INFLUENCE OF INDUSTRIAL SYMBIOSIS ON SOLID WASTE REUSE IN MANUFACTURING INDUSTRIES IN KISUMU COUNTY, KENYA

BY

ADALLA MORELLY KATHY

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN ENVIRONMENTAL SCIENCE

SCHOOL OF AGRICULTURE, FOOD SECURITY, AND ENVIRONMENTAL SCIENCES

MASENO UNIVERSITY

DECLARATION

I declare that this thesis is my original work and has never been presented for the award of any degree in any other University.

Signature: ………………………………………. Date: ……………………………..………

Adalla Morelly Kathy

MSC/NS.00134/017

Approval by Supervisors

This thesis has been submitted for examination with our approval as university supervisors:

Signature: ………………………………………. Date: ……………………………..………

Prof. Raphael A. Kapiyo

Department of Environmental Sciences

Maseno University

Signature: ………………………………………. Date: ……………………………..………

Prof. Boniface O. Oindo

Department of Environmental Science

Maseno University

ACKNOWLEDGEMENTS

First, I would like to thank God Almighty for provision and protection throughout my study period. Second, my success and completion of my thesis would not have been possible without the support, guidance, and continuous mentorship of my supervisors, Prof. Raphael Kapiyo and Prof. Boniface Oindo from the Department of Environmental Science of Maseno University; thank you. I acknowledge and appreciate the industries that agreed to participate in this study and offered valuable information that was critical to the success of this study. I am grateful to the Kenya Industrial Research and Development Institute for allowing me time away from work to attend classes and complete my thesis. My colleagues and friends, M. Amolloh and W. Oluoch, offered insightful opinions that enriched this work; thank you. I thank my family for their profound belief in my abilities. A special mention to B. Oure for the moral, technical, and financial support offered. The list is not exhaustive; therefore, may all those who supported me in one way or another feel acknowledged.

DEDICATION

To my beloved parents.

Where I am is because of

The foundation you laid

ABSTRACT

The growth of the manufacturing sector signifies economic progress, but waste generation poses a notable drawback, creating significant environmental challenges. Effective waste management, particularly the reuse of solid waste, remains a critical issue for industries striving towards green growth and circularity. Traditional waste management practices are often inefficient, contributing to environmental degradation and missed opportunities for resource optimization. Addressing the problem of solid waste reuse requires innovative approaches such as Industrial Symbiosis (IS) that integrate economic and environmental benefits. IS, a cooperative approach where industries exchange materials, energy, water, and byproducts, offers a sustainable alternative to conventional solid waste disposal methods. Industries can minimize waste, reduce costs, and promote circular economies through IS. Despite its potential, research on IS has primarily concentrated on its technical aspects, particularly in developed countries, while the social dimensions of IS—such as geographical proximity, information flows, and the intensity of industrial cooperation—remain underexplored. Understanding these social interactions is vital for creating effective IS networks, yet research in African contexts, including Kisumu County, Kenya, is lacking. Studies in Kisumu have primarily addressed waste management challenges and end-of-pipe solutions but have not sufficiently explored how IS can drive more sustainable solid waste reuse. This study aimed to fill that gap by examining how IS influences solid waste reuse in Kisumu County's manufacturing industries. The specific objectives were to determine the influence of geographical proximity on type of solid waste-material exchanged, examine association between information flows and type of solid waste-material exchanged and lastly, examine the influence of symbiotic intensity on amount of solid waste-material reused in the network. This study employed a descriptive cross-sectional research design. The exchange network theory guided the study. A total population sampling approach was utilized following the application of specific inclusion and exclusion criteria to industries. Among the 49 industries that satisfied the criteria, only 41 consented to participate in the study. Fieldwork was conducted between August and October 2021. Data was collected through surveys and interviews with five key stakeholders from the Kisumu County Government in the Department of Water, Environment, Natural Resources and Climate Change, Department of Physical Planning, Lands and Urban Development, Department of Energy and Industrialization, Kenya Association of Manufacturers and National Environmental Management Authority. The study established that geographical proximity did not significantly influence the type of waste exchanged ($p = 0.687$). Information flows showed a significant relationship between the frequency of communication and the type of waste exchanged ($p = 0.013$), although the type of information exchanged was not statistically significant ($p \geq 0.005$), limiting the ability to detect relationships. Symbiotic intensity, however, significantly influenced the amount of waste reused ($p = 0.039$). The study concluded that geographical proximity may not be a decisive factor in determining the types of solid waste exchanged within industrial symbiosis in Kisumu County. The type of information exchanged did not significantly influence the type of waste exchanged, but communication frequency strongly influenced solid waste reuse, implying it's not what information is exchanged but the frequency of communication that influences waste exchange. Lastly, symbiotic intensity significantly influences solid waste reuse, with a greater impact observed from increasing the number of actors within a network compared to increasing the types of waste exchanged. The study recommends improving data collection and monitoring efforts related to waste reuse across the region to help track IS initiatives across different proximities, enhancing information flows and increasing the number of industries in the IS network to promote more solid waste reuse. These findings can inform and benefit policymakers, manufacturing industries, and environmental regulators on how to optimize IS networks. Future research should explore the role of economic incentives, communication channels, and policy support in industrial symbiosis and assess how technology, innovation, and information flows impact solid waste reuse and symbiotic intensity.

TABLE OF CONTENTS

ABBREVIATIONS AND ACRONYMS

BPS- By-Product Synergy

CGK- County Government of Kisumu

EIP- Eco-Industrial Park

GoK- Government of Kenya

IE- Industrial Ecology

IS- Industrial Symbiosis

KAM- Kenya Association of Manufactures

LCA- Life Cycle Analysis

M&E- Monitoring and Evaluation

NACOSTI- National Commission for Science Technology and Innovation

NEMA- National Environmental Management Authority

NISP- National Industrial Symbiosis Programme

3Rs -Reduce, Reuse, Recycle

DEFINATION OF TERMS

Element value solid waste material: It refers to all types of solid waste materials that contain valuable chemical elements or compounds that can be extracted and reused. Types of solid waste material that fell under this category included plastics, glass, metal, lime, filter mud and ash from sugar processing, sludge, paint waste.

Energy value solid waste material: It refers to all types of solid waste materials that can be used as an alternative source of energy, either through direct combustion or conversion into fuel. Type of solid waste material included under this category were bagasse, rice husks, slurry, peanut hulls, sawdust and timber shavings

Fibre/Cellulose value solid waste material: It refers to all types of solid waste materials rich in fibrous content that can be reprocessed into packaging paper, leather and textile. The types of solid waste material included under this category were waste paper, hides and skins, fabric and leather offcuts

Geographical proximity: it refers to the distance in kilometers between industries involved in symbiotic exchanges. This variable was be analyzed in relation to the types of solid waste material exchanged.

Industrial symbiosis (IS): It refers to the collaborative practice whereby solid waste material from and industry is reused as an input in manufacturing another product within the facility or in another collocated industry with the network. In this study, it was measured as geographical proximity, information flows and symbiotic intensity.

Information flows: This is the exchange of information/knowledge between actors in a network. In this study, information flows was measured in terms of frequency and type of communication between actors.

Manufacturing industries: These industries are based on the fabrication, processing, or production of material from raw materials. The manufacturing industries were categorized as agroprocessors, food and beverage, energy sector, building and construction, chemical and allied, metal and allied, timber, paper and board, leather and textiles and plastics.

Nutrient value solid waste material: It refers to all solid waste materials that are rich in nutrients and can be repurposed for animal feed. The types of solid waste material under this category included molasses, maize germ, wheat pollard, rice bran, peanut skins,spent grain, hops, breadcrumbs, slaughter house waste.

Solid waste material: The by-products of a process can be reused as input (resource) in another process. This study measured it based on the type of solid waste material exchanged. The categories of the type of waste were based on the value attached to the waste material, i.e., nutrient value waste, energy value waste, element value waste, fibre and cellulose value waste.

Solid waste reuse: Refers to solid waste material of the manufacturing process that are reprocessed into other products. In this study, it was measured in terms of the type of solid waste-material exchanged and the amount of solid waste-material reused annually in a network.

Social dimensions: It refer to the elements that influence interactions and relationships between industries involved in industrial symbiosis. Specifically, they include geographical proximity (the physical distance between actors in the network), information flows (types and frequency of communication among actors), and symbiotic intensity (the number of actors and types of resources exchanged within the network). These factors affect collaboration, trust-building, and the success of symbiotic exchanges between industries.

Symbiotic intensity: the connectedness of actors based on solid waste-material (by-product) exchanges. In this study, the symbiotic intensity was measured by the number of actors in the network and the number of types of solid waste material exchanged in the exchange network.

LIST OF TABLES

LIST OF FIGURES

CHAPTER ONE

INTRODUCTION

1.1 Background to the study

Industrial Symbiosis (IS) is an emerging approach focused on the 3Rs: recovery, recycling and reuse of waste (material, water, and energy) from the industry-generating wastes to the collocated industry using those wastes as raw materials for industrial processes (Chertow, 2000). IS anchors on the upheld strategies in the hierarchy of waste management, that is, waste minimization, re-use, material cycling, energy recovery, and waste disposal (Costa *et al.*, 2010), 3R reduces the amount of waste from production to disposal, thus managing it more efficiently and lessening its public health and environmental risks (Memon, 2010). While efforts to implement sustainable waste management practices have been initiated globally, including the promoting recycling and waste-to-energy technologies, these strategies have often been hindered by ineffective policy frameworks, lack of infrastructure, and poor stakeholder engagement (Hoornweg & Bhada-Tata, 2012). Furthermore, these approaches largely focus on end-of-pipe solutions rather than addressing waste generation at the source, particularly within the industrial sector (Geng et al., 2012). The global waste generation is projected to reach 3.4 billion tonnes annually by 2050, driven largely by urbanization and industrial growth in developing regions (Kaza et al., 2018). In many regions, including developing countries like Kenya, solid waste management remains a critical challenge, with most waste either being disposed of in landfills or inadequately managed, missing opportunities for reuse. Similarly, in Kisumu, the strain from this increasing waste burden is already visible in unsightly dumpsites, pollution of water bodies, and the degradation of living conditions, emphasizing the urgent need for more sustainable waste management strategies like industrial symbiosis. IS's rationale is to organise industrial activities to have negligible effects on natural ecosystems. However, industrial activity is not a natural process and may not fully align with natural ecosystem models. This study explored how IS can influence waste reuse with in the manufacturing industries.

IS was first developed in Kalundborg, Denmark (Ehrenfeld & Gertler, 1997), and private actors formed symbiotic networks to exchange resources for profitability, production cost reduction, and business expansion. Van Berkel, (2009) studied symbiosis from the structural view of actors in the network and established that symbiotic intensity—defined as the number of actors and types of resource exchanged—has been a key indicator of the complexity and effectiveness of IS networks. For example, Kawasaki City, Japan, implemented IS across 74 industrial facilities to address challenges related to municipal solid waste (Dong *et al.*, 2013). China established a network of 31 symbiotic industries between 1991 and 2011, contributing to material exchanges that have significantly improved waste management and environmental sustainability (Yu *et al.*, 2015). These transactions are more than simple exchanges—they represent high-level collaborations that involve continuous networking among industries. However, despite these successes, it remains unclear how collaborative networks between industries can be strengthened and sustained over time, especially from a social perspective. Additionally, the literature suggests that higher symbiotic intensity typically leads to better environmental outcomes, as evidenced by the waste diversion seen in Kawasaki and Kalundborg. However, most studies focus on developed regions and offer limited insights into how multifaceted exchanges in developing countries contribute to overall waste management. This research examined how the social dynamic of these collaboration networks influence solid waste reuse.

In their study, Gibbs and Deutz (2007) developed the Virtual Eco-Industrial Park (EIP) that redefines the Kalundborg model by allowing firms not in proximity to engage in IS. They further argued that if waste streams can offset their transportation cost and make economic sense, then a 'virtual' EIP can include exchanges throughout the region and even the world (Gibbs & Deutz, 2007). Hence5, collaboration and synergistic opportunities offered by the geographical proximity of interacting industries are essential to IS (Chertow, 2000). Undoubtedly, the proximity of actors in industrial estates fosters the linking of utilities and the exchange of waste and by-products (Boons, 2008). Furthermore, proximity facilitates and eases the development of trust and cooperation between companies (Hewes & Lyons, 2008). However, proximity may not be a confounder when the by-products in question have a high value attached to them, such as pure Sulphur, a by-product of sour-gas treatment (Chertow & Ehrenfeld, 2012). The context of these studies is developed nations where planning and zoning of activities are well executed to improve the efficiency of systems. Industries are zoned into what is described as industrial estates and eco-industrial parks. These studies have focused on developed nations, where efficient planning and zoning is standard practice, with industries often located in industrial estates and eco-industrial parks. In contrast, in developing countries, industries establish collaborative networks even in the absence of formal zoning which creates challenges for implementing Industrial Symbiosis (IS) effectively. This study critically examined how geographical proximity operates in such contexts and how it influences the exchange of solid waste materials, particularly in the absence of formal industrial planning.

A reliable method is needed to create an industrial ecosystem that fosters material cycling within networks and ensures strong, long-term cooperation and information exchange at a technical level among participating businesses (Ayres & Ayres, 2002). Cooperation, in the form of inter-firm relationships or partnerships, involves the sharing of information, resources, and certain risks to achieve common goals (Bowersox *et al.*, 2003). To maximize material and energy recovery in closed-loop systems, it is essential to understand the social dimensions that drive exchanges within IS networks and foster cooperative business partnerships (Domenech & Davies, 2011). In Kenya, IS could be promoted by establishing forums that encourage cooperation and information sharing between stakeholders (Kenya Association of Manufacturers, 2015). ICT technologies designed for industrial symbiosis are frequently highlighted in research on information and knowledge transfer, as they facilitate the exchange of expertise and help identify potential synergies (van Capelleveen *et al.*, 2018). Techniques such as New Process Discovery, Case Study Mimicking, Material Budgeting, and Input-Output Matching have been developed specifically for IS to uncover and promote symbiotic partnerships (Grant *et al.*, 2010; Holgado *et al.*, 2018). While studies have explored the role of information exchange in promoting IS, critical challenges remain, particularly in business contexts like manufacturing, where information is often not freely shared due to various concerns. Therefore, this research assessed the relationship between information flows (the types of information exchanged and the frequency of communication) and the type of waste exchanged.

