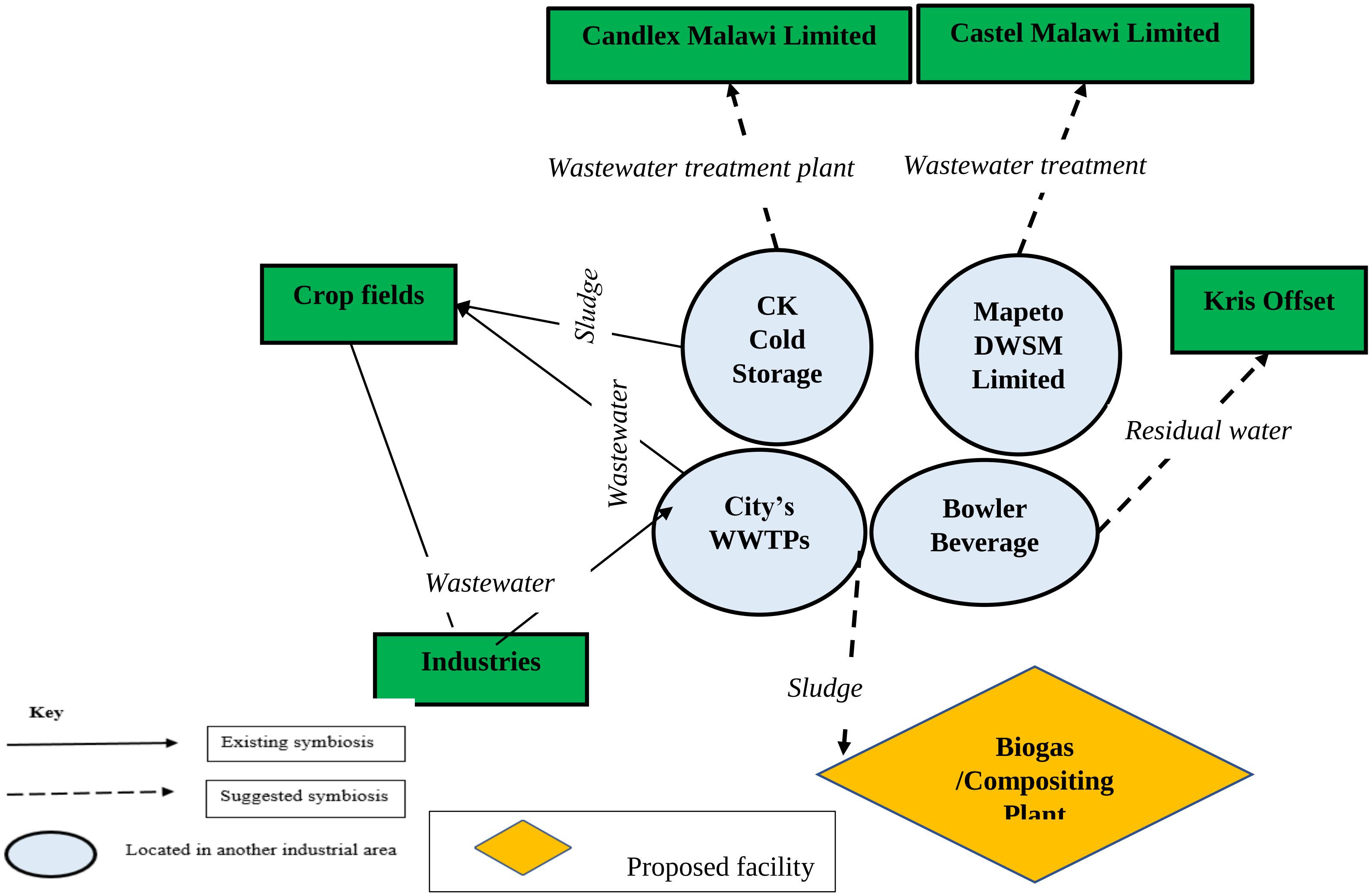

Figure 13: Figure 4.11 Proposed water symbiosis for Blantyre City

4.4 SWOT Analysis of industrial symbiosis in Blantyre City

4.4.1 Strengths

The industrial symbiosis seems to exhibit exciting strengths. Firstly, the city has vast industries and waste streams, which offers opportunities for more symbiotic relationships. Furthermore, the industries have already established industrial relationships, providing a foundation for developing additional symbiotic connections. These established relationships mean that there are already communication channels and trust among the industries. Lastly, promoting industrial symbiosis would be the first of its kind, thereby offering an exciting option for industries in their quest to address the waste management issues faced by individual companies.

4.4.2 Weaknesses

Despite the strengths outlined above, there are likely weaknesses that could negatively affect the sustainability of industrial symbiosis. Industrial symbiosis requires state-of-the-art technological facilities to be involved in the recycling of waste. Malawi, as a country, is not very advanced technologically, making the implementation of industrial symbiosis a challenging task. Furthermore, there is an unreliable supply of waste and byproducts. This uncertainty can be attributed to several factors, such as the fact that most industries are not large enough to generate sufficient waste or byproducts to serve as a reliable source of raw materials for industries that utilize the waste. In addition, production is generally affected by an overreliance on foreign exchange, which is currently scarce, and unreliable infrastructure, such as electricity. However, the problem of unreliable waste supply can be addressed through hedging, a concept in which industries involved in industrial symbiosis obtain additional waste supply from other industries outside the initiative to mitigate the shortage of waste for their day-today production. Lastly, the lack of data and crucial information necessary for the establishment and maintenance of industrial symbiosis, such as the quantity and quality of waste generated by industries, is also a significant issue. In terms of liquid water symbiosis, there is a lack of WWTPs both at industry or city level, and most of the BCA's WWTPs are old, non-functional, and mostly inefficient. This implies less opportunities for utility sharing among industries and unsustainable reuse of treated water.

4.4.3 Opportunities

However, the study revealed a number of opportunities for symbiosis. There is a presence of policies for waste management that can support the establishment of an industrial symbiosis policy and framework. The road network connecting the city to the industrial areas is also crucial. However, some renovations are needed to ease the transportation of materials among industries. Additionally, there are already existing recycling and reuse practices and relationships among industries. Lastly, there are existing public-private partnerships, such as the relationship between the BCC and the industries regarding waste management.