The UNIDO (2017) report highlights environmental challenges for African manufacturing: pollution, waste management, and resource use. The environmental performance of Africa's manufacturing industries varies depending on several factors, including the country, the sector, and the specific companies involved (Belhadi *et al.*, 2020). The report notes that many industries struggle with poor environmental performance due to limited financial and technical resources, weak regulatory enforcement, and low public awareness of environmental issues. Additionally, some industries prioritize economic pressures and face regulatory barriers, which further hinder progress in addressing environmental concerns. Despite these challenges, there are significant opportunities to enhance environmental performance by adopting innovative and sustainable practices. This paper proposes insights into industrial symbiosis, that will advance sustainable manufacturing processes in Africa.

Although industrial parks exist in Africa, their activities often do not align with the international standards of eco-industrial parks, as seen in cases like Pretoria and Hartbeespoort in South Africa (Brent *et al.*, 2008). Cases of industrial symbiosis (IS) have been reported in West Africa, Liberia, and the Benin Republic, particularly in integrated smallholder agriculture, where material and energy flows are optimized. Studies by Alfaro and Miller (2014) and (Kamndaya, 2015) identified collaboration opportunities in Zanzibar's tourism and agriculture sectors, including sharing food waste for animal feed and reusing wastewater for irrigation. In South Africa, significant potential exists in the agro-processing sector for resource sharing and waste reuse, but challenges such as poor communication, lack of cooperation, and fragmented networks hinder broader adoption (Cárcamo & Peñabaena-Niebles, 2022).

A case study of IS in Tanzania's sugar industry further revealed an evolving network of byproduct and utility synergies among seven industries, demonstrating the importance of collaboration and material exchanges (Rweyendela & Mwegoha, 2021). While IS holds promise for sub-Saharan Africa by improving resource efficiency, economic competitiveness, and waste reduction, broader implementation faces obstacles due to limited inter-industry cooperation, low awareness of IS benefits, and challenges in building effective communication networks (Oni *et al.*, 2022). While many studies emphasize the role of regulations, it is crucial to investigate the social and practical factors that enable IS to thrive in challenging contexts. This paper highlights how information flows geographical proximity and symbiotic intensity drive waste reuse in IS networks to enhance environmental performance within the manufacturing sector.

In Kenya, IS can be promoted and supported with a series of recommendations, including awareness-raising and capacity-building activities, the development of supportive policy and regulatory frameworks, and a platform for stakeholders to collaborate and exchange information

(Kenya Association of Manufacturers, 2015). One notable effort was the SWITCH Africa Green project, an initiative of the European Union (EU) aimed at promoting sustainable consumption and production patterns in six African countries, including Kenya. This project, which ran from 2014 to 2018, focused on encouraging sustainable industrial development and transitions to a green economy(European Union, 2018). Kenya is now making strides toward implementing circularity in critical sectors by embracing the 3Rs (reduce, reuse, recycle) concept. This shift is expected to spur the development of new enterprises involved in redesigning, recycling, and waste management, thanks to effective collaboration between government agencies and the private sector. Furthermore, recent policy initiatives such as the Sustainable Waste Management Act 2022 and the Extended Producer Responsibility regulations 2021 (Kenya Circular Economy Network, 2021) are key steps in formalizing these efforts. However, despite these advancements, there remains a gap in understanding how IS can be effectively integrated into Kenya's existing waste management and industrial frameworks. This study attempted to demonstrate how IS influences solid waste reuse as a sustainable waste management approach and thereby shape policy from the recommendations.

Mainstreaming the culture of Eco-Industrial Parks (EIPs) in Kenya faces several challenges, such as limited stakeholder awareness, inadequate collaboration between industries, and poor infrastructure (Khisa *et al.*, 2018). Overcoming these challenges requires practical strategies focusing on increasing stakeholder participation, building stronger collaborative networks, and fostering effective communication between industries and communities. For instance, the potential to create a waste exchange platform at the Ruaraka Industrial Park could significantly improve resource efficiency and promote circular economy practices through direct industry cooperation. While policy support is often cited as essential for the success of Industrial Symbiosis (IS) (Damgaard *et al.*, 2019) the critical enabler is the collaborative efforts of stakeholders, including industries, local communities, and government agencies. Studies have provided insights into the practical aspects of implementing IS in industrial parks, emphasizing the need for collaboration between stakeholders, including government agencies, industries, and local communities, to achieve the goals of eco-industrial parks (Ramin *et al.* 2021;Ronoh 2020). While these studies highlight the significant benefits IS could bring to Kenya, such as improved resource efficiency and reduced waste, they also point out the considerable challenges that need to be addressed for effective implementation. While existing studies primarily focus on the challenges and recommendations for implementing Industrial Symbiosis (IS), there has been minimal research on understanding how IS practices manage to thrive in the face of these obstacles and what specific factors contribute to their success. Moreover, little attention has been given to quantifying the actual benefits of IS in terms of solid waste reuse. This study shifted focus from the challenges of IS implementation to exploring how IS networks operate despite these barriers, and measured how IS contributed to waste reuse.

Despite its potential to revolutionize sustainable waste management, Industrial Symbiosis (IS) remains severely underutilized in many developing regions, where inefficient waste disposal practices continue to exert immense pressure on environmental resources. Kisumu City generates roughly 400 tonnes of solid waste daily, but only 20%-25% is collected for disposal in an open dump site. Of the waste collected, 65% is organic and 27% recyclable, representing a vast untapped potential for value recovery (County Goverment of Kisumu, 2018). Over the years, Kisumu County has struggled with severe waste management issues, compounded by factors such as rapid population growth, inadequate planning, and weak waste management systems (Munala & Moirongo, 2017; Sibanda *et al.*, 2017). Pollution from improper waste disposal and illegal discharge of liquid waste and air pollutants by local industries has worsened the situation, leading to the denial of operating licenses for several manufacturers (The Star, 2019; Standard

Media, (2019). The waste crisis in Kisumu is further aggravated by the inefficient capture of waste resources, which are largely lost to the dumpsite instead of being integrated into the city's waste economy (Awuor *et al.*, 2021). Despite the potential for resource recovery, there has been a lack of participation from producers in solid waste disposal and management, and the techniques used in Kisumu have failed to maximize value recovery prospects (Awuor et al., 2021). Dianati et al. (2021) and Mascarenhas et al., (2021) compared various waste management technologies, assessing them based on financial costs, electricity production, greenhouse gas emissions, land footprint, and environmental contamination (Dianati *et al.*, 2021; Mascarenhas *et al.*, 2021).

These studies suggest that solid waste management in Kisumu faces several challenges, including inadequate infrastructure, lack of awareness and participation of industries in circular economy. Solutions provided in these studies have focused on highlighting challenges in solid waste management and giving end-of-pipe solutions which are inadequate. Industrial Symbiosis offers a better alternative, although there has been limited research into circular economy approaches such as Industrial Symbiosis and specifically how geographical proximity, information flows, and symbiotic intensity could offer transformative potential in waste management. The study investigated the influence of IS on waste reuse in Kisumu's industries. The study sought to understand how collaborative networks between industries could enable Kisumu to reclaim significant amounts of waste, turning it into valuable inputs for other industries, thereby reducing the amount of waste sent to dumpsites, cutting down environmental pollution, and enhancing resource efficiency. Given the city's ongoing waste management challenges, this research explored how IS can be applied to optimize solid waste reuse and unlock sustainable growth opportunities. The circular economy framework IS offers presents a promising alternative to the existing linear waste disposal methods, warranting its research as a critical solution for Kisumu County's waste management challenges.

1.2 Statement of the problem

In developing countries and Kisumu County too, current waste management efforts are primarily focused on end-of-pipe solutions, addressing waste after it has already been generated. This traditional waste management approach is inadequate, leading to environmental degradation and lost opportunities for waste minimization and resource recovery and an unsustainable accumulation of waste in dumpsites. Additionally, waste management at the production stage, particularly in manufacturing industries, remains under-addressed. The expansion of the manufacturing sector, often a marker of economic growth, has further exacerbated the waste management problem because of increased waste generation from manufacturing processes. Industrial symbiosis provides an integrated approach that incorporates circular models that industries can implement to promote the reuse of waste with the end goal of lessening the burden on the environment. Despite the technical feasibility (innovative solutions to transform waste into valuable resources) of IS being well-documented, particularly in developed countries, its successful implementation relies on several critical social dimensions such as geographical proximity, information flows, and symbiotic intensity. These factors remain underexplored in regional contexts, including Kenya and Kisumu County, where few studies have examined the practical application of IS for waste management at the manufacturing level. Regionally and in Kenya, research studies have brought forth the challenges and barriers of the practice of IS; however, there is a gap in understanding how the few cited IS activity thrives in the wake of the challenges and to what extent the practice has influenced solid waste reuse. This research sought to explore IS by assessing how the social dimension (geographical proximity, information exchange, and symbiotic intensity) influences solid waste reuse within Kisumu's manufacturing sector. Understanding these factors provided insights into how IS can drive waste reuse at the production level, support sustainable growth, and improve environmental outcomes of waste management in Kisumu County.

1.3 Objective of the study

The main objective of this research was to examine the influence of industrial symbiosis on solid waste reuse in manufacturing industries in Kisumu County.

Specific Objectives:

1. To determine influence of geographical proximity on types of solid waste-material exchanged.
2. To establish the association between information flows and types of solid waste-material exchanged.
3. To examine the influence of symbiotic intensity on amount of solid waste-material reused in the network.

1.4 Hypotheses

1. Geographical proximity has no significant influence on the types of solid waste material exchanged in the network.

2. There is no significant association between information flows and the types of solid waste material exchanged.

3. Symbiotic intensity has no significant influence on the amount of solid waste material reused in the network.

1.5 Justification of the study

Kisumu County, located on the shores of Lake Victoria, was selected for this study due to its strategic position as a major commercial, industrial, and transport hub for Western Kenya and the broader East African region. Its rapid industrial growth, coupled with population expansion, has resulted in increased waste generation, putting tremendous pressure on the environment. Existing waste management strategies in Kisumu have primarily focused on post-consumption waste, leaving production-level waste largely unaddressed. This study focuses on Industrial Symbiosis (IS) an approach that promotes the reuse of waste within manufacturing industries, aligning with the principles of a circular economy to reduce environmental degradation.

Industrial symbiosis is especially relevant for Kisumu, as it offers a solution to the growing waste management crisis by encouraging industries to collaborate in the exchange and reuse of byproducts, thus reducing the volume of waste sent to dumpsites. Existing studies have mostly addressed the technical and infrastructural aspects of waste management, leaving unexplored the influence of these social dimensions, which are crucial for effective collaboration in IS. The relevance of this study is underscored by the need to understand how social dimensions (examining the geographical proximity, information flow, and symbiotic intensity), which are crucial for IS, influence waste reuse, especially in Kisumu County, where many challenges and barriers of IS exist as highlighted from previous research in developing countries.

Geographical proximity is essential because closer proximity can lower transportation costs and foster more waste exchange partnerships. Additionally, efficient communication is a critical enabler of the timely exchange of solid waste materials, whereas greater symbiotic intensity has the potential to improve the amount of waste reused, thus improving resource efficiency and reducing waste disposal, making this a key factor for successful IS implementation. By addressing these objectives, the study provides insights that will benefit manufacturers by identifying sustainable opportunities for IS. Policymakers will also gain valuable knowledge to shape industrial policies that support sustainable waste management, while environmental agencies can use the findings to scale practical solutions that contribute to Kisumu's transition toward a zero-waste economy, fostering green economic growth.

1.6 Scope and Limitations of the Study

This study was carried out in the manufacturing industries in the following sectors: agro-processing, food and beverage, metal, chemical, building mining and construction of buildings, leather and textile, paper, energy, and plastics. Collaboration industries within the exchange network were established to be within a minimum radius of 0.4 km and a maximum of 121km. Three limitations were faced during the study. Firstly, data collection was conducted during the COVID-19 pandemic; some industries did not allow physical meetings to administer the questionnaires. This was overcome by emailing the questionnaires to the respondents and virtual administration performed via phone calls for those particular industries. The second limitation of the study came from the failure to secure an introduction letter from the Kenya Association of Manufacturers that would be issued to the industries that belong to the association to enhance the transparency and validity of the research. This was overcome by carrying out the study alongside the Sustainable Energy Access and Climate Action Plan project that was ongoing at the same time within Kisumu County. Lastly, many industries did not inventory the amount of waste generated, so estimates were established based on respondents’ estimations. The study's findings depend on the availability and accuracy of the data collected from manufacturing industries and key stakeholders.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

The background knowledge of industrial symbiosis lays the groundwork for understanding its key principles and applications in industrial processes to facilitate waste management. This chapter reviewed how specific aspects of IS, such as geographic proximity, information flows, and symbiotic intensity, shape its practical implementation and their influence on solid waste reuse. The study's main objective was to assess how industrial symbiosis influences solid waste reuse in Kisumu County's manufacturing sector. The chapter concludes by conceptualizing a theoretical framework that aided in understanding the interactions between the variables in the study.

2.2 The Concept of Industrial Symbiosis and the 3Rs

This concept draws back to 1989, following the Brundtland Commission report (Brundtland, 1985), when Frosch envisioned Industrial Ecosystems in which the consumption of energy and material is optimised and the effluent of one process serves as raw material for another system (Frosch & Gallopoulos, 1989). A comprehensive and widely accepted definition of IS in the field of industrial ecology (IE) research is that one offered by Chertow (2000), which characterizes IS as an aggregated approach to the competitive advantage that involves the exchange of materials, energy, water, and/or by-products across industries that are conventionally and physically separate. Industrial Symbiosis (IS) is a collaborative practice resulting in environmental benefits such as waste reuse while promoting resource efficiency and economic development (Jensen *et al.*, 2011). Researchers have expressed various opinions on the content of exchange in these networks. Collaborations are viewed in aspects of material exchanges (Graedel & Lifset, 2016), exchange of knowledge and other resources (Mirata & Emtairah, 2005); by-product, utility exchanges, and joint provision service (Chertow, 2007), expertise, and technology transfer (NEW, 2018). IS relies on the established strategies of waste management, the 3Rs, which include waste minimization, reuse, material cycling, energy recovery, and waste disposal (Costa *et al.*, 2010). In the 3Rs of waste management, the practice of obtaining resources or value from waste is typically referred to as recycling, which involves recovering or reusing the material. IS is anchored within the broader context of sustainability and is characterized by natural ecosystems and integration of the 3Rs, which are solid waste management principles for resource efficiency and minimization. This study offered further understanding on how the practical implementation of IS amongst industries supports the 3Rs, considering that natural ecosystems may not perfectly explain the practice of firms in an industrial network because it is a man-made factor.

Capitalizing on resource and energy use through IS can minimize the waste of resources and energy through waste-material exchanges (Mangan & Olivetti, 2010). The waste hierarchy prioritizes waste minimization through classifying strategies based on the desirability of the waste to reduce reuse and recycle (Siddique *et al.*, 2008). While these strategies are distinct, they are also interrelated and mutually supportive, as they all contribute to reducing waste generation, conserving virgin resources, and mitigating the environmental impact of waste. IS has successfully demonstrated "win-win" outcomes by aligning industrial production with environmental protection (Raafat *et al.*, 2013). Industrial Symbiosis has integrated the 3Rs in various sectors of the manufacturing industry. For instance, Chapparal Steel and Texas Industries developed a new technology of adding slag from the steel plant to the raw cement mix, which resulted in a 10% increase in cement production and a more than 10% drop in energy consumption (Mangan & Olivetti, 2010). Other research on IS in the iron/steel industry points toward recycling metal ores into production processes (Branca *et al.*, 2020; Dong *et al.*, 2013).

Kamndaya (2015) explored potential collaboration opportunities in Zanzibar's tourism and agriculture sectors. They established that sharing food waste for animal feed and reusing wastewater for irrigation were among the identified opportunities (Kamndaya, 2015). A case study of IS in Tanzania's sugar industry revealed an evolving network with byproduct and utility synergies among seven collated industries (Rweyendela & Mwegoha, 2021) that reuse the byproducts of sugar processing for energy recovery. In Kisumu, Ojijo (2023) explored the role of waste value addition and established that reuse and recycling, composting, and waste-to-energy initiatives have been implemented by the county to manage solid waste. The connection and benefits of 3Rs and IS is made apparent. Still, there is not a sufficiently critical evaluation of the practical implementation of IS to integrate the 3Rs in the collaborative relationships formed. This research focused on elements of collaborative relationships in IS influenced solid waste material reuse.

2.3 Geographic proximity and Types of Solid waste-material exchanged

Globally, it has been observed that the key to industrial symbiosis is collaboration and synergistic opportunities offered by geographical proximity (Chertow, 2000). van Berkel *et al.* (2006) clarified that synergies based on by-product synergies are those that entail the reuse of a previously disposed of by-product from one facility by another facility to produce a valuable product. By-product synergy is not merely a waste exchange process, which is inherently a static process, but is an active process that allows synergies that would otherwise not be possible (Mangan & Olivetti, 2010) Mangan and Olivetti (2010)explain by-product synergy as the creation of exchange linkages by complementing undervalued by-products from one facility with potential users at another (Mangan & Olivetti, 2010). While literature highlights geographical proximity as a crucial factor for fostering collaboration and synergies in industrial symbiosis (IS), a closer examination reveals that proximity alone may not be sufficient to achieve sustainable synergies, particularly in the context of solid waste material reuse. The emphasis on geographical proximity assumes that physical closeness will naturally foster synergies, but it often fails to consider that certain solid waste materials may limit reuse potential, limiting the effectiveness of IS practices. This research explored how geographical proximity exists influences different types of solid waste materials exchanged.

Geographical proximity is essential in developing eco-industrial parks (Lowe, 2002).This is because the proximity of actors in industrial estates fosters the linking of utilities and the exchange of waste and by-products, as reiterated by (Boons, 2008). Generally, symbiotic industrial facilities need to be close to avoid high transport costs and energy degradation during transit; however, this may not be a confounder in the case of high-value by-products such as pure sulfur from sour-gas treatment (Chertow *et al.*, 2008). Close proximity facilitates and eases the development of trust and cooperation between companies (Hewes & Lyons, 2008). Geographical proximity is beneficial because it minimizes costs incurred in these waste exchanges, and trust between actors in the network is increased (Domenech & Davies, 2011). The benefits of cooperation offered by geographically proximate industries are established. However, industries are not necessarily organized in eco-industrial parks, and as such, the interactions of such industries might differ in comparison to those organized within parks. Therefore, this study sought to quantify geographical proximity in industries outside eco-industrial parks to have a data-driven understanding of how the physical location of firms impacts their ability to form symbiotic relationships and assess how it influences the type of solid waste material exchanged.

Jensen *et al.* (2011) found that the median distance between materials within an exchange of solid wastes relationship was 20.4 miles in the UK. Furthermore, minerals and hazardous waste in the UK cover the longest distance in exchange networks at 259.7 miles. The material that moves the shortest distance is wood by-products at 0.1 miles. In other regions, the geographical distance is much higher than that of the Kalundborg network, in which material exchange occurs within a two miles radius (Domenech & Davies, 2011). Bulky low-value waste, such as construction and demolition waste, is typically limited to local (city/metropolitan area) transactions, whereas low-volume high-value resources, such as cobalt, may have an international market. Because steam and waste heat cannot be transported over long distances, they must be limited to the local level (Domenech *et al.*, 2019).The study findings on the geographical distance for nutrient value waste exchanges were consistent with the patterns observed by Jensen et al. (2011), though there were variations due to the nature of materials and the geographical context of the studies. Studies have demonstrated that materials like minerals and hazardous waste are exchanged over long distances, while bulky, low-value materials like construction waste are confined to local exchanges. However, limited research has been conducted on how specific material characteristics, such as value that make it of particular reuse interact with proximity to shape the efficiency and viability of industrial symbiosis networks. This research looked into the relationship between material type and exchange distance, particularly in different geographical and industrial contexts.

Industrial symbiosis, as portrayed in eco-industrial parks (EIP), is a relatively new concept in African countries. Although the concept of EIPs has, to some extent, been adopted, the ideal has yet to become practiced (Brent *et al.*, 2008). In West Africa, IS has been linked to the growing field of integrated agriculture research in smallholder farms in Liberia to increase farm production (Alfaro & Miller, 2014). In East Africa, IS has been practiced in Tanzania's sugar industry, where there have been physical exchanges of bagasse, molasses, filter cake, and boiler ash and utility sharing among seven co-located units (Rweyendela & Mwegoha, 2021). These examples highlight isolated successes rather than widespread adoption. Despite commendable research efforts in the African context, existing studies have failed to explore the critical role of geographical proximity as a foundational element of IS, particularly in relation to the types of solid waste byproduct exchanges. This research aimed to address this gap by examining how proximity and the type of solid waste materials exchanged impact the effectiveness of industrial symbiosis networks in terms of waste management.

Distance to the main road is a determinant factor in a household's choice of solid waste management in for slum dwellers in Nairobi (Nthambi et.al, 2013). The SWITCH Africa Green project, funded by the European Union, launched a two-year program in Uganda and Kenya, aimed at empowering SMEs through capacity-building initiatives focused on industrial symbiosis (European Union, 2018). 60% of waste in Kisumu is organic making anaerobic digestion the most appropriate treatment option for Kisumu (Mascarenhas et.al, 2021). K'oyoo et.al, (2022) established distance to be a restricting factor for households to use abandoned quarries to dump waste**.** Geographical proximity could be equally crucial in the context of developing countries and Kisumu given that previous studies highlight that distance plays a crucial role in determining waste management practices. This supports the idea that geographical proximity may be a limiting factor in the exchange of solid waste among industries, just as it affects household-level waste management. The SWITCH Africa Green project's focus on enhancing IS capacity in Kenya demonstrates the focus on promoting circular economy practices. Studies largely ignore how the distance between industries can either facilitate or hinder the exchange and reuse of waste materials. Given that Kisumu's industrial growth has led to increased waste generation, this study sought to understand if and how geographical proximity impacts the type of solid waste exchanged between industries.

2.4 Information flows and types of solid waste-material exchanged

Information means a stream of messages conveying facts pertinent to the recipient (Davenport & Prusak, 1998). In the context of industrial symbiosis, information sharing plays a crucial role in fostering eco-innovation and cultural shifts, enabling mutually beneficial exchanges between organizations (Lombardi *et al.*, 2012). Comprehending the social determinants of IS network exchanges and cooperative business relationships is crucial for understanding IS dynamics and maximising material and energy recovery in closed-loop systems (Domenech & Davies, 2011). Geng *et al.* (2012) highlighted the importance of information sharing and communication in promoting symbiotic relationships between industries. However, much like geographical proximity, the effectiveness of these exchanges depends heavily on the social dimensions that underpin collaboration and information flow. This research examined how information flows interact with proximity to influence the success of industrial symbiosis networks, providing insights into how cooperation and communication drive efficiency in material reuse.

The technological viability of exchanges has been the primary focus of industrial symbiosis (IS) research globally, while social components have received considerably less attention (Korhonen, 2001). Beyond the technological feasibility of by-product exchanges between businesses, social dimensions considerably impact the growth of IS networks (Domenech & Davies, 2011). A complex range of social interactions behind the physical flows of commodities, waste and utilities, which Chertow and Ehrenfeld (2012) refer to as "social embeddedness," enables synergies and collaboration. Velenturf (2017) further supports this by asserting that IS inherently involves the creation of social networks (Velenturf, 2017). While an increasing number of scholars recognize the challenges and importance of information and knowledge exchange, few scientific studies have addressed the lack of these exchanges as a major barrier to IS. This research explored how information flows influence the reuse of solid waste-material from manufacturing processes.

To establish an industrial ecosystem that fosters material cycling within a network, a trustworthy system for long-term cooperation and information exchange at the technical level must be developed (Ayres & Ayres, 2002). Cooperation in industrial symbiosis (IS) involves sharing information, resources, and some level of risk, with partnerships defined by collaborative links between enterprises to achieve common goals. (Bowersox *et al.*, 2003). Bowersox further argues that an industrial symbiosis model cannot be developed without first identifying consistent relationships, described as the matching results (score) between two or more stakeholders using specified rules and algorithms. The success of Kalundborg has been attributed to the coordination role of Symbiosis, which helped to institutionalize the exchange of knowledge and information (Chertow, 2007). Membership in the Puerto Rico Manufacturers' Association was associated with IS, indicating that professional associations provided a forum for managers from various industries to interact (Ashton, 2008). In Kisumu, Sibanda et.al, (2017) highlights the importance of collaboration in promoting reuse waste by stakeholders where industrial waste such as organic food wastes and inorganic wastes types like plastics, ash, wood pellets, demolition waste, glass bottles and cardboards (Nyaluongo, 2016). While substantial cooperation through information exchange has been recognized as crucial to the success of industrial symbiosis, limited research has explored how these information-sharing mechanisms foster symbiotic exchanges. This study examined the processes of information exchange in terms of type of information and frequency of communication to understand their role in building industrial symbiosis networks, particularly in different types of waste exchanged.

Research frequently highlights the role of ICT tools in facilitating information and knowledge transfer for industrial symbiosis (IS), with these tools being valuable for identifying potential synergies (van Capelleveen *et al.*, 2018). The formalization of consistent linkages is based on many entities, including the market sector, the input/output of materials, and the geographical position and distances between enterprises (Marconi *et al.*, 2018). From a technical standpoint, matching waste supply and demand is crucial for IS growth, but a lack of information among companies often hinders this process (Fraccascia and Yazan, 2018). Methods like New Process Discovery, Case Study Mimicking, Material Budgeting, and Input-Output Matching have been developed to identify potential IS partnerships through ICT tools(Grant *et al.*, 2010; Holgado *et al.*, 2018). The most common method is input-output matching, which involves identifying potential IS matches by analysing the characteristics of output streams (i.e., wastes and by-products) from industries and the material inputs they require before matching one to the other (Low *et al.*, 2018; Yeo *et al.*, 2019). The National Industrial Symbiosis Programme (NISP), which uses bottom-up approaches to facilitate IS in a given region, is the most well-known programme that uses input-output matching. NISP can identify opportunities among stakeholders participating in workshops using a cross-sectoral and supply-chain approach (NEW, 2018). ICT plays a critical role in communication and innovative synergies. The majority of previous research has focused on ICT tools developed for symbiosis in developed countries, where IS practices are well-established. This research examined how manufacturing industries in developing countries exchange information and foster collaborative synergies, particularly in contexts where advanced ICT tools for symbiosis are unavailable or underutilized.

The National Industrial Symbiosis Programme (NISP), a network facilitator in the United Kingdom, engaged in three strategic actions in the network: conversation, connection, and co-creation (Paquin & Howard-Grenville, 2012). They argued that conversation actions are necessary to develop exchanges between firms, using data on resource flows, regulation, regional profiles, established contacts, and interaction spaces. Schlueter, (2017) in her study of the role of local government in Kisumu in solid waste management established that the absence of effective communication channels and the blame-shifting between departments have significantly diminished the potential for cooperation, thereby obstructing efforts to enhance the efficiency of solid waste management. Conversational approach plays a critical role in identifying potential synergies among firms, enabling the effective exchange of materials and resources. Kosmol (2019) highlights the interchangeability of information and knowledge in many instances, though she distinguishes between the two and elaborates on the types of information relevant to industrial symbiosis. This includes data on produced and required resources, waste quality, composition, hazardousness, supply patterns, and company details such as location and willingness to cooperate. Yeo *et al.* (2019), in their assessment of the 1994 review of industrial waste exchanges, the United States Environmental Protection Agency (US EPA) found that waste exchanges may function as information clearing houses (disseminating information on waste type, location, and availability)or brokers, where staff actively facilitate transactions between firms. They demonstrated that free-market mechanism-based matching tools require detailed information such as company profiles, waste descriptions, availability, and pricing to create effective exchanges. Despite these insights, there is still limited research that has examined how the frequency of communication and various types of information, such as waste quality, composition, and company details, interact with the effectiveness of industrial symbiosis exchanges. This research explored the relationship between the type of information shared and the type of solid waste-material exchanged, particularly in different geographical and industrial contexts.

Skvoretz and Lovaglia (1995), examined the structural factors influencing the frequency of exchange in negotiated exchange networks and emphasized the importance of social structure and power dynamics in determining exchange patterns in negotiated exchange networks. Similarly, Staber (2001) emphasized that firms innovate and thrive through collective learning processes, which heavily depend on existing synergies among a network of firms. He argued that for innovation and collaboration to be successful, a highly flexible network that facilitates the free exchange of information and knowledge is essential. Hartwick and Barki (2001) further noted that frequent communication should be an integral part of user participation in the development of industrial symbiosis systems. Communication frequency improves trust because it allows for a better understanding of personal characteristics and the organizational context (Irma Becerra-Fernandez, 2001). However, limited research has explored how social dimensions, such as communication frequency interact with the structure of IS networks to influence the effectiveness of exchanges of different types of waste. This study investigated the relationship between frequency and type of communication and the exchange of different types of solid waste materials in the network.