4.4.4 Threats

The country is facing an acute shortage of foreign currency. The forex shortage has negatively affected the industrial sector, as most industries rely on imported raw materials. The disruption in production implies a disruption of resource flow, which can eventually affect industrial symbiosis. Secondly, the city also has an unreliable water and electricity supply. The unreliable infrastructure poses a risk to industrial symbiosis, as it greatly affects industrial production. Furthermore, industrial symbiosis initiatives require funds and incentives for purchasing equipment necessary for recycling waste and conducting industrial symbiosis research. Insufficient funds and incentives can thus be considered one of the threats to industrial symbiosis in Blantyre City, as some industries do not have the capacity on their own. A lack of willingness to adopt industrial symbiosis by both the government and the industries, as well as other stakeholders, can also be problematic in the implementation of industrial symbiosis. Thus, the willingness to change is crucial in the implementation of industrial symbiosis. Seasonality challenges, such as dry spells, can negatively impact industries that rely on agricultural produce, such as food processing industries. The prolonged dry spells also contribute to water scarcity, thereby affecting industrial production. The last threat to industrial symbiosis is data security risks. A lack of proper sensitization on industrial symbiosis leaves industries with no choice but to withhold data related to their production processes, including the type and quantity of waste. The lack of this important data can be detrimental to the creation of waste-sharing pathways among the industries.

4.5 Case studies and best practices

The success of an EIP depends on a number of factors. Perrucci et al. (2022) identified and discussed four EIP success factors that have been key defining elements of the most renowned and successful EIPs in the world. These factors are geographic requirements, stakeholder involvement and dedication, community involvement, and, last but not least, regulatory system/agency support.

4.5.1 Examples of successful eco-industrial parks

4.5.1.1 EIPs in Denmark: Kalundborg EIP

Began in the 1960s and often hailed as the world's first eco-industrial park, this model showcases water, material, and energy (and knowledge) sharing among companies, significantly reducing waste and costs (Domenech & Davies, 2011). It must be understood that Kalundborg was not initially designed as an EIP but later developed into one after the industries realized the economic and environmental benefits that accrued from sharing or recycling common resources among them (Perrucci et al., 2022). The main industries making up the EIP are the coal-fired Asnaes Power Station, Statoil Refinery, Gyproc Plasterboard Factory, and Novo Nordisk Biotechnological Company, which produces pharmaceuticals, as well as the City of Kalundborg. These industries are involved in both energy and material sharing. For instance, Asnaes conduits steam to Novo Nordisk, thereby eliminating the necessity for new boilers, to Kalundborg City for district heating, and to the Statoil Refinery. Fly ash produced by the power plants is used by a cement company, gypsum produced by the desulfurization unit at Asnaes is taken up by Gyproc for wallboard making, pure sulfur produced by the refinery's desulfurization process goes to Kemira for sulfuric acid production, sludge produced by pharmaceutical processes at Novo Nordisk and other companies, as well as from the fish farms' water treatment plant, is used as fertilizer on nearby farms, and lastly, the surplus yeast produced from Novo Nordisk's insulin production is used as animal feed by the farmers (Desrochers, 2001; Lowe & Evans, 1995; Mathews & Tan, 2011). Today, more synergies have developed, leading to an increase in economic and environmental benefits (Jacobsen, 2006). The success of the Kalundborg EIP is due to several factors. Firstly, there has been a "close mental distance." This means that there are frequent meetings between industry managers to discuss strategies and projects for implementation, and the managers also engage with local communities. The continued interactions at all levels helped generate productive ideas related to industrial synergies and aided the integration of industries in the symbiosis (Jacobsen, 2006; Lowe & Evans, 1995). Interactions and research and development were encouraged through the establishment of the Kalundborg Symbiosis Center, and later on a broader scale, the Symbiosis Center Denmark (Faria et al., 2021).

Another factor is that the industries worked closely with the authorities, who did not over-control the initiative but rather allowed voluntary and proactive participation from the industries. There were collaborative dialogues and consultations between the government and the industries, and the government's flexibility in allowing industries to write and submit their action plans facilitated the easy formulation of synergies, as the initiatives were not simply imposed on the industries. In addition, the government provided funds to support the running of the project. Furthermore, the industries are in close physical proximity, which helps eliminate high transportation costs (Lowe & Evans, 1995).

In addition, Kalundborg had diverse industries that contributed to the system's resilience and stability (Chertow, 2007; Desrochers, 2001; Lowe & Evans, 1995)

4.5.1.2 EIPs in Netherlands

The promotion of EIPs in the country dates back to 1997 when the Dutch government implemented its Environmental Policy(Perrucci et al., 2022). Apart from the policy framework, the government provided economic support to more than 200 EIP initiatives while clearly incorporating the EIP development process into their educational curriculum, allowing both EIP developers and the government to work collaboratively. To motivate more companies to participate in the EIPs, the government ensured that it provided all the necessary support so that industries perceived the EIPs as viable business locations (Behera et al., 2012). Due to the support the government invested in the EIP initiatives, the Netherlands registered the highest number of attempts and success rates (Perrucci et al., 2022).

4.5.1.3 EIPs in South Korea: Ulsan Eco-industrial Park

This was formally launched in 2005. The success of the Ulsan EIP is built around strong stakeholder collaboration. The stakeholders include the government, acting through the

Ministry of Knowledge Economy, which provides funds and EIP policies to the Ulsan EIP; the Ulsan IPE Centre, which works directly with the government on policy formulation and is tasked with educating the involved parties on eco-industrial parks; and Ulsan City, which regulates operations and provides funding. Another stakeholder is the Korea Industrial Complex Corporation (KICOX), an affiliate of the Korean Ministry of Knowledge Economy and the owner of the Ulsan EIP. KICOX is responsible for park management and the dissemination of policy information. The last two stakeholders are the Research and Development centres and the companies. The country has eight R&D centres, and their role in the success of the Ulsan EIP is to provide technical support and research and development assistance. On the other hand, the role of the companies is to participate in the symbioses while promoting cooperation and providing lessons key to the sustainability of the project (Behera et al., 2012; Park et al., 2008)

In addition to the success attributed to the government's economic and policy support, the Ulsan EIP's success is also due to the Research and Development into Business (R&DB) framework, which aims to expand the symbioses in Ulsan. The framework involves three steps: network searching, feasibility study, and commercialization. In the first step, potential synergies are explored by obtaining data concerning production and wastes or byproducts from local and central government agencies (top-down approach) or from industry managers or forums made up of companies, universities, and city governments. In step two, the feasibility of the synergies is assessed with funding from the government. This focuses on evaluating the potential uses of the waste, assessing the technological, economic, and environmental aspects of the proposed synergies, and finally developing a conceptual design in line with the synergies. A final feasibility report is then produced. The final step in the R&DB framework is commercialization.