A high frequency of interaction can lead to shared beliefs among team members (Nicholson *et al.*, 2001). Team activities, whether as formal weekly meetings or informal (and often daily) gatherings within the workplace, provide an essential forum for knowledge sharing through face-to-face exchange (Hocking *et al.*, 2007). Frequent communication also aids in developing and maintaining social capital, which is embedded in the relationships of the team members (Gajendran & Joshi, 2012). According to Park and Lee (2014), project teams must try to increase trust in the partner by utilizing diverse expertise and frequent communication because trust affects knowledge sharing between clients and IS consultants. Research studies echo the importance of frequency of communication in improving trust and social capital necessary for IS. However, there is limited research on how communication frequency influences the actual material exchanges within industrial symbiosis networks. This study examined the role of communication frequency in shaping the types of solid waste materials exchanged, particularly in different industrial contexts.

2.5 Symbiotic intensity and amount of waste reused

A framework for comprehending the structure and dynamics of industrial ecosystems was developed by Chertow (2000) under the name "3-2 heuristic model" of industrial symbiosis, which postulates that an exchange of at least two distinct resources requires the participation of a minimum of three separate entities. Symbiotic intensity measures give insight into the organizational complexity of the industrial environment (Berkel et al., 2009). He examined the symbiotic intensity of industrial networks in Kawasaki, Japan, where three entities exchanged four distinct resources, leading to 14 symbiotic projects across nine companies, four of which belonged to the one-company group. He further noted that this methodology can be used to track IS growth but falls short in comparing different IS cases. in Kawasaki, Japan, Berkel et al. (2009) noted that 565,000 tonnes of waste were diverted from landfills or incineration through seven material exchanges. Gutberlet et al., (2016) in their study of solid household waste management chain in informal settlements in Kisumu, illustrated a complex, multilevel, and highly networked system of waste management actions. This system encompassed a diverse range of interactions and actors across multiple levels. The objective of studying the influence of symbiotic intensity on the amount of waste reused, therefore, aligns with the need to understand how various actors and exchanges contribute to improved waste management outcomes. This study investigated this relationship in Kisumu to provide valuable insights into optimizing industrial symbiosis practices and enhancing waste reuse.

Other well-documented symbiotic intensities based on counting the number of symbiotic projects include Kalundborg, with 13 symbiotic projects across 11 firms (Jacobsen, 2006) with estimated resource savings on oil at 20,000tonnes/year and 200,000 tonnes/ year for natural gypsum (Chertow and Lombardi, 2005) . These changes were measured by measuring changes in consumption of natural resources. Gladstone (Australia) is comprised of five symbiotic projects between six firms; Kiwinana (Australia) comprises 47 symbiotic projects between 22 firms (Van Beers *et al.*, 2007) citing the growth and complexity of the networks. Dong et al. (2013) established that in Liuzhou, China, there were three symbiosis activities between industries with an annual waste exchange of more than 2 million tons/year, whereas in Jinan, China, had seven symbiotic links between industries, with a total waste exchange of more than 8 million tonnes/y. While these studies provide valuable insights into the scale and complexity of IS networks and highlight natural resource savings, they do not fully address the relationship between symbiotic intensity and the amount of waste reused. The focus on resource savings like oil and gypsum consumption provides a partial view of the environmental impact but overlooks the quantitative effect of these exchanges on waste reduction through reuse. Studies that have cited the amount of waste reused have failed to demonstrate how the complexity of the networks, as evidenced by the number of projects and firms involved, is linked to how much waste is being reused within these networks. This study looked into an in-depth analysis to address the shortcomings of the previous studies and what aspects of the intensity i.e number of actors or number of types of solid waste material contributed more to the outcome of amount of waste reused.

Although there is a clear depiction of IS creating a win-win situation where all actors are bound to gain, there is minimal research on the environmental impacts of individual actors along networks in multifaceted exchanges (Chertow & Lombardi, 2005). Furthermore, firms with higher symbiotic intensity tended to have higher economic and environmental benefits (Chertow & Lombardi, 2005). Symbiotic Intensity is particularly suitable for tracking the growth and development of case-specific IS networks, but it cannot be used to compare IS for different cases or to assess the network's benefits to the environment or the economy (Berkel et al., 2009). The overall environmental consequences may be quantified using the hybrid Life Cycle Analysis technique because it took both direct and indirect effects into account (Mattila *et al.*, 2010). Industrial symbiosis can potentially increase economic benefits and reduce environmental impacts (Martin, 2013). Various methods and indicators are used to assess industrial symbiosis's environmental, economic, and social impact (Neves *et al.*, 2019). Economic and environmental benefits are traditionally the goal of industrial symbiosis application (Lu *et al.*, 2020). Most studies have, however, traditionally focused on economic and environmental benefits as the primary goals and proposed various methodologies to assess these benefits, often without clearly linking the intensity of symbiotic relationships to the amount of waste reused. Moreover, case-specificity highlights the unique dynamics of each IS network, it also creates a gap in understanding how symbiotic intensity—the number of actors and types of resources exchanged—impacts the amount of waste reused across different cases. This research addressed this gap by focusing on the relationship between symbiotic intensity and waste reuse. The study analyzed how different actors and types of materials interact to influence the amount of waste diverted from landfills. This study provided a deeper understanding of how IS can be optimized, even within its case-specific nature, to achieve greater environmental sustainability.

2.6 Theoretical framework

The exchange network theory, which George Homans first developed in 1958 (Homans, 1958), served as the foundation for this study. According to the hypothesis of exchange networks, social interactions develop due to the sharing of resources between individuals or groups. This theory contends that people are driven to seek social ties that offer the most significant rewards with the least costs. It bases social relationships on a system of costs and benefits. According to exchange network theory, social connections between people are woven into broader social networks in which people are interconnected. These networks can vary in complexity and scale. The theory further suggests that people are driven to develop relationships with people who can give them the resources they value, such as information, material goods, or social support. To build and maintain relationships, people may provide resources to others.

Individual and network interactions have been evaluated using the theory. The framework proposes that actors' exchange behaviours are influenced by their position within the more extensive exchange network at the individual level. Actors who are well-connected and have many exchange partners may be more likely to engage in frequent and diverse exchanges, whereas actors who are isolated or have fewer exchange partners may have fewer exchange opportunities. On the other hand, the framework's network-level proposal suggests that the exchange network structure can affect exchange patterns and the results of exchange interactions. Networks with a high degree of centralisation, where one or a few participants hold key roles, can result in power imbalances and unequal exchange outcomes. However, more egalitarian or decentralised networks, with many individuals having comparable levels of centrality, may promote more equitable and reciprocal exchange outcomes.

This theory was used by Skvoretz and Lovaglia (1995) study, which investigated the structural determinants of exchange frequency in negotiated exchange networks and highlighted the importance of social structure and power dynamics in shaping patterns of exchange in negotiated exchange networks. It was also used, in part, by (Hein *et al.*, 2017) to assess stakeholder power and critical resources in IS. Exchange theory provides a valuable framework for understanding how social relationships are formed and maintained through the exchange of resources. This can help explain various social phenomena, from economic transactions to social support networks. However, the theory assumes that people make rational choices based on the costs and benefits of different social interactions. However, not all social behaviour can be explained by rational calculation, and other factors such as emotions, values, and social norms may also play a role.

Despite this limitation, the exchange theory still provided a useful framework for understanding the dynamics of the exchange practice in symbiotic networks in this study. The study anchored on the theory suggestion that industries are motivated to establish exchange relationships when there are benefits. This was embedded in the study in that symbiotic exchanges are more likely to occur between actors that are geographically close, and social interactions are driven by the desire to share resources in ways that maximize rewards through information sharing, which is critical for waste reuse between actors in a network. Furthermore, industries that are part of denser exchange networks (with many actors and multiple solid waste material exchanges) will likely benefit from more opportunities for waste reuse

2.7 Conceptual framework.

Based on the exchange theory, the conceptual framework identified the independent, dependent, and intervening variables.

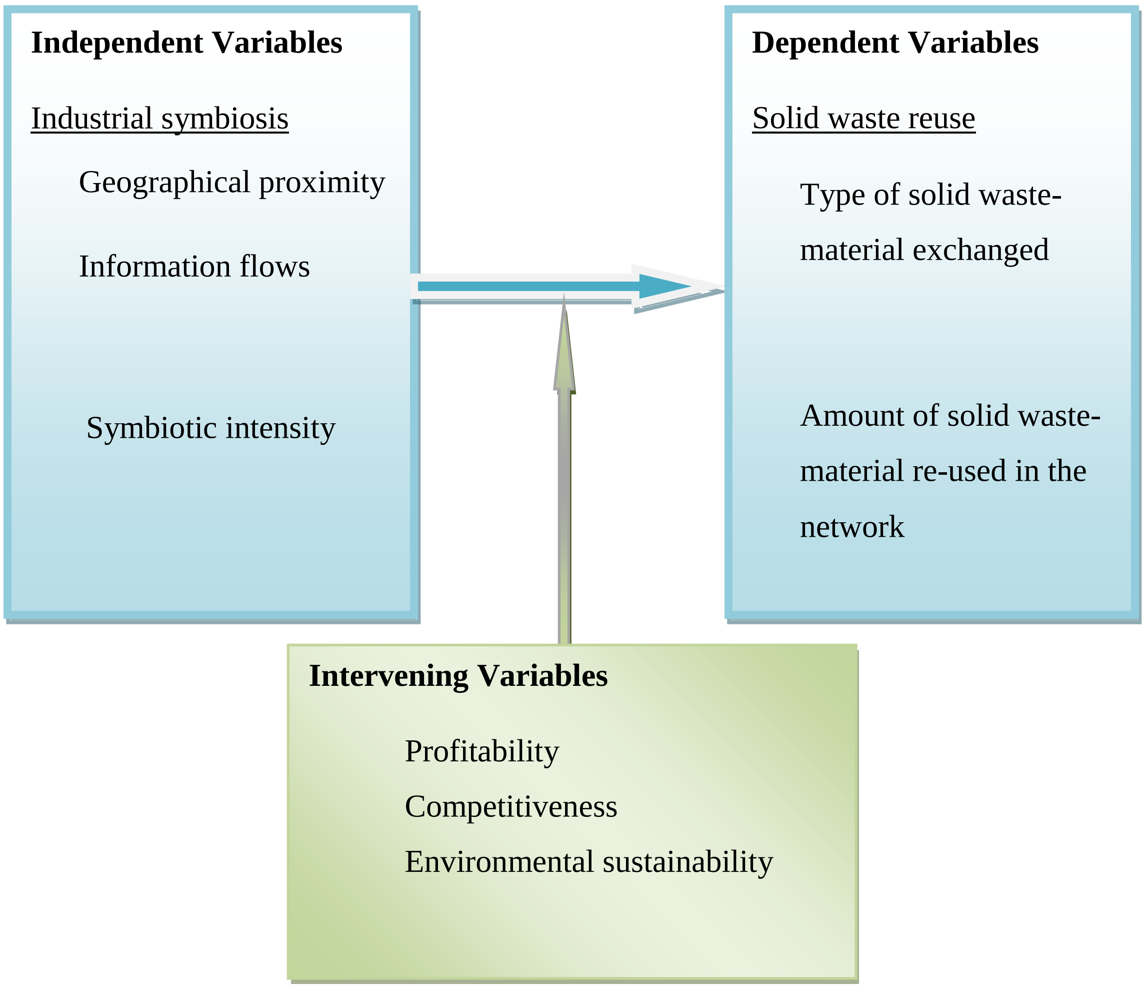


Figure 1: Conceptual Framework

CHAPTER THREE

METHODOLOGY

3.1: Introduction

This section outlines the methodology used to address the study's objectives. This research employed a descriptive cross-sectional study design, combining both quantitative and qualitative approaches to explore the influence of Industrial Symbiosis (IS) on solid waste reuse within Kisumu County's manufacturing sector. The following subsections detail the procedures followed.

3.2: Study Area

The study was conducted in Kisumu County, an important region in Kenya situated between longitudes 33°20'E and 35°20'E and latitudes 0° 20' South and 0° 50' South. Covering approximately 567 km^2 of water and 2086 km^2 of land, the county represents about 0.36% of Kenya's total land area **(CGK, 2023).** Kisumu County consists of eight sub-counties: Kisumu East, Kisumu West, Kisumu Central, Muhoroni, Nyando, Seme, Nyakach and Kadibo with a population of 1,155,574 according to the 2019 National Census **(KNBS,2019).**

Figure 2: Location of Kisumu County in Kenya (Source: Initial Energy Status Report, Kisumu County 2020)

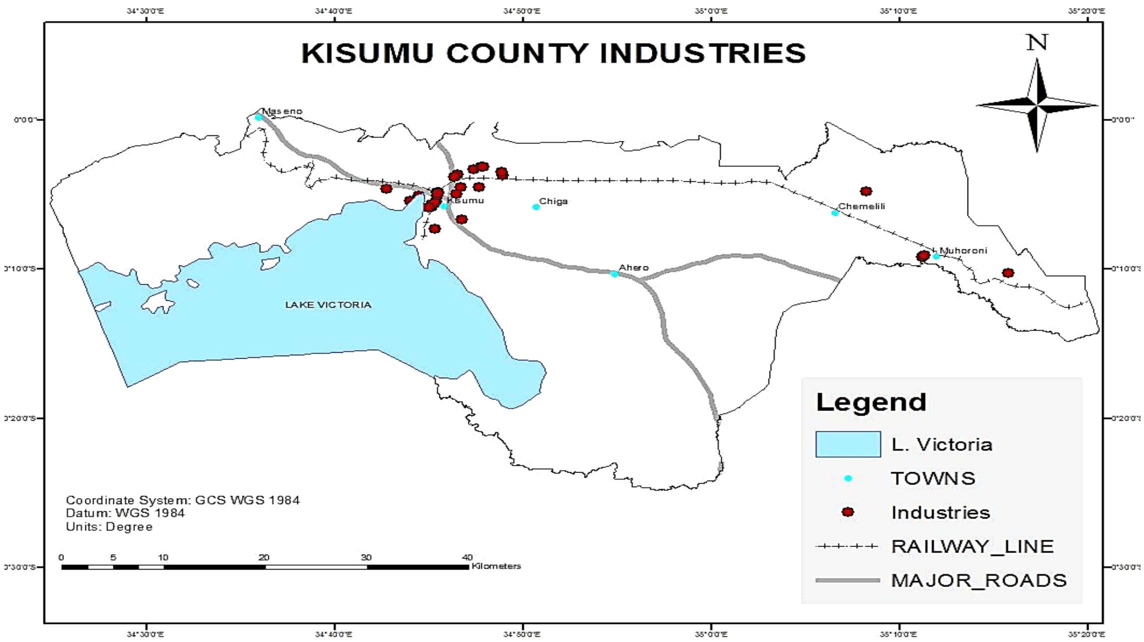


Figure 3: Kisumu County showing the location of manufacturing industries and transport infrastructures. ***Source: author generated***.

Characteristics of the study area

Industrial activities

A synthesis of the list of manufacturing industries obtained from the Ministry of Investment Trade and Industry -Kisumu County office **(**appendix 17) revealed that industrial activities in Kisumu include agro-processors, food processors, textiles and leather, molasses, and fish processing plants, chemical factories, building and construction, mining, timber, and wood factories. As established from the survey, Kisumu County has several industries located within Kisumu East, Kisumu West and Kisumu Central (Fig 3). This included industries under agro-processing sector in activities such as cereal, fish, animal feeds, sugarcane processing, food and beverage including manufacturing soft and alcoholic beverages, leather and textiles, timber paper and board, energy, plastics sector industries. Industries outside the city boundary included sugar factory, building mining and construction, chemical, metal and allied. The concentration of industries within Kisumu East, Central and West were indicative of close geographical proximity of industries.

Transport and Communication

Kisumu is an important node on the northern corridor. Arterial roads such as Nairobi Road, Kisumu-Kakamega Highway and Kisumu-Busia Highway pass through it. There is also a 217 Km narrow-gauge rail linking Kisumu with other cities and towns along the line. Water transport is also available, with ferry services connecting towns on the shows and linking the county to Tanzania and Uganda. Kisumu International Airport has inland and international flights from Kisumu to Nairobi, Mombasa, and several cities around East Africa (CGK, 2020). This study established that the transportation of solid waste material is primarily by road. Fig 3 shows that industries are located near road networks. This indicates the critical role road infrastructure plays in industrial activities. The Standard Media (2021) reported that Kisumu was rated the best in mobile connectivity with network coverage by major service providers such as Safaricom and Airtel according to a Communications Authority report. Postal and courier services are also available.

Waste management

Kisumu City generates roughly 400 tonnes of solid waste daily, of which 20%-25% is collected for disposal in an open dump site. 65% of all municipal solid trash collected is organic, and 27% recyclable (CGK, 2018). Solid waste is mainly handled by open burning and dumping. In Kisumu County, most of the waste generated comes from municipal waste, which results from consuming processed products at the household, commercial, and industrial levels. Industrial activities contribute significantly to the volume of waste. However, the county government lacks the legal authority to regulate the production processes responsible for generating this waste, which limits its ability to reduce waste at the source (CGK, 2020).

3.3 Research design

The study employed a descriptive cross-sectional study design combining quantitative and qualitative methods. Being that data was collected at a single point in time, this approach provided a snapshot overview of solid waste reuse in manufacturing sector and offered insight in how IS influences type and amount of waste reused. This study used both quantitative and qualitative methods, making it well-suited for capturing multifaceted data on waste reuse practices and stakeholder perceptions. The qualitative component involved in-depth interviews that explored underlying factors behind the patterns observed in the analyzed data. Since this research design does not measure causality, the interview insights provided a deeper understanding to explain the findings. The key informants involved were technical officers from the Kisumu County Government offices in the Department of Water, Environment, Natural Resources and Climate Change, Department of Physical Planning, Lands and Urban Development, Department of Energy and Industrialization, Kenya Association of Manufacturers and National Environmental Management Authority. This approach not only ensured an appropriate fit for the variables under study but also optimized the allocation of resources, which means it was both cost-efficient and time-effective.

3.4 Study Population and Sample Size

The study population comprised two main groups: manufacturing industries within Kisumu County and key stakeholders involved in industrial symbiosis practices. Manufacturing industries were identified from various sectors, such as food processing, textiles, chemicals, and leather, including small, medium, and large enterprises. A list of 71 industries was obtained from the Ministry of Investments, Trade, and Industry, Kisumu County (Appendix 17). Based on the exclusion criteria that ensured the study only considered relevant industries practising industrial symbiosis, 22 industries were omitted.

Industries were excluded if they did not generate solid waste, were not involved in solid waste reuse, were dormant or shut down, and belonged to the informal sector ("jua kali") with no permanent physical place for operation. These criteria ensured the study focused on industries that were actively engaged in practices related to waste reuse and symbiosis, aligning with the research objectives. Therefore, 49 industries were considered for the study. These industries were located within Kisumu County, represented diverse sectors, and were actively involved in waste reuse. Due to the relatively small population of relevant industries within Kisumu County that met the criteria, all the eligible industries were sampled for the study. However, only 41 industries consented to participate (Appendix 13). This was a response rate of 83.67%, which is above the reasonable acceptable response rate of 55.6% as established by Baruch, (1999).

Five key stakeholders, with specific knowledge of waste management practices in Kisumu County and play critical in the manufacturing industry were involved. They included technical officers from County departments of Water, Environment, Natural Resources and Climate Change, Physical Planning, Lands and Urban Development, Energy and Industrialization, the Kenya Association of Manufacturers, and the National Environmental Management Authority. This targeted focus aligned with the study’s objectives of examining solid waste reuse.

3.5 Data collection methods

3.5.1 Instruments and data collected

Two instruments were employed for data collection in this study. The first instrument was a semi-structured questionnaire administered to manufacturing industries (Appendix 15). This questionnaire collected both quantitative and qualitative data related to the types of solid waste generated, reuse practices, and distances between industries involved in waste exchange. Section A was the preliminary section which sought to establish the profiles of the industry in terms of sector and scale of operation. Section B of the questionnaire, addressed questions that measured the variables on geographical proximity between industries and the type of solid waste exchanged for objective one. Respondents were asked to indicate the approximate distance between their industry and other industries with which they exchange solid waste materials considering solid waste material brought into the facility and those going out to another industry. These questions also captured the type of solid waste materials being reused within the industry or by other industries, specifying the kind of materials and their intended use. This information allowed for classifying the types of waste involved in exchanges and their specific reuse applications. Section C covered objective two by focusing on information flows between industries. Respondents were asked to indicate whether they exchanged specific types of information, such as the amount of produced and required resources, resource types, waste quality, waste composition, emission inventory, supply patterns, company location and willingness to cooperate, operating costs, and technical knowledge on reuse pathways. This provided insight into the variety of information being shared, which reflects the depth of collaboration between industries. The frequency of information sharing was captured through multiple options, such as daily, weekly, or as needed. This variable was essential in determining how often industries engaged in information sharing, which could influence the effectiveness of the type of waste exchanged. Section D directly addressed the third objective. The respondents were asked to indicate the type of solid waste material reused within their facility and the approximate amount reused per year in tonnes. This measured the internal reuse of by-products within the industry. For industries that received solid waste material from other companies, the questionnaire captured the source company and the amount outsourced annually. Respondents also provided details about the solid waste materials picked up from their facility, including the recipient industry and the amount transferred annually in tonnes.

The second instrument, an interview schedule, was used for key informant interviews (KIIs) with stakeholders, including government officials and industry representatives. Each interview schedule was tailored to address the objective of the study and align them with the role of the stakeholder. The key informant interviews provided in-depth insights into various aspects related to geographical proximity, information flows, and symbiotic intensity, which were crucial for understanding the dynamics of industrial symbiosis in Kisumu County.

3.5.2 Procedure for data collection

Data collection was done over a period of 9 weeks between the Months of August and October 2021. The initial plan, which set a target of administering five questionnaires per week, was not adhered to due to the rescheduling of appointments. To compensate for the lost time, the target was increased to a minimum of seven questionnaires per day. Prior to administering the tool, the participants were called via telephone to inform them of the study and to schedule when and how (whether virtually or face-to-face due to the COVID-19 restrictions at the time) they wished to participate if they consented to participate in the study.

The questionnaire took approximately 25-30 minutes to administer. The KII took approximately 30-45 minutes. Respondents from the industries were technical officers in the production/processing plants, whereas the KIIs were technical officers from the Kisumu County Government in the Department of Water, Environment, Natural Resources and Climate Change, Department of Physical Planning, Lands and Urban Development, Department of Energy and Industrialization, Kenya Association of Manufacturers and National Environmental Management Authority.

3.6 Data analysis

Data from the study was first coded. Double entry was then done using MS Excel version 2021 for comparison purposes. Errors were minimized by cleaning and rechecking all the entries with the original data forms. Data analysis was done using SPSS software version 28; descriptive statistics like mean, frequencies and percentages were used to describe the data and presented through tables, pie charts, graphs and schematic diagrams to summarise data.

A multinomial logistic regression was performed for objective one. The independent variable for this objective was: ' distance between actors.' The variable was measured under question 6 and 7 of the questionnaire sample data provided under (Appendix 13). The SI unit for measurement was kilometres. The level of measurement was scale. Data on distance was logarithmically transformed to normalize the data to ensure there were no violations before performing the multinomial logistic regression. Since there was only one independent variable, the assumption for multicollinearity did not apply.

The dependent variable for objective one was ‘type of waste’, which was a nominal (categorical) variable. This was measured in question 6 of the questionnaire. What was observed was there were a variety of waste streams across all the sectors that made the data spread out thinly (Fig 5). To ensure the data's statistical validity, the types of solid waste materials were grouped into broader categories based on responses to Question 6 in the questionnaire, which asked about the specific reuses of solid waste. Consequently, the data were reorganized into four nominal categories: Energy value waste which included materials used for energy production, Element value waste which encompassed waste that can be repurposed for elemental or chemical applications, Fibre & Cellulose value referred to materials with fibrous or cellulose content for reuse waste, and Nutrient value waste represented organic waste primarily used in agricultural or animal feed sectors. (see Appendix 5 and 13).

The observations for these categories were mutually exclusive. The independent variable, ' distance between actors.', was transformed by multiplying the natural log (ln) by the actual value to ensure a linear relationship between the categorical dependent variable, 'type of waste," and the logit transformed the independent variable, ' distance between actors.' Outliers identified in the 'nutrient value' waste type were not included.

Objective two was analyzed using Chi-square tests. Both the dependent and independent variables were categorical. The independent variable -information flows- was measured in two levels. First, was type of information exchanged which was a nominal level to which respondents gave a YES or NO as a response on whether they shared a certain type of information (See question 12 of the questionnaire- appendix 15 and sample data appendix 13). Second was frequency of communication which was measured on an ordinal scale; daily, as need arises and weekly (Appendix 13) Data were checked to ensure no violations before running the test statistic on the data. Both predictor and response variables were categorical variables and independent of each other.

Objective three was analyzed using multiple linear regression. Symbiotic intensity, the independent variable, was a composite measure based on the number of actors an industry exchanged waste materials with and the number of types of solid waste material exchanged. Both variables were measured at the scale level. The amount of waste reused was quantified using Question 23 of the questionnaire, where respondents estimated the volume of solid waste reused. This estimate was cross-validated against the annual production volumes provided in Question 22 and compared with solid waste generation rates for various manufacturing sectors based on previously published research (see Appendix 14). Data were checked to ensure no violations before running the test statistic on the data. The following tests were performed on the data:

Test for normality of the dependent variable

The test for normality of the dependent variable indicated as “waste amount” was first log-transformed to the base of 10. The new data set was then subjected to a normality test. The Shapiro-Wilk test showed a no statistically significant result ($p=0.061$; $p>0.05$) (Appendix 8), indicating that the assumption of normality of distribution of the dependent variable was met.

Test for Multicollinearity between Predictor Variables

The predictor variables, number of IS connections and Number of types of solid waste exchanged correlated (0.615), indicating no severe multicollinearity between the two predictor variables (0.615< 0.8). Furthermore, the “Number of IS connections” had a correlation of 0.388, and the ‘number of types of solid waste exchanged” had a correlation of 0.331. Both were >0.3, indicating that there was a weak to moderate correlation between the independent variables and the dependent variables.

Linear Relationship between Independent and dependent variables

To check for linearity, a scatter plot analysis was performed. The points in the probability-probability plot (Appendix 9) generally followed the line with minimal deviations. The scatter plot (Appendix 10) showed that the points fell between -3 and 3 on both the X and Y axes (standard residual = min,-2.382; max, 1.425). When the points on a scatter plot fall between -3 and 3 on both the X and Y axes, the data are relatively tightly clustered around the centre of the plot. This can indicate a strong relationship between the two variables, where there is little variability in the data. The range of -3 to 3 on the X and Y axes represents a distance of six units from the centre of the plot in all directions. When the data falls within this range, it indicates that most of the observations are close to the mean of the dataset, and there is little deviation from this central tendency. This suggests that the relationship between the two variables is strong and that changes in one variable are closely associated with changes in the other variable (Gelman & Hill, 2006). The Cook distance indicated (min 0.00; max 0.195) showed that the results were less than 1, which is the limit. The minimum Cook distance (0.00) indicated that the observation with the smallest Cook's distance had no undue influence on the model. The maximum Cook distance (0.195) suggested that there may be one or more observations that had a moderate amount of influence on the model. Data having met all the assumptions, the multiple linear regression was for objective three (Cook, 1979).

Manual content analysis was systematically conducted on the qualitative data collected from key informant interviews. The responses were categorized into specific themes that aligned with each research objective. This thematic categorization helped identify patterns and insights relevant to each objective. These qualitative findings were then used to support and provide context to the quantitative results, offering a more comprehensive understanding of the dynamics of industrial symbiosis in Kisumu.

3.7 Validity and Reliability of Data

Content validity was established by having research experts review the data to ensure that the questions or items were comprehensive and representative of the measured construct. The research team systematically determined whether each data item contributed and that no aspect was overlooked in answering the research question. The validity was based on where a question was “essential, " "useful, but not necessary,” or “not necessary”. Those that fell under ‘not necessary’ were omitted. A pilot study was conducted with three manufacturing industries. Feedback from the pilot study participants was used to refine the questionnaires and interview guides to ensure that they measured the intended constructs accurately.

Internal consistency reliability was tested to examine the degree to which the items or questions in a measure were consistent. This was done through Cronbach's alpha method. The instrument was also reliable, with a Cronbach Alpha value of 0.818. A construct is reliable if the alpha value is greater than 0.7 (Hair. et al., 2013).