This step involves negotiations and contracts between different EIP stakeholders. The EIP center manages these negotiations by facilitating discussions among the participating industries and addressing barriers related to funding by attracting financial assistance from the government and private sector. In addition, the center addresses barriers related to any existing laws that may hinder the implementation of the projects (Behera et al., 2012)

4.5.1.4 EIPs in China: Technological Development Area, Suzhou Industrial Park and Technological Development Area EIPs

The vast growth of China's economy and industrialization led the government to contemplate ways to address pollution, discourage the overexploitation of natural resources, and achieve a sustainable industrial sector. This gave birth to the creation of circular economy strategies (Liu & Côté, 2017). In 2001, China saw the activation of the National Pilot EIP Program (NPEIPP) and the National Pilot Circular Economy Zone Program (NPCEZP), whose concerted efforts led to the production of at least sixty approved pilot EIP initiatives (L. Zhang et al., 2010). Like the Ulsan EIP, the initiatives in China are chiefly government-led. In 2006, the Technological Development Area was declared by the MEP as one of the first three National Demonstration Zones, before Suzhou Industrial Park and the Technological Development Area were declared the same two years later (C. Yu et al., 2015). Apart from the government's support, the Technological Development Area EIP is a success story in China because it has had strong leadership, received international support and expertise during its developmental stage, and has well-developed synergies due to the presence of vast and heterogeneous industries (Erkman & Van Hezik, 2016).

In 2001, Suzhou Industrial Park was labeled a National Demonstration Zone before being considered one of the first three National Demonstration EIPs by the country's

Ministry of Environmental Protection in 2008. Suzhou Industrial Park is involved in the sharing of materials, water, and energy. For instance, the wastewater treated by a public wastewater treatment plant is channeled to a cogeneration plant for cooling. The sludge produced after treating the wastewater is then taken to a sludge drying plant before the cogeneration plant uses it as fuel to generate electricity. The ash produced is then adopted by the construction industry for the production of construction materials.

Another initiative that was declared a National Demonstration EIP the same year was the Technological Development Area (L. Shi & Yu, 2014). China's approach to its EIP initiatives is a government-driven model. That is, the government, both central and local, is an enabler of EIPs, where, among other things, it is involved in defining policies and regulations, including planning guidelines, technical standards, evaluation indicators, and funding (Behera et al., 2012; L. Shi & Yu, 2014). Shi and Yu continue to add that all the EIP initiatives in China are successful because they provide room for research to allow for more technological innovations, information exchange, and funding, among other things. However, the authors warned against the government overreaching in its role, as this can negatively affect the EIPs.

4.5.1.5 EIPs in Brazil

The success of EIPs in Brazil was attributed to the support of the state and federal government, with 2002 being the year the country saw its first EIP initiative called the Sustainable Eco-Industrial Development Program (Rio ECOPOLO). However, the withdrawal of government support led to the collapse of EIPs in the country, and most of the initiatives that survived ended up yielding unsatisfactory outcomes related to waste management (Elabras Veiga & Magrini, 2009)

4.5.2 Lessons learned from global experiences

Blantyre City can benefit economically and socially from the implementation of industrial symbiosis in the city, in addition to obtaining environmental benefits such as waste and pollution reduction. The Vice President of Novo Nordisk shared lessons drawn from the Kalundborg industrial symbiosis that can be key for replicating the model. These lessons were: "industries must be different and fit each other; arrangements must be commercially sound and profitable; development must be voluntary, in close collaboration with the authorities; a short physical distance between the partners is necessary for the economy of transportation (many transfers are uneconomic over long distances); and at Kalundborg, the managers at different plants all know each other" (Lowe & Evans, 1995, pg. 49-50).

It is clear that for a successful implementation of industrial symbiosis in the city of Blantyre, industries should be given the liberty to participate voluntarily in the industrial symbiosis, and the government, through the Blantyre City Council, should provide a conducive environment for the thriving of these relationships. Lowe & Evans (1995) argue that for a successful implementation of an eco-industrial park to be realized, a self-organizing approach that defies top-down control must be adopted. The Vice President of Novo Nordisk asserted the importance of voluntary participation of industries in the model by reporting that during its initial stage, they were just doing what was profitable and what made sense, which was considered a brilliant idea in terms of material and energy sharing. The self-organized approach to the implementation of industrial symbiosis, which involves the voluntary participation of industries, builds trust and promotes cooperation among them. Neves et al. (2019b) highlight that a lack of cooperation among industries can negatively affect the implementation of industrial symbiosis. Negative effects from the lack of active participation of industries in EIP initiatives have been experienced in the USA. Despite registering more attempts to establish EIPs, the USA has the highest failure rate (Perrucci et al., 2022). The initiatives in the USA were not initiated by the stakeholders but rather by the government, and the overreach of the government contributed to the unsuccessful story of the USA EIPs (Korhonen et al., 2004). For any EIP to thrive, there is a need for a cordial relationship among the industries, and face-to-face interactions are more effective (Hewes & Lyons, 2008). This builds trust among the involved industries, and most importantly, there is smooth information exchange. In Kalundborg, industries were always in close contact regarding material exchanges, and they were in close proximity. This interconnectivity of industries led to the success of the Kalundborg initiative, a renowned model of all EIPs (Chertow, 2000). The majority of EIPs in the USA lacked this element, contributing to the higher failure rate, with the exception of the Londonderry EIP, which embraced social relationships for enhanced interconnectivity (Perrucci et al., 2022). Therefore, for Blantyre City to succeed in transitioning its industrial areas to eco-industrial parks, there is a need to allow active participation of industries in its formulation. Thus, this approach will provoke industries' interest in participating in industrial symbiosis, as they will gain knowledge about industrial symbiosis and identify industries capable of receiving or supplying waste. It will promote a willingness on the part of industries to provide data on production processes and waste generation, and it will help to clarify uncertainties about the benefits, costs, and risks of participating in the symbiosis (Neves et al., 2019b).

Another lesson for Blantyre City is that it should ensure the establishment of more industrial symbiosis scenarios among its industries and promote the concept to help them understand the benefits of achieving synergies. As seen in the successful initiatives described in the previous section, both the central and local governments should provide funding to facilitate the exploration of waste-sharing options. Developing more industrial symbiosis scenarios will help address the uncertainty surrounding the supply of waste or byproducts. (Perrucci et al., 2022) acknowledged this as another factor contributing to the unraveling of the EIP initiatives in the USA. He explained that the supply uncertainty dilemma contributed to the failure of the EIPs in the USA, as most industries were unsure of the reliability and consistency of the supply of raw materials in the form of waste and byproducts from partnering industries. After all, when the supplier fails, the benefiting industry also suffers (Gibbs, 2003). This uncertainty can be addressed by tapping into waste or byproduct supplies from industries not involved in the EIP, a strategy referred to as hedging (Chertow, 1998b). Therefore, in the event that the Blantyre City EIP faces the challenge of a lack of sufficient industries to participate or is unable to meet the supply demand for waste and byproducts, hedging could be a viable option.

Another lesson for the proposed eco-industrial parks in Blantyre City is that the government should play a key role in providing a conducive environment for the initiative by, among other things, providing EIP policies, regulations, funding, and incentives. Lack of government support in EIP initiatives might lead to the failure of EIPs (Perrucci et al., 2022). The governance dilemma concerns the extent to which the government should be involved in EIPs. As seen in the examples above, government participation in EIP initiatives is important, though over-controlling can be detrimental. Lack of governmental support in areas such as funding, policy formulation, and regulatory duties can impede the development of EIPs. This dilemma has led to more EIP initiatives failing. This was also experienced in Brazil; in the aftermath of government support for the EIPs, the initiatives declined, and most of those that survived ended up yielding unsatisfactory intended outcomes related to waste management (Elabras Veiga & Magrini, 2009). Neves et al. (2019a) argue that the unavailability of appropriate policies, inefficient regulatory frameworks, and lack of financial support to promote the model are detrimental to the implementation of industrial symbiosis and eco-industrial parks. The success story behind the implementation of industrial symbiosis in Asia, as seen in the previous section, was achieved through having appropriate policies and funding in place. The Malawi government, in conjunction with the BCC, should therefore embrace this approach for a sustainable EIP.

There is also a need to establish an EIP resource and development centre that will be responsible for sensitizing industries and the public about industrial symbiosis and EIPs. This centre will be involved in research and development activities related to EIPs, provide information about EIP projects, and serve as a venue where industry managers can hold meetings focused on generating more industrial symbiosis scenarios and addressing all matters involving the EIP.

One of the barriers to the implementation of industrial symbiosis is the lack of interest from industries to participate, which stems from a lack of knowledge about industrial symbiosis and a lack of awareness of industries capable of receiving or supplying waste. In the Kalundborg and Ulsan industrial symbiosis cases, all the industry managers knew each other through face-to-face interactions at the EIP centres, as they frequently held meetings aimed at generating more partnerships and innovation at the research and development centres (Castellet-Viciano et al., 2022; Faria et al., 2021; Lowe & Evans, 1995).

Promoting collaboration among industries is a key lesson for implementing industrial symbiosis in Blantyre City. This will bridge the information gap among industries in

Blantyre City regarding their industrial processes and the waste they generate. It will also help establish material-sharing opportunities among the industries.

The Kalundborg symbiosis was self-organized, as industries sought to ensure that resources were used optimally. This can also be key in the implementation of industrial symbiosis and eco-industrial parks in the city of Blantyre. Industries should be directly involved in establishing waste-sharing relationships among themselves. For a successful implementation of an eco-industrial park to be realized, an evolutionary approach that defies top-down control must be adopted (Lowe & Evans, 1995). Other barriers to the realization and application of industrial symbiosis include a lack of trust among industries, the unavailability of appropriate policies and inefficient regulatory frameworks, a lack of funds to promote the model, a lack of interest from industries to participate in industrial symbiosis due to insufficient knowledge about it, and a lack of awareness of industries capable of receiving or supplying waste. Additionally, there is often an unwillingness on the part of industries to provide data on production processes and waste generation, uncertainty about the benefits, costs, and risks of participating in the symbiosis, and the implementation of waste reduction measures by some industries that threaten the quantity of waste flow (Neves, et al., 2019b). Thus, national awareness programs on industrial symbiosis for industries and the general public are crucial for Malawi.

The last lesson is that the EIP should be ready to incorporate different stakeholders, including the government (both central and local), industries, research and development centers, and the community. A cordial relationship among the stakeholders is key. When one category of stakeholder withdraws, the whole system can fall apart. The successful models of EIPs discussed above relied on this rapport among the stakeholders. The local communities surrounding the EIP are crucial because they are an integral part of the environmental, social, and economic benefits through employment in the EIP. Involving them in the affairs of the EIP gives them a sense of pride and ownership. According to Raheem and Sauvant (2009), the city's economic activities are affected by a number of challenges, including security issues such as petty theft. The development of a sense of ownership as a result of involving the local communities in the EIP initiative would help address the security issue.

4.5.3 Applicability of these models to Blantyre

Like Kalundborg, Blantyre City faces a number of resource constraints, such as insufficient water supply, reduced accessibility to electricity, waste management challenges, and pollution. Thus, the promotion of industrial symbiosis and the transformation of the city's industrial areas into eco-industrial parks can be key in addressing these challenges. However, these initiatives require technological advancements, research incentives, funding, and supportive policies and frameworks. With proper planning, resource mobilization, and leveraging the available opportunities for industrial symbiosis, the eco-industrialization of the industrial areas and the transformation of the city into an eco-city in the long term can be a possibility.

4.6 Developing an eco-industrial park concept for Blantyre City's industrial parks

For the city to be transformed into an eco-city, the industrial areas will need to be converted into eco-industrial parks. These eco-industrial parks would be responsible for achieving the circularity of materials within the city as industries engage in material sharing. One of the goals of eco-cities is the reduction of pollution in urban areas.

4.6.1 Principles of eco-industrial parks

Eco-industrial parks are built on principles of partnership governance, resource efficiency, innovation, sustainability, waste minimization, and closed-loop systems

(Hein et al., 2017; Lowe & Evans, 1995; Neves et al., 2019b). Partnership governance involves industrial actors and other stakeholders, such as the government and the community, making collaborative decisions on industrial symbiosis matters (L. Baas & Boons, 2004; L. Willem. Baas, 2005; Hein et al., 2017; R. Paquin & Howard-Grenville, 2009). This promotes cooperation and trust among the players, leading to successful industrial symbiosis and eco-industrial parks. Hein et al. (2017); R. Paquin and Howard-Grenville (2009); R. L. Paquin and Howard-Grenville (2012) argue that collaboration also leads to improved competitiveness among industries, resulting in better quality products and services.