3.8 Ethical Considerations

The study was approved by the Maseno Ethics Review Committee and the National Commission for Science, Technology, and Innovation, which issued a research permit, granting authority to conduct the study. A consent letter was provided to participants, which informed them about the study's objectives, and clarified that their participation was voluntary. The consent letter was signed by participants who agreed to take part. There were no known risks associated with participating in the study. Codes were used to uniquely identify industries to ensure their anonymity. To enhance confidentiality, only the principal researchers had access to the raw data. The findings of this study were fully anonymized. Additionally, reporting of the findings ensured that originality was upheld throughout the writing of this report with citations given appropriately to ensure no plagiarism. The study results were intended for academic purposes, future research in the field of industrial symbiosis, to benefit manufacturing industries aiming for green economic growth, and to assist policymakers in formulating and implementing data-driven policies.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Introduction

This chapter presents the study's findings on influence industrial symbiosis of solid waste reuse in Kisumu County's manufacturing industries. It provides insights into the industries engaged in symbiotic exchanges; the solid waste material exchanged. The findings to the specific objectives are then presented as follows: section 4.2 gives an outlook of industries practicing symbiosis in the county. Section 4.3 addresses objective one section 4.4 focuses on objective two, and the third objective is tackled under section 4.5

4.2 Manufacturing industries that practice industrial symbiosis in Kisumu County

The study established that Kisumu County had a variety of collaborating industries from various sectors. These industries were classified according to the Kenya Association of Manufacturers classification, based on the UNIDO classification and the type of raw material input or product produced. Figure 4 illustrates a pie chart of the Kisumu County manufacturing industry sectors that practice symbiosis.

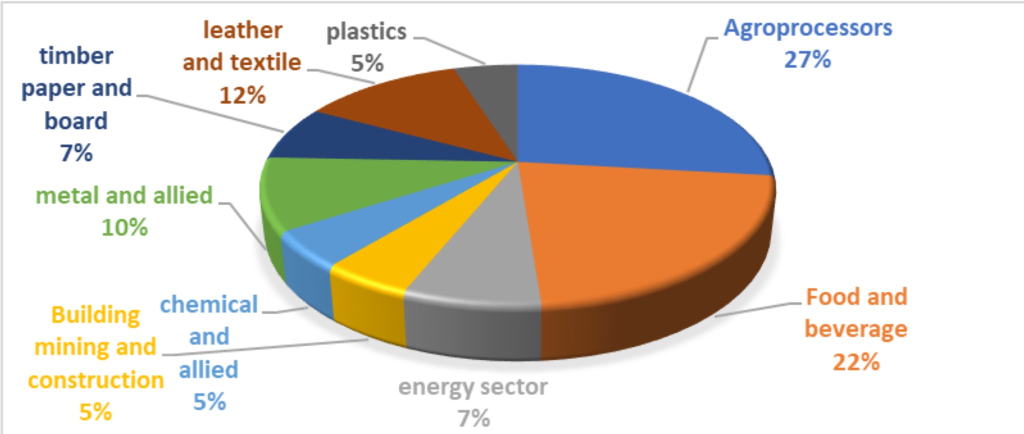


Figure 4 Collaboration of manufacturing industries by sectors in Kisumu County and the percentages of the total number of industries sampled

The study found that agro-processing industries dominate Kisumu County's manufacturing sector, representing 27% of industries practicing industrial symbiosis (IS), with the sugar and cereal processing industries accounting for most agro-processing industries. The large share of agro-processors could be explained by Kisumu County's resource base, which is characterized by large-scale sugarcane farming and borders counties with large-scale cereal farming. The food and beverage sectors ranked second with 9 (22%). Plastics and chemical and related sectors, as well as the mining and construction sectors, had the lowest representation, at 5%. This finding indicates that solid waste is mainly biodegradable and voluminous, as in agro-food waste. Per the present results, a previous report by the County government of Kisumu demonstrated that 65% of all municipal solid trash collected is organic, with the remaining 27% recyclable (County Government of Kisumu, 2018). This result supports evidence from previous observations by Were (2016), who established that agro-industries, including the food and beverage sectors, dominated the representation of the manufacturing industry in Kenya. Solid waste, mainly organic/biodegradable waste, remains the focus of solid waste management, even within the manufacturing industry.

The industry sectors were categorized by size according to the Micro and Small Enterprises Act of 2012, where the number of employees defines the scale of industries. Small enterprises have 10-49 employees, medium-sized enterprises have 50-99 employees, and large enterprises have 100 and above employees (GoK, 2012). Table 4.1 shows the industry sectors and the number of industries per category in terms of scale.

Table 4.1: Industry sector distribution by scale of operation

Sector	Large	Medium	Small	Total (%)
Agro-processing	54.5	18.2	27.3	100
Food & Beverage	55.6	22.2	22.2	100
Energy	0.0	33.3	66.7	100
Building & Construction	100.0	0.0	0.0	100
Chemical & Allied	0.0	0.0	100.0	100
Metal & Allied	50.0	25.0	25.0	100
Timber, Paper & Board	0.0	33.3	66.7	100
Leather & Textile	60.0	0.0	40.0	100
Plastics	0.0	50.0	50.0	100
Total (%)	43.9	19.5	36.6	100

43.9% of the industries sampled were classified as large-scale. Small-scale industries came second, with 36.6% and medium-scale industries came third, with 19.5% representing industries sampled. This indicates that large-scale industries primarily drive IS in the manufacturing sector. Large-scale production requires the input of large amounts of raw material and subsequent large amounts of solid waste material as output. Apart from location, Van Berkel (2009) argues that the scale of production determines the influence of an industry in the network. This finding is consistent with Menato *et al.* (2017), who established that micro-entities (less than nine employees) had not implemented symbiotic measures, while 85% of large enterprises did. However, this finding contradicts Patricio *et al.* (2018), who found that small and medium enterprises (SMEs) account for most business cooperation in the European Union. The Industrial Policy for Sustainable Development Goals indicates that small firms make up most of them and have an uphill task in making sustainable changes because they need more assistance or resources to ensure sustainability. A key informant from the Department of Energy and Industrialization pointed out that most industries in the county are small and medium enterprises; however, concrete information regarding their activities' environmental sustainability and performance is missing. He further mentioned that small- to medium-scale industries are thus important contributors to local, national, and regional economic growth; however, mainstreaming waste management issues was still challenging. Addressing this gap is critical for improving the overall performance of IS networks in Kisumu and enhancing waste reuse across various sectors, particularly in agro-processing and the food and beverage industry.

4.3 Geographical proximity and type of solid waste material exchanged

4.3.1 Distance and types of solid waste material exchanged amongst industries

Industries generate a wide range of solid waste materials from their processing/production line, known mainly as byproducts. Figure 5 shows a summary of the solid waste exchanged by industries within Kisumu County and the frequency of exchanges in the network.

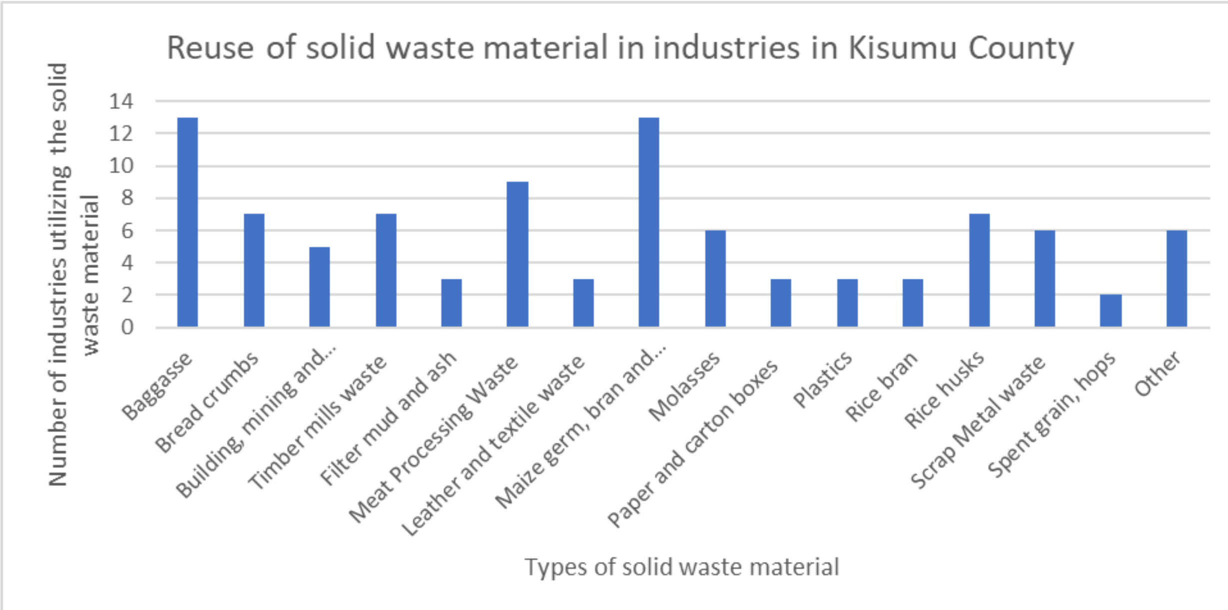


Figure 5: Types of solid waste materials and the number of industries that use solid waste materials in the network.

More than 15 types of solid waste material were identified. This represented the diversity in the manufacturing sector in the County. Figure 5 shows that the two primary solid waste materials exchanged in the network for reuse were bagasse and maize germ, bran, and wheat pollard (13 counts in each category). Other than plastics, scrap metal, and the "other" category, which included glass and paint pigments, quarry dust and lime, the solid waste was primarily organic. Jensen *et al.* (2011) and Domenech *et al.* (2019), in the studies of IS in Europe, also presented a wide diversity in types of material exchanged through IS networks, which included different types of chemicals, plastics, woods of various qualities, biomass, redundant stock, reusable construction materials, textile, rubber hazardous waste, foodstuffs composite packaging amongst others. However, their studies contradicted the findings of this study in the sense that most of the waste exchanged in the European industries was inorganic. The results of this study support the idea that the diversity of industries and type of waste characterizes symbiosis.

Given the wide variety of waste types initially identified, with over 15 distinct categories, the data were streamlined by reorganizing them into broader, more meaningful categories based on their specific reuse applications. This reclassification grouped the solid waste materials according to their value in industrial symbiosis. As a result, the data were condensed into four solid waste material types: Energy Value Waste, which included materials used for energy production; Element Value Waste, which encompassed waste that can be repurposed for elemental or chemical applications; Fibre & Cellulose Value Waste, referred to materials with fibrous or cellulose content for reuse; and Nutrient Value Waste represented organic waste primarily used in agricultural or animal feed sectors (Table 4.2).

Table 4.2:Source of solid waste material, types of by-products of solid waste traded, value attached to the solid waste materials, mean distance of exchange, industry sourcing and reuse of by-products (linkages) and expected end products

Type of solid waste material	Mean distance of exchange (km)	Constituents of solid was material	Source of solid waste material	Symbiont industry	End products
Nutrient Value	11.10	Molasses	Agro-processing industry (Sugar sector)	Food and Beverage	Alcohol
		Maize germ, wheat pollard, rice bran, peanut skins,	Agro-processing industry Cereal sector)	Agro-processing industry (animal feed sector)	Animal feed
		Spent grain, hops, bread crumbs, blood, bones,	Food &Beverage industry	Agro-processing industry (Animal feed sector)	
Energy Value	19.62	Baggasse,	Agro-processing industry (Sugar sector)	Energy Sector	Briquettes
		Rice husks, slurry, peanut hulls, sawdust, timber shavings			
Element Value	22.76	Plastics, glass,	Food and beverage industry	Plastic and glass recyclers	Recycled plastic and glass
		Metal	Metal Industry	Metal industry	Recycled metal
		Lime	Building Mining and construction	Agro-processing industry	
		Filter mud and ash,	Agro-processing industry (sugar sector)	Agro-processing industry	Fertilizer
		Paint pigments	Chemical and allied industry	Chemical and allied industry	Paint
Fibre and Cellulose Value	16.28	Paper and carton boxes (packaging)	Food and Beverage industry	Paper and board industry	Kraft paper
		Hides and skins (meat processing)	Leather and textile industry	Leather and textile industry	Leather
		Fabric and leather offcuts		Timber industry (furniture sector)	Pillow stuffing

Symbiotic networks are formed as a result of the exchange of the solid waste material generated by one entity that another can use based on the value attached. Projecting these symbiotic relationships onto the physical landscape where solid waste material must be moved from one entity to another brings the factor of physical distance between actors to the forefront. As seen in Table 4.2, the mean distance covered in the exchange of material through the network varied across waste the four types of waste; nutrient value waste of 11.10km; Element value waste, =22.76km; Energy value waste, =19.62km; and Fibre&cellulose value waste, =16.28km. Notably, nutrient value waste had the shortest average exchange distance at 11.1 km, likely because of the immediate application of organic waste in agricultural uses such as animal feed and fertilizer production (Chertow, 2007). This finding is significant because it highlights the role of geographic proximity in facilitating IS, particularly for low-value waste materials where transportation costs could outweigh the benefits of reuse (Jensen et al., 2011).

Conversely, element value waste, which includes plastics, metals, and construction materials, had the longest mean exchange distance at 22.76 km. This could be due to the fewer industries capable of reprocessing such materials within close proximity, necessitating longer transport distances to specialized recycling or processing facilities (Velenturf & Purnell, 2017). These findings align with studies conducted in Europe, where high-value and hazardous waste materials are often transported over longer distances due to the scarcity of specialized facilities (Domenech et al., 2019).

The study further revealed that energy value waste (such as bagasse and rice husks) had an average exchange distance of 19.62 km, emphasizing the importance of localized clusters of industries, particularly in agro-processing sectors, where by-products are readily converted into energy or fuel products like briquettes. The findings support previous research indicating that collocation of industries reduces transportation costs and improves resource efficiency (Van Berkel, 2009).

4.3.2 Importance of geographic proximity to solid waste exchanged

Geographic proximity was identified as an essential consideration in symbiotic exchanges. 26.83% cited distance as 'Important,' 'Fairly Important' (31.70%) and "Very Important" (21.95%). Very low percentages were recorded on either extreme of the ordered classification scales; 7.32% of respondents in the study stated distance as "Slightly Important," while 12.2% cited "Extremely Important" as their response, as summarized in Table 4.3.