Eco-industrial parks also seek to ensure sustainability. They strive for environmental, economic, and social sustainability (Lowe and Evans, 1995). Environmental protection is achieved through reduced waste and pollution as industries share waste, byproducts, and residues. Economic benefits are gained through the sale of waste and byproducts and services to other firms, as well as by cutting costs for waste management, virgin raw materials, and utilities such as water and energy (Huang et al., 2019). In addition, collaborative governance may contribute to innovation as stakeholders engage, leading to the creation of job opportunities in areas such as waste management, recycling, and green technologies (De Gobbi, 2022). This results in the economic empowerment of communities.

Furthermore, eco-industrial parks strive to achieve social benefits. This is accomplished through collaborative activities among industrial actors, communities, and other stakeholders involved, which leads to cooperation and trust-building among industries (Chertow, 2007). In addition, Lowe and Evans (1995) highlight that the enhanced environmental quality achieved through industrial symbiosis leads to better health outcomes for people in the surrounding communities, as the model ensures a reduction of waste and pollution.

Furthermore, eco-industrial parks aim to ensure resource efficiency. This involves maximizing the use of materials and energy. By implementing circular economy principles such as material sharing, recycling, and reusing (Camilleri et al., 2023; Geissdoerfer et al., 2017; Ghisellini et al., 2018), industries make full use of the intrinsic value of a material, even after it has initially been considered useless or waste. With industrial symbiosis, waste, residues, and byproducts of one industry are utilized by another industry as inputs, thereby maximizing their use, along with recycling and reuse of materials.

The final principle of eco-industrial parks is waste minimization. This focuses on turning waste products into valuable inputs for other industries (Chertow, 2007; Ghisolfi et al., 2017). This is achieved by shifting from open-loop systems, which release waste into the environment, to closed systems that encourage the circulation of materials within industrial systems (De Gobbi, 2022). Some strategies for implementing closed-loop systems include recycling, reuse, and sharing of materials among industries (Camilleri et al., 2023; Chertow, 2007; Geissdoerfer et al., 2017).

Thus, the waste and byproducts sharing pathways for Blantyre City proposed in this study will lead to a sustainable industrial sector by transforming the industrial areas into eco-industrial parks that aim to implement industrial symbiosis and achieve these principles.

4.6.2 Vision and goals for the Blantyre City's eco-industrial parks

The vision for turning the city's industrial areas into eco-industrial parks is to act as a step toward transforming Blantyre City into an eco-city. By promoting symbiotic relationships among industries within and between the eco-industrial parks, the city aims to achieve the following: reduce pollution caused by improper waste management and significantly decrease waste generation; create job opportunities for people in the surrounding communities; allow industries to reap economic benefits by engaging in the selling and use of waste and byproducts; and reduce pressure on virgin raw materials by using waste and byproducts.

4.6.3 The framework for implementing industrial symbiosis in Blantyre City

The implementation of industrial symbiosis in the city of Blantyre will involve putting in place a number of things, including; regulatory support, infrastructure development and stakeholder engagement. It is worth noting that for this to be a success story, political will on the part of the city council and the government, funding and partnerships and acclimatization of the initiatives to addressing the social, economic and needs of the local industries.

4.6.3.1 Policy and Regulatory Framework

Current policies affecting industrial practices.

The Constitution of Malawi recognizes environmental protection as a right, and thus waste management is crucial if this right is to be upheld. This has led to the formulation of different policies and legislation aimed at protecting the environment and ensuring proper waste management. Some of this legislation includes the Environmental Management Act (2017), the Local Government Act (1998), and the Environmental Management (Waste Management and Sanitation) Regulations (2008), which guard against waste generation and poor infrastructure. The National Environmental Policy (NEP) (2004) seeks to promote waste segregation at the source, recycling, and proper waste disposal using appropriate technology. In addition, there is the Environmental

Management (Plastics) Regulation (2015), which promotes circular economy interventions for plastic waste, the National Waste Management Strategy (2019-2023), which outlines strategies and budget allocations for reducing, reusing, recycling, and recovering energy from waste, and lastly, the National Climate Change Management Policy (2016), which seeks to address climate change by tackling emissions of greenhouse gases from different economic sectors. Most recently, Malawi Vision 2063 was introduced, which among other things seeks to ensure that Malawi attains a sustainable industrialization.

Recommendations for supportive policies and regulations

It is quite obvious that the country lacks policies for industrial symbiosis, and there is a need to formulate such policies that would facilitate the operation and monitoring of the symbiosis initiative in Blantyre City and the rest of the cities nationwide. Neves et al. (2019b) argue that the unavailability of appropriate policies, inefficient regulatory frameworks, and lack of financial support to promote the model are detrimental to the implementation of industrial symbiosis and eco-industrial parks. The European and Asian governments' commitment to provide financial support and to formulate industrial symbiosis policies such as Roadmap to a Resource Efficient Europe, Closing the Loop—An EU Action Plan for the Circular Economy, Closing the Loop—An EU Action Plan for the Circular Economy, Directive 2018/851 on Waste, The China National Eco-Industrial Demonstration Programme, has led to successful industrial symbiosis in these regions (European Commission, 2011; (European Parliament, Council of the European Union, 2018; H. Shi et al., 2010; Huang et al., 2019; Liu & Côté, 2017). This demonstrates how important policies that promote industrial symbiosis are for the establishment and sustainability of industrial symbiosis and eco-industrial parks. Therefore, in the context of regulatory support for implementing eco-industrial parks in Blantyre City, there will be a need to develop and integrate industrial symbiosis policies and guidelines into the city's urban development plan and into the already existing nation's policy framework. These policies may include; Environmental Management Act (2017), Local Government Act (1998), Environmental Management (Waste Management and Sanitation) Regulations (2008), The National Environmental Policy (NEP) (2004), Environmental Management (Plastics) Regulation (2015), National Waste Management Strategy (2019-2023), National Climate Change Management Policy (2016) and Malawi Vision 2063. The generated guidelines will be key in making decisions involving the circular economy and the implementation and sustainability of industrial symbiosis and eco-industrial parks. Furthermore, the regulatory support will involve the development of incentive and compliance tools to guide and uphold symbiotic practices. This may include incentives or subsidies for participating in the symbiosis, penalties for sending reusable waste to landfills, and encouraging and mandatorily requiring industries to produce waste audit reports to help in the generation of waste-sharing pathways. Lastly, there will be a need to establish a committee within the city council whose job will be to coordinate, monitor, and promote industrial symbiosis initiatives.

4.6.3.2 Infrastructure improvement

In the context of infrastructure development, there is a need to revamp the city's infrastructure. The city is facing a number of infrastructural challenges, including water and electricity problems, as well as issues with the road network. Water and electricity utilities directly affect industrial production; therefore, addressing these challenges will ensure a sustainable flow of resources for sharing among industries. A vibrant transport and road infrastructure will also facilitate the smooth transportation of materials between the sharing industries.

Additionally, there is a lack of proper planning in the industrial areas, as industries are haphazardly situated. This uncontrolled pattern may limit the implementation of industrial symbiosis initiatives. There is a need to co-locate industries whose waste and resource streams are complementary. The proximity of complementary industries is key and is considered one of the enablers of industrial symbiosis, as it eases the logistical burden of waste and resource sharing, as well as facility utility sharing (Akrivou et al., 2021).

Furthermore, there is a need to upgrade the waste management infrastructure, which is currently very poor. In the context of liquid waste management, this study reveals that the lack of sufficient and efficient wastewater treatment plants the city is experiencing will likely make industrial symbiosis difficult to implement. This highlights the need for more efforts in addressing the problem of wastewater management.

Regarding solid waste, in addition to needing an advanced landfill in place of the current poor landfill, which is now just a ‘dumpsite’ due to poor management and lack of proper engineering necessary for achieving proper waste handling, there is also a need for a sorting facility. This will facilitate easy access to solid waste of interest, as the study found that most industries do not segregate their waste.

There is also a need to create a flexible digital database for the industries, where they can share information concerning the types of waste or by-products they generate, their quantities, and their utility needs. This will ease the generation of waste and resource sharing pathways.

4.6.3.3 Stakeholder engagement framework

Lastly, there will be a need to promote stakeholder collaboration. The eco-industrial parks to be implemented in the city will comprise of actors namely; the industries, the government and the city council, the communities and the academia. The interaction of industries, which in this case include, but are not limited to, plastic industries, food industries, construction industries, textile industries, home and personal products industries, food/beverage/brewery industries, transport and maintenance industries, metal/steel industries, decorative industries, and packaging industries, will help in fostering trust, idea sharing, and generation of waste/resource sharing pathways.

The city council in conjunction with the government and other partners will help in guiding the roadmap for implementation of symbiotic initiatives and provide the necessary industrial symbiosis policies and programmes and coordinating financial and research incentives. Formulation of appropriate industrial symbiosis policies, economic incentives that can stir industries to be involved in industrial symbiosis, and are also crucial for creation and expansion of resource sharing among industries. (Bacudio et al., 2016; Illsley et al., 2007; Mauthoor (2017); Neves et al. (2019b) stress the importance of funding and subsidies in establishment of industrial symbiosis, by arguing that it is of paramount importance that local or national governments should provide financial incentives that promote industries to create resource sharing partnerships. Thus, the government of Malawi and/or the Blantyre City Council will be required to provide financial support to the industrial symbiosis projects and programmes and research. The success story of China's industrial symbiosis initiatives is contemplated to be a fruit of implementation of policies and plans, financial incentives, and research incentives (Neves et al., 2019a), which resulted into minimization of industrial solid waste generation (Guan et al., 2019).

Involvement of the communities and the NGOs will assist in dissemination of information about circular economy principles to the general public and helping in easy integration of the informal sector such as waste pickers into the industrial symbiosis initiatives. In addition, engaging the communities will instil a sense of belonging to the initiatives, thereby acting as monitors of environmental performance of the initiatives. As previously reported, the success story of the Kalundborg eco-industrial park is due, among other factors, the involvement of local communities in the decisions related to the eco-industrial park. The academia, on the other hand, which will involve the universities and researchers in Malawi will be also crucial in the industrial symbiosis initiatives. Among other things, they will make an important team involved in conducting feasibility studies, lifecycle assessments, technology assessments and applied research to provide insights on innovative applications of waste/resources.

4.7 Potential benefits of the industrial symbiosis in Blantyre

Industrial symbiosis leads to environmental, economic, and social benefits (Jacobsen, 2006; Mathews & Tan, 2011). It is believed, therefore, that Blantyre City would benefit significantly if the industrial parks were transitioned into eco-industrial parks.

4.7.1 Environmental benefits

4.7.1.1 Reduced waste

The industries are generating enormous waste, and apparently, most of it ends up being indiscriminately disposed of. Sharma and Akhtar argue that, despite industrialization being an input for socio-economic development, rapid industrialization is regarded as the greatest problem faced by towns in the developing world, as it results in the heavy generation of waste to be disposed of in landfills. Khonje argues that underbudgeting, lack of staff, insufficient waste collection vehicles, and a lack of will by those in power and the general public to push the government on waste management issues have led to poor solid waste management in Blantyre City and Malawi in general. These factors and others have led to irregular waste collection by the Blantyre City Council, resulting in waste being heaped on roadsides, in open spaces, and on riverbanks (Chikukula et al., 2024; Kasinja & Tilley, 2018; Mpoola, 2011; SDI, n.d.). Truss Group Ltd also echoed that most hazardous industrial waste in Malawi is not pre-treated before reuse, recycling, or disposal and is often dumped illegally at municipal dumpsites. Additionally, industrial liquid waste is also being improperly disposed of into open drains and directly into the city's rivers, which has contributed to water pollution. However, with the implementation of industrial symbiosis, the industries will be involved in sharing waste and byproducts, thereby reducing pollution, as industries will put the waste to use instead of dumping it indiscriminately. The sharing of waste and byproducts will also significantly reduce the quantity of waste to be dumped into the city's landfill, a facility that lacks proper engineering of a modern landfill. Ayres et al. (2002) echo that recycling and sharing this waste among industries helps avoid a greater percentage of waste emanating from industrial processes.

The city is also facing an incessant lack of resources for waste management challenges, such as insufficient staff, appropriate waste collection vehicles, and funds. This has resulted in irregular waste collection by the city council, which has contributed to the apparent improper waste disposal. Thus, transforming the industrial areas into eco-industrial parks will reduce the pressure on the city council regarding waste management as less waste will be generated since the industries will be involved in waste sharing synergies.