Table 4.3: Importance of distance to solid-waste material exchange, number of responses, and percentage of responses

Importance of distance	**Number of responses**	**Percentage of responses**
Slightly Important	3	7.32
Important	11	26.83
Fairly Important	13	31.70
Very Important	9	21.95
Extremely Important	5	12.20
Total	**41**	**100.00**

While distance is acknowledged as an important factor in most cases, the varied responses across different levels of importance suggest that geographic proximity may not be a universal determinant for all types of solid waste material exchanged in industrial symbiosis. Factors like the value and usability of the exchanged waste material may weigh more heavily when deciding to engage in symbiotic activities. For instance, industries handling element-value waste materials were less affected by distance, as depicted by the average distance this waste material covered (Table 4.2), while nutrient-value solid waste material had closer proximity to reduce transportation costs yet the product made out of the waste has low profit margins as cited by industries in agro-processing. These findings align with Chertow's (2007) assertion that geographic proximity is often a prerequisite for industrial symbiosis due to cost reductions associated with shorter transportation distances. Moreover, Velenturf and Jensen (2016) noted variations in the importance of proximity across different cases of industrial symbiosis, with proximity being more critical in specific sectors such as agricultural feedstock and waste-to-fuel.

Previous studies also reinforce the significance of geographic proximity. Chertow and Ehrenfeld (2012) found that proximity often facilitates exchanges but is not a confounder in high-value by-product cases. Similarly, Lowe (2002) emphasized the development of eco-industrial parks as being driven, in part, by the advantages of geographic proximity. In contrast, other sectors, particularly those benefiting from new technologies or facing unfavorable regulatory contexts, were able to develop synergies over longer distances.

In this study, the emphasis on proximity's role in symbiotic exchanges particularly among industries with regular and consistent waste supply highlights the potential for enhancing industrial symbiosis through deliberate spatial planning. Spatial clustering of industries with complementary solid waste material can facilitate more efficient resource exchange and reduce logistical barriers. Nonetheless, for materials of higher value or requiring specialized reuse technologies, the distance may play a lesser role, as noted by the more varied importance ratings for proximity.

4.3.3 Distance between the actors in the network and the exchange of solid waste material

Table 4.4 summarises the statistics for each type of solid waste material.

Table 4.4: Mean, median, and spread (standard deviation and quartiles) of distances (km) of solid waste material exchanged (with values attached: nutrient, energy, element, fibre & cellulose) between the manufacturing industries in Kisumu County

	Element Value	**Energy Value**	**Fibre & Cellulose Value**	**Nutrient Value**	**Overall**
Mean (km)	22.76	19.62	16.28	11.10	15.85
Standard Deviation	36.07	37.34	35.66	30.47	33.65
Minimum	0.60	0.40	0.40	0.30	0.30
Maximum	114.00	121.00	121.0	180.0	180.0
Median	6.50	2.65	4.80	4.50	4.5
Lower Quartile	4.5	0.925	1.675	2.225	2.05
Upper Quartile	10	12.725	7.975	8.075	8.75
Quartile deviation	2.75	5.9	3.15	2.925	3.35

The standard deviation in the four categories was larger than the respective mean value; "element value" waste (μ=22.76, ∂ =36.07), "energy value" waste (μ=19.62, ∂ =37.34), "fibre & cellulose value' (μ = 16.28 km, ∂= 35.66 km), waste (μ=16.28km, ∂ =35.66km), "nutrient value" waste (μ=22.76km, ∂ =36.07km), suggesting that there is a wide variation amongst the data as seen in the extensive range in the distance (minimum = 0.3 km and maximum=180km). Therefore, the median and quartile deviation represented the data better. The ideal radius for exchange was (overall median = 4.5 km); however, apart from the nutrient value waste, the other three categories registered different ideal exchange distances (element value = 6.5 km, Energy value=2.65km, Fibre & cellulose value=4.8km). Energy value waste had 75% of exchanges occurring within a 12.725km radius and 50% (median) of the exchanges within a 2.65km radius. Plausibly, the closeness of the median to the lower quartile (0.925km) but far from the upper quartile (12.725km) indicates that the distances between most symbiotic industries are relatively far from each other. This was also supported by a considerable quartile variation (5.9) for energy-value waste. Cooperation between symbiotic industries that reuse solid waste material should be ideal within a radius of 12.725 km. This difference shows that the industries in the element value are most spread out in proximity, and those exchanging energy value waste are least spread out or otherwise put are collocated. Collocation in energy value industries was observed to be by design, where the anchor industries supplying the primary resource material, such as bagasse, led to the mushrooming of complementary industries that were interested in the by-product.

This is consistent with findings from Jensen et al. (2011), who observed similar trends in the UK, where energy-related by-products travelled longer distances due to their specific reuse pathways. The results also support Chertow's (2007) argument that geographic proximity is a key determinant of by-product exchange, particularly for lower-value waste streams. However, as shown by the element value waste category, high-value waste can be transported over longer distances if the value of the material justifies the transportation costs. This finding aligns with Velenturf and Purnell (2017), who noted that materials with higher economic value, such as metals and hazardous waste, often travel further distances within symbiotic networks. In their case study, hazardous materials moved an average of 259.7 miles within the UK's industrial symbiosis network, underscoring that geographic proximity becomes less critical when dealing with materials of high economic or regulatory importance.

Another significant aspect of geographical proximity is the distance dispersion for each solid waste exchanged by symbiotic industries, as depicted by the boxplot in Fig 6. Solid waste exchanged for 'element value,' 'energy value,' and 'fibre&cellulose value' have box and whisker plots with uneven sizes (that is, the mean and median do not divide the box into two equal parts). This shows that many industries have relatively similar distances between them in certain parts, but the distances between them are relatively more variable in other parts. Solid waste exchanged with 'nutrient value' has a relatively short box-and-whisker plot and outliers (Fig 6). Industries that exchange 'nutrient value' solid waste materials were geographically the most closely located. This suggests that the overall distances between most symbiotic industries are relatively close to each other, while only a few industries are far from them.

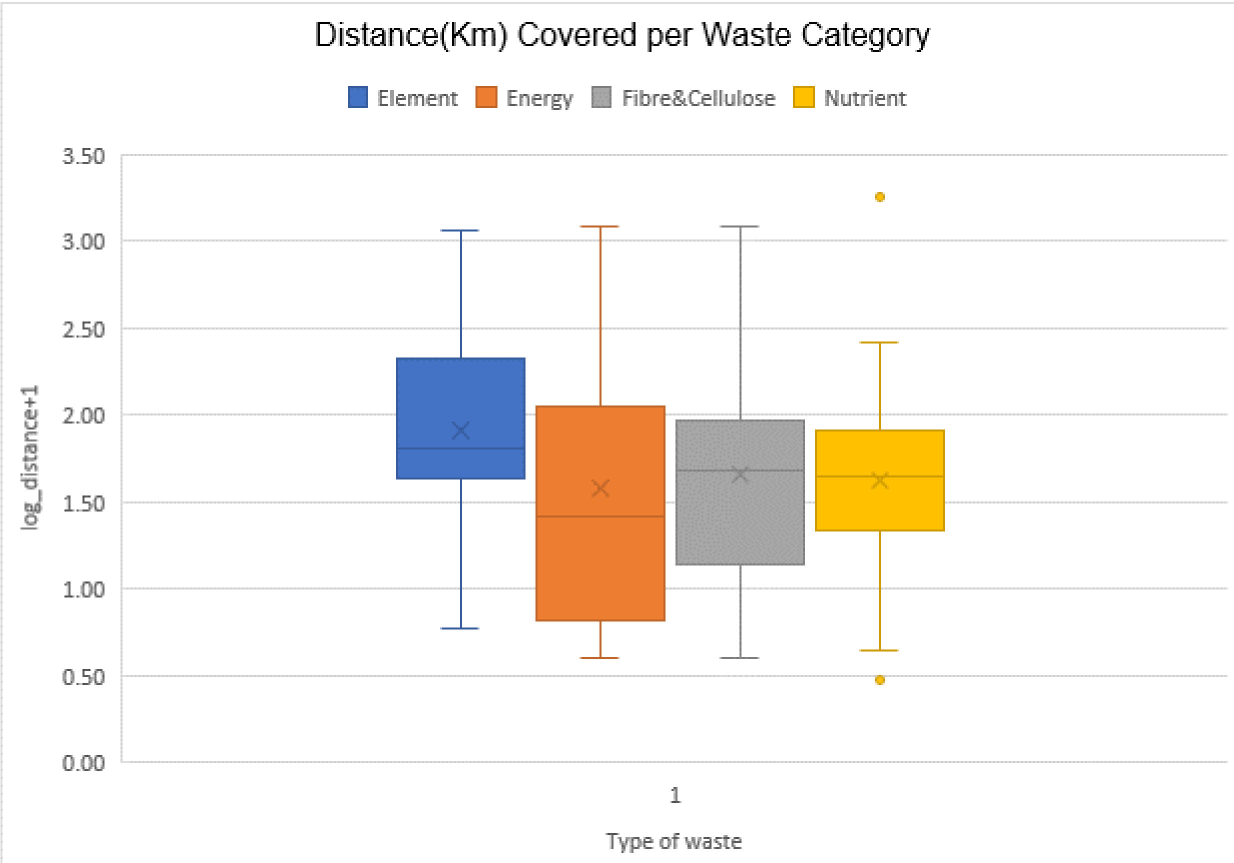


Figure 6: Box plot showing the distances covered by the exchanged solid wastes (with values attached: nutrient, energy, element, fibre &cellulose) between the manufacturing industries in Kisumu County

Although 'nutrient value' waste had the most negligible dispersion observed, two outliers were identified at 0.3 km and 180km. The first case involved an industry that uses molasses to produce alcohol within the facility—in contrast, the second involved a parent company that supplies its subsidiary 180 kilometres away with maize germ, bran, and wheat pollard for animal feed production without transaction costs.

The 'Energy value' waste had a comparatively tall box and whisker plot (Fig 6), implying that distances between most industries are relatively far from each other. Hence, symbiotic industries travelled longer distances to facilitate the exchange of solid waste. The optimal distance for symbiotic exchanges of ‘energy value’ waste in the manufacturing industries of Kisumu County was 8.75km or less. This represented 75% of the distance observed from the four types of waste. However, for the energy and element value categories, the ideal symbiotic distance could be stretched to 10km and 12.725km, respectively, indicating that these materials moved longer distances than the County's overall upper quartile distance for material exchange and perhaps had a higher value attached to them. It was observed that these types of waste were reused for the production of fertilizer, the generation of power, and the production of industrial briquettes, and therefore. Industries engaged in this waste reuse pathway argued that these solid waste materials required high-tech reuse pathways that may not be within the locality of the waste-generating industry.

The spatial dispersion also aligns with findings from Jensen et al. (2011), who argued that more specialized and high-tech reuse pathways often require materials to move further distances, particularly in regions with low geospatial diversity. The findings from this study suggest that symbiotic networks in Kisumu County could benefit from more deliberate spatial planning. Strategic co-location of industries that exchange complementary waste materials could reduce transportation costs and enhance the efficiency of the symbiotic exchanges. While geographic proximity plays a significant role in lower-value waste exchanges, the results demonstrate that value-added waste materials are more likely to be transported over longer distances due to their higher economic value. Therefore, while proximity should be considered in planning, factors such as waste value, processing technologies, and infrastructure availability are equally important in shaping the nature of symbiotic exchanges.

4.3.4 Influence of geographical proximity on type of solid waste material exchanged

To assess the influence of geographical proximity on the type of solid waste material exchanged, a multinomial logistic regression analysis was conducted. The results, presented in Table 4.5, revealed some insights into the role of distance in shaping the exchange patterns of different types of solid waste material. Parameter estimates for the odds ratio (Exp (B)) are shown in Table 4.5. The odds ratio of locating an "element value" or "energy value" solid waste material resource rather than a "nutrient value" increased by 1.002 for every 1km increase in distance. This indicates that the odds ratio increases by 0.2%. On the other hand, for every 1 km increase in distance, the odds ratio of finding a "Fibre & Cellulose value" solid waste material resource rather than a "Nutrient value" solid waste material resource increases by 1.001, or by 0.1%. The model indicated a low odds ratio (0.2%, 0.1%).

Table 4.5: Presentation of multinomial logistic regression results for Element, Energy, Fibre & Cellulose value waste material, compared to distance

							95% Confidence Interval for Exp(B)	
Type of Waste		B	Std. Error	Df	Sig(p).	Exp(B)	LB	UB
Element Value	Intercept	-.811	.321	1	.012			
	Distance	.002	.002	1	.298	1.002	.998	1.006
Energy Value	Intercept	-.636	.303	1	.036			
	Distance	.002	.002	1	.327	1.002	.998	1.005
Fibre&Cellulose	Intercept	-.592	.300	1	.048			
	Distance	.001	.002	1	.535	1.001	.997	1.005

a. The reference is Nutrient value.

The results showed that the data did not provide strong evidence to support a statistically significant influence of geographical proximity on types of solid waste material exchanged (p =.298, p =.327, and p =.535, respectively) in any of the three categories. The study failed to reject the null hypothesis. This finding could be explained by the significant variability in how far apart industries were located in the four categories of waste types that were exchanged (Table 4.4). The lack of a significant association between distance and waste type contradicts some of the foundational literature on industrial symbiosis (Chertow, 2007), which argues that geographical proximity is crucial in fostering by-product exchanges and enabling frequent exchanges of resources. In contrast, the findings from this study suggest that proximity may not be as critical for certain types of waste materials, particularly high-value or specialized waste such as element and energy value materials, which tend to travel longer distances.

The finding that energy value waste traveled longer distances (mean = 19.62 km) than nutrient value waste (mean = 11.10 km) highlights the complexity of determining the role of geographical proximity in waste exchanges. Energy value waste, such as bagasse or rice husks, often requires specific processing technologies to convert the waste into usable energy forms such as briquettes. As noted by Jensen et al. (2011), in regions with less industrial diversity or availability of specialized technology, industries may need to transport materials further to access facilities capable of processing these waste streams. Similarly, Domenech and Davies (2011) observed that in self-organized industrial symbiosis networks, waste materials with higher economic value or more specialized reuse pathways tend to be exchanged over longer distances, as industries are willing to incur the additional transportation costs.

On the other hand, nutrient value waste, which consists mainly of agricultural by-products like molasses, maize germ, and wheat bran, tends to be exchanged over shorter distances.