4.7.1.2 Lower resource consumption

Industrial symbiosis strives to ensure resource efficiency by maximizing the use of materials and energy through recycling and reuse. Lowe and Evans (1995); Neves et al. (2019) assert that with industrial symbiosis, industries shift from using virgin resources to utilizing waste or byproducts, thereby reducing pressure on natural resources. Hence, the implementation of industrial symbiosis in Blantyre City will contribute to minimizing the demand for virgin resources such as water through recycling and reuse. By implementing material sharing, recycling, and reuse, industries will fully utilize the intrinsic value of a material, even after it has initially been considered useless or waste.

4.7.2 Economic benefits

On the other hand, the industrial symbiosis will contribute to economic benefits. This will be achieved through selling of waste and byproducts and services among firms and cutting costs for waste management and virgin raw materials and for utilities such as water and energy. In addition, due to collaborative governance which may contribute to innovation as the stakeholders engage, there will be creation of job opportunities in avenues such as waste management, recycling, and cleaner technologies.

4.7.3 Social benefits

Blantyre City's current waste management problems have led to indiscriminate waste disposal and environmental pollution. The city council is overwhelmed and is failing to execute its duties due to insufficient funds, a lack of appropriate waste collection vehicles, and a shortage of staff. The repercussions of this situation have contributed to many significant health and environmental risk factors, such as diarrheal diseases, respiratory diseases, vector-borne diseases, injuries, unintentional poisonings, and air, water, and soil pollution. However, implementing industrial symbiosis in Blantyre City will minimize waste generation and pollution, leading to improved environmental quality. The enhanced ecological quality will result in better health outcomes for the city residents. In addition, the involvement of local communities in environmental initiatives cultivates a culture of sustainability. Communities surrounding an industrial symbiosis initiative are directly affected, among other things, by the creation of job opportunities and improved environmental quality. As such, involving them in implementing industrial symbiosis initiatives can be key. There is a sense of ownership of the project, considering the benefits accrued from the implementation. For instance, people from the surrounding townships of Blantyre City are seen collecting plastic from various sources, such as markets and homes, and selling it to plastic manufacturing industries for recycling. By being involved in industrial symbiosis and understanding its benefits, the communities will take pride in it and work towards its sustainability. Raheem ranks security issues, such as petty theft, as the second worst challenge faced by industries in Blantyre City.

4.8 Chapter summary

Chapter four presents the results and discussion of the study, highlighting the proposed pathways for sharing waste and byproducts among industries.

CHAPTER 5

CONCLUSION & RECOMMENDATIONS

5.1 Conclusion

The study aimed to address the waste management challenges facing Blantyre City by exploring pathways for waste and byproduct sharing among industries, to transform the industrial areas into eco-industrial parks and, ultimately, turning the city into an eco-city capable of implementing the circular economy 5R framework. Aside from the service firms, the study revealed that Blantyre City has a variety of industries, some of which include plastic, metal/steel, decorative, food/processing/beverage/brewery/dairy, construction, packaging, textile, manufacturing, meat, and pharmaceutical industries. These industries rely on either imported or locally sourced raw materials, or both, and generate a diverse range of waste or byproducts. The solid wastes identified in the study include construction waste, metal scraps, slag, ash, fiber/rubber waste, food waste, slaughterhouse waste, textile waste, plastic waste, and paper/carton waste. Among these, the most generated wastes are plastics, food waste, and paper/carton waste. In addition to being produced by plastic and carton manufacturing industries, plastic and paper waste are generated as packaging waste. Waste in the industrial areas is managed in various ways, with recycling, reuse, incineration, onsite dumping, and landfilling at the city's landfill being the most common practices. However, the city's landfill is in poor condition and lacks the features of a standard landfill, making it more of a dumping site. In addition to these waste management practices, industries share their wastes, either within the industrial area or with industries outside the industrial areas. However, it was revealed that symbiosis is in its infancy, as only a few scenarios of waste/byproduct sharing among industries were identified. The industrial symbiotic cases revealed involved the sharing of plastic waste with plastic manufacturing industries for recycling, crude oil with oil refining industries, used oils with other industries for heating, waste tires with the tire recycling industry for retreading, cotton and paper/carton waste with egg tray manufacturing industries, and scrap metals with formal metal recycling industries. However, the majority of industries shared their waste with the informal sector, such as farmers, sofa makers, metal recyclers like tinsmiths, and people from the surrounding communities. Other forms of industrial symbiosis revealed include warehousing, consultancy, buying/borrowing of raw materials, and collaborative efforts on matters such as theft and safety. The study also identified other waste-sharing pathways. These symbioses include more options for sharing plastic waste among plastic manufacturers themselves and the construction industry, sharing slag, fiber/rubber waste, paint waste, and ash with the construction industry for use in concrete, roads, ceramics, and cement blocks/bricks, and sharing glass waste with cement manufacturing industries and the construction industry for cement and concrete block production. Additionally, spent waste was shared with the meat industry for animal feed. Aside from solid waste, the study revealed that industries release wastewater rich in heavy metals into the environment, as most industries were observed engaging in improper liquid waste disposal, evidenced by the dumping of untreated effluents into open drains and spaces. Laboratory analyses of the liquid waste samples revealed the presence of heavy metals, with iron, chromium and cadmium registering high concentrations above the WHO's set limits for both drinking and irrigation water. Only two industries were found to have water treatment plants, and that the city's WWTPs are in bad shape. The study proposed sharing these treatment facilities with nearby industries, and established that water symbiosis involving sharing of utilities and reuse of treated water by industries can only be sustainable if the city's WWTP infrastructure is improved and if complementary industries capable of sharing utilities are in close proximity. The study also revealed a need for more government intervention to support the implementation of these symbioses and more. Among other things, there is a need for the government to formulate and implement an eco-industrial park policy and framework, as well as provide financial and research incentives. Additionally, it is important to raise awareness among industries and the general public about industrial symbiosis and eco-industrial park initiatives. As such a framework for implementing the eco-industrial parks was proposed. The framework considered the following; policy and regulatory support, infrastructure development and stakeholder engagement.

To take advantage of the large quantities of organic waste, the study proposed the introduction of a composite facility responsible for converting organic waste into fertilizer. This would address pollution resulting from chemical fertilizer use and help farmers access fertilizers that are cheaper compared to chemical options. Furthermore, the study identified several opportunities for transforming Blantyre City's industrial areas into eco-industrial zones. Coupled with the promotion of stakeholder collaboration, these opportunities include the presence of some degree of recycling and reuse of waste, some form of waste sharing of byproducts, a good road network for easy transportation of resources within the city, and the presence of interrelationships among industries on matters other than waste sharing.

5.2 Recommendations

For the transition of industrial areas into eco-industrial parks to be successful, there is a need for:

- Support from the government to expedite the implementation of industrial symbiosis projects in the country's industrial areas.
- Promotion of collaboration among the industrial symbiosis stakeholders, such as the government, the city council, the industries, and the surrounding communities.
- A legislative framework that supports the establishment of industrial symbiosis and eco-industrial parks.
- Improvement of the existing WWTPs and/or building enough WWTPs in the city to promote water symbiosis
- The establishment of a flexible and accessible waste/byproduct database for the city to assist industries in generating industrial symbiotic relationships.

5.3 Areas for further studies

- Feasibility study of the suggested waste sharing pathways.
- Quantitative study of economic and environmental benefits of the eco-industrial parks
- Industrial symbiosis involving energy sharing.

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APPENDICES

APPENDIX 1: Data collection introductory letter

OFFICE OF THE EXECUTIVE DEAN OF NATURAL AND APPLIED SCIENCES

6th February 2024

TO WHOM IT MAY CONCERN

TESTMONIAL LETTER FOR ALEX BARNET PHIRI (MSC/ENV/05/21)

This letter serves to confirm that the bearer, Mr. Alex Barnet Phiri (Registration Number MSC/ENV/05/21) is a candidate under the MSc Degree programme in Environmental Sciences here at the University of Malawi. This is a two-year postgraduate programme that is offered in the School of Natural and Applied Sciences.

Mr. Phiri was admitted into the Masters in Environmental Sciences programme in 2021. He is collecting data for his thesis.

Please feel free to contact the undersigned if need arises.

Sincerely,

UNIVERSITY OF MALAWI
06 FEB 2024
SCHOOL OF NATURAL & AS
P.O. BOX 280 ZOMBA

Professor Cosmo Ngongondo
Executive Dean, School of Natural and Applied Sciences

APPENDIX 2: Part of the data on liquid waste after laboratory analyses

	Mn	Zn	Cu	Cr	Cd	Pb	Fe	K	Mg	Ca	Na	Hg
ID	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
A	<0.002U	<0.0010U	0.004	0.569	<0.002U	<0.0100U	<0.006U	0.5624	0.6065	4.974	7.778	<0.200U
A	<0.002U	<0.0010U	<0.003U	0.588	<0.002U	<0.0100U	<0.006U	0.4416	0.7311	5.535	3.1787	<0.200U
A	<0.002U	<0.0010U	<0.003U	0.594	<0.002U	<0.0100U	<0.006U	0.6187	0.7481	5.698	10.2252	<0.200U
A	<0.002U	<0.0010U	0.007	0.601	<0.002U	<0.0100U	<0.006U	0.6375	0.7041	5.266	8.5437	<0.200U
B	<0.002U	<0.0010U	<0.003U	0.61	<0.002U	<0.0100U	<0.006U	0.6472	0.7131	5.601	8.725	<0.200U
B	<0.002U	<0.0010U	<0.003U	0.612	<0.002U	<0.0100U	<0.006U	0.5779	0.6514	5.206	10.7099	<0.200U
B	<0.002U	<0.0010U	<0.003U	0.608	<0.002U	<0.0100U	<0.006U	0.5976	0.7927	6.011	10.8432	<0.200U
B	<0.002U	<0.0010U	0.004	0.636	<0.002U	<0.0100U	<0.006U	0.5684	0.685	5.652	13.1595	<0.200U
C	<0.002U	<0.0010U	<0.003U	0.634	<0.002U	<0.0100U	<0.006U	0.5377	0.6718	5.477	12.2749	<0.200U
C	<0.002U	<0.0010U	<0.003U	0.668	<0.002U	<0.0100U	<0.006U	0.595	0.746	5.718	11.3757	<0.200U
C	<0.002U	<0.0010U	<0.003U	0.677	<0.002U	<0.0100U	<0.006U	0.554	0.6572	5.314	11.3731	<0.200U
C	<0.002U	<0.0010U	<0.003U	0.677	<0.002U	<0.0100U	<0.006U	0.4845	0.8368	6.167	4.1019	<0.200U
D	<0.002U	<0.0010U	<0.003U	0.652	<0.002U	<0.0100U	<0.006U	0.6068	0.8193	6.166	11.2882	<0.200U
D	<0.002U	<0.0010U	<0.003U	0.696	<0.002U	<0.0100U	<0.006U	0.5878	0.7723	5.746	11.8532	<0.200U
D	<0.002U	<0.0010U	<0.003U	0.689	<0.002U	<0.0100U	<0.006U	0.6723	0.8213	6.037	11.7126	<0.200U
D	<0.002U	<0.0010U	0.011	0.716	<0.002U	<0.0100U	<0.006U	0.621	0.7067	5.484	12.8953	<0.200U
E	<0.002U	<0.0010U	<0.003U	0.685	<0.002U	<0.0100U	<0.006U	0.6775	0.8359	6.233	12.2986	<0.200U
E	<0.002U	<0.0010U	<0.003U	0.723	<0.002U	<0.0100U	<0.006U	0.5957	0.7594	6.024	13.2319	<0.200U
E	<0.002U	<0.0010U	<0.003U	0.712	<0.002U	<0.0100U	<0.006U	0.595	0.6836	5.383	11.9966	<0.200U
E	<0.002U	<0.0010U	<0.003U	0.731	<0.002U	<0.0100U	0.208	1.5533	2.6264	18.149	16.4701	<0.200U

APPENDIX 3: Interview guide

Introduction (Name and type of industry)

Product(s) produced
What products do you produce?

Raw materials used
What raw materials do you generate?

Source (imported or locally sourced)?

How much waste do you generate annually?

Waste products and by-products and their annual generation rate

What type of waste do you generate, and how much per year?

Waste management practices and existing industrial symbiosis

How do you manage your waste?

What waste/byproduct produced is shared or sold to other industries?

What are these industries?

Aside waste/byproduct sharing, how else do you collaborate with other industries?