This aligns with the findings of Velenturf and Purnell (2017), who noted that lower-value, high-volume materials often remain within a smaller geographical radius to reduce logistical costs. In this case, the low-value but voluminous nature of nutrient waste materials means that industries prioritize minimizing transportation costs, thus reinforcing the importance of proximity for these waste types.

The small odds ratios (1.002 for element and energy value waste) suggest that geographical proximity is not a decisive factor in determining the type of waste exchanged within the network. This contrasts with earlier studies that emphasize the importance of distance, particularly for lower-value, bulky waste streams (Boons, 2008; Chertow, 2007). However, the results of this study are consistent with research by Velenturf (2017), who found that while geographical proximity can facilitate exchanges, other factors, such as the economic value of waste materials, transportation infrastructure, and the availability of processing technologies, play more significant roles in determining the success of waste exchanges.

This study's findings point towards the minimal role of geographical proximity in influencing the type of waste exchanged it also highlight the need for improved spatial planning particularly for industries that nutrient value solid waste reuse. As indicated by a key informant from the County Department of Urban Planning, spatial planning in Kisumu County is not yet fully coordinated, which could explain the wide variation in distances covered by different types of waste materials. Strategic co-location of industries with complementary waste streams could enhance the efficiency of symbiotic exchanges, particularly for waste materials that currently travel long distances.

4.4. Types of information and Frequency of Communication in information flows

Communication between industries involved in industrial symbiosis (IS) is vital for facilitating effective collaboration and waste exchange. The results from this study indicated that all industries (100%) exchanged information regarding their physical location, followed by 97.56% communicating the type of waste generated and 75.61% sharing information on waste quality (Fig 7).

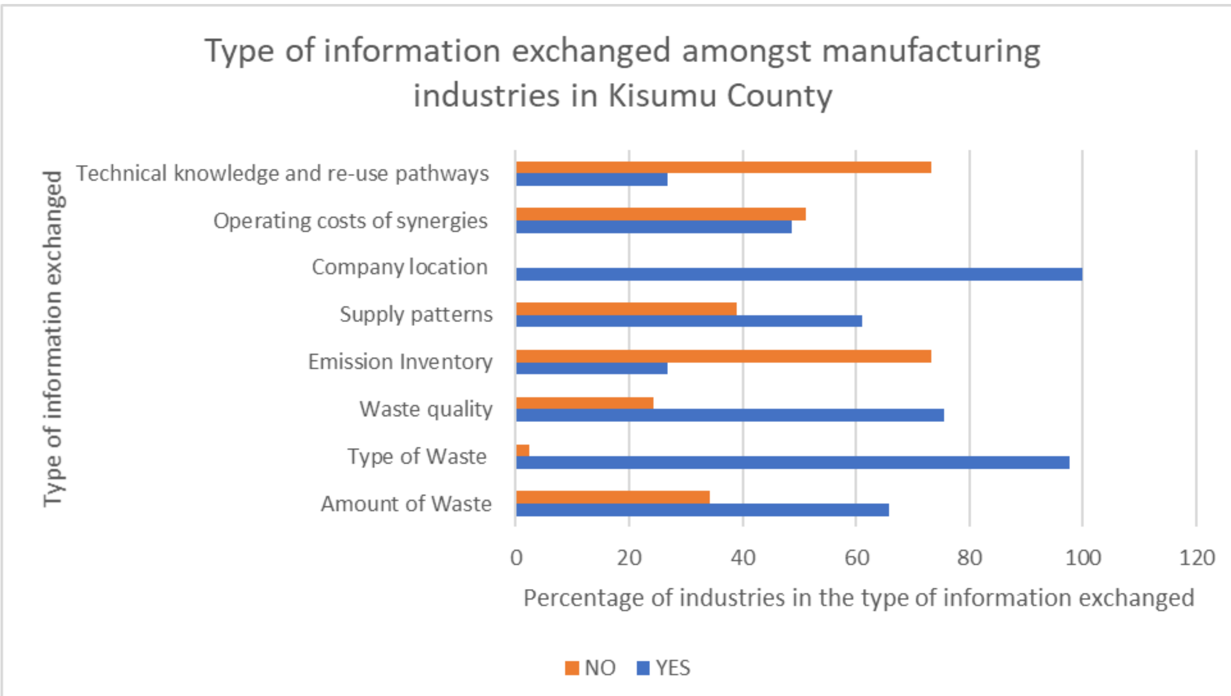


Figure 7: Type of information exchanged and proportion of industries that information.

Surprisingly, only a minority of the respondents (26.83%) shared information on technical knowledge and reuse pathways. It can be inferred that, in a business sense, it is vital for an enterprise to position itself and disclose its location for marketing purposes strategically, and this is why the 100% response was seen in the case of sharing information on company location. The exchange of solid waste material is about the type of waste and quality, which is important because this by-product will be used as input in another process, and hence, quality must be ensured.

These findings are aligned with those of Paquin and Howard-Grenville (2012), who found that effective communication is essential for coordinating resource availability, continuity of supply, and returning customers in IS networks. However, the limited exchange of technical knowledge in this study points to concerns over competitive advantage and possibly the lack of technical expertise for waste reuse. The importance of sharing information on waste type and quality stems from the need to ensure that by-products from one process can be effectively repurposed in another. This is also consistent with the findings of Kosmol (2019) and Yeo et al. (2019), who highlighted the role of waste exchanges as information clearinghouses, where information on waste characteristics, location, and availability periods is actively shared to facilitate transactions. In Kisumu's case, the high percentage of industries sharing information on waste types reflects the importance of such exchanges for initiating collaboration, while the lower figures for technical knowledge highlight potential barriers to more advanced symbiotic activities, such as reuse.

The findings from this study contrast with Chertow & Lombardi (2005), who emphasized that IS not only connects organizations to enable eco-innovation but also drives cultural change through knowledge-sharing. In Kisumu, the lack of trust and limited communication on technical matters may hinder the full realization of IS benefits. More structured efforts to build trust and foster knowledge exchange, such as joint ventures or public-private partnerships, could help overcome these obstacles.

4.4.1 Frequency of communication and type of solid waste material exchanged

The frequency of communication was measured on three levels (daily, weekly, as need arises to ascertain how regularly industries exchanged information (Fig 8). It was established that more than half of industries (56.1 %) communicated 'as needed,' 29.27% communicated weekly, while the least representation (14.63%) communicated daily.

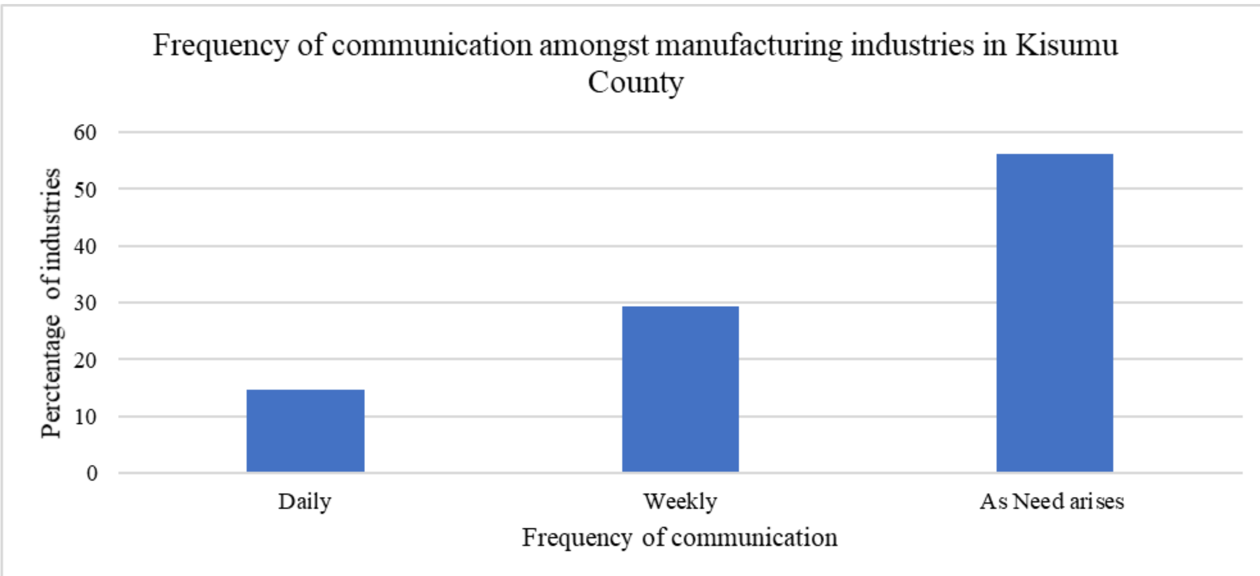


Figure 8: Frequencies of levels of information exchanged between actors involved in industrial symbiosis.

A high frequency of communication leads to better cooperation and shared beliefs between enterprises. This finding points to strained communication amongst actors regarding their frequency of communication. A possible explanation is the lack of trust and confidentiality concerns among actors. This, coupled with the absence of a network facilitator, can contribute to less cohesiveness and communication within the network. As supported by Gajendran and Joshi (2012), frequent communication can enhance social cohesion within a network and promote more consistent information flow. In this context, the relatively low frequency of communication observed in this study could indicate strained relationships or a lack of coordination mechanisms, potentially limiting the effectiveness of waste exchange partnerships.

Industries that communicated more frequently, particularly those exchanging energy value waste, exhibited a more collaborative approach, which may lead to more proactive identification of symbiotic opportunities. This finding aligns with studies by Park and Lee (2014), who found that frequent meetings or informal exchanges in IS networks foster innovation and stronger partnerships. The lower communication frequencies among industries exchanging element value or nutrient value waste may point to either lower interest or barriers such as confidentiality concerns, which restrict information-sharing and limit the potential for symbiotic relationships.

4.4.2 Association between information flows (Frequency of communication) and the type of solid waste material exchanged

A cross-tabulation of the frequency of communication intervals (daily, weekly, as need arises) and type of solid waste material exchanged (nutrient, fibre & cellulose, energy, element) was used to establish how regularly industries exchanged information. It can be seen from the industries data in Table 4.6 that the sampled communicated when necessary in 56.1% of the cases, weekly in 29.3% of cases, and daily in 14.6% of the cases. The highest percentage observed in the column labelled "Nutrient" was (50%), representing the percentage of observations seen for 'As need arises.' This meant that nutrient value waste was not exchanged frequently. Under the "Fibre&Cellulose" waste type, (50%) of observations were observed 'weekly' depicting a more standardized network and 50% observation for 'Daily.' A unique observation is in the element value waste type, where

100% of the respondents communicated only ‘as a need arose,’ indicating that information exchange was minimal. The ability of businesses to discover prospective opportunities for symbiotic exchanges, negotiate agreements, and coordinate their actions depends on effective communication.

Table 4.6: Presentation of results of chi-square analysis of the four distinct types of solid waste material (Nutrient value Fibre cellulose, Energy and Element value) and Frequency of communication intervals (daily, weekly and as need arises)

		Type of waste										X^2 (df)	P	*Phi*	*cramersV*
		Nutrient		Fibre&Cellulose		Energy		Element		Total					
		N	%	N	%	N	%	N	%	N	%				
Frequency of Communication	Daily	2	12.5	2	20.0	2	50.0	0	0.0	6	14.6	16.147a(6)	.013	.628	0.44
	Weekly	6	37.5	5	50.0	1	25.0	0	0.0	12	29.3				
	As need arises	8	50.0	3	30.0	1	25.0	11	100.0	23	56.1				
Total		16	100.0	10	100.0	4	100.0	11	100.0	41	100.0				

a. 9 cells (75.0%) have an expected count of less than 5. The minimum expected count is 59.

α= 0.05

A chi-square independence test was performed to test the association between the frequency of communication and the type of waste exchanged. The chi-square test model established the symmetric measure Cramer’s V(V = 0.44), indicating a moderate effect size between the frequency of communication and the type of waste exchanged. This implies that the frequency with which industries communicate has a moderate effect on the type of waste materials they exchange. Therefore, industries that communicate more frequently are moderately more likely to exchange certain types of waste compared to industries that communicate less frequently. The statistical significance of this association was also tested. Table 4.6 shows that the p-value ($p=0.013$) is less than the significance level ($\alpha= 0.05$), and therefore there was a statistically significant association between frequency of communication and type of solid waste material exchanged ($\chi^2 =16.147$, $p=0.013$, $\alpha= 0.05$). The study rejected the null hypothesis.

Higher communication frequencies among companies exchanging energy value waste indicate a more collaborative and proactive approach to identifying and executing symbiotic opportunities. Regular communication fosters trust and shared understanding, leading to more successful exchanges and a greater willingness to invest in long-term relationships. In contrast, lower communication frequencies in the element and nutrient value waste exchanges suggest a lack of commitment or reluctance to share information, potentially resulting in missed opportunities and more transactional relationships. This finding aligns with the statement from the Kenya Association of Manufacturers (KAM) officer, highlighting the restricted flow of information due to concerns over business secrets.

The statistically significant association between communication frequency and the type of waste exchanged may be tied to the higher demand for energy value waste in production processes, necessitating more frequent interaction between suppliers and industries. The faster growth of symbiotic activity in this category could be attributed to the large volumes of waste exchanged and the operational maturity of the industries. In the early stages of symbiosis, frequent communication is essential to establish trust and cooperation, while more established partnerships—such as those in element and nutrient waste exchanges—may require less frequent engagement.

Although specific research linking communication frequency to waste type is limited, these findings align with studies by Chertow (2007), Domenech and Davies (2011), and Boons et al. (2013), all of which emphasize the importance of communication in building trust and overcoming barriers in IS networks. Frequent communication facilitates collaboration and the development of a shared understanding of IS benefits. Johnson (2017) also noted that beginner companies communicate more often to meet the demands of sustainability, while more advanced businesses engage in less frequent but structured interactions. The results of this study underline the importance of stable information exchange patterns to support effective waste reuse in symbiotic networks.

4.4.3 Association between information flows (types of information) and types of solid waste material exchanged.

The study classified the information shared by respondents into eight categories: type of waste generated, quantity of waste produced, waste quality, emission inventory, supply patterns, synergy operating costs, technical knowledge, and company location. Respondents from 41 manufacturing industries were asked to indicate whether they shared each type of information with other companies by selecting either "Yes" or "No," allowing for a clear assessment of what type of information is shared across the four types of waste exchanged. For company location, 100% of the respondents answered "Yes," indicating complete transparency regarding this information. A chi-square test of independence was conducted for each category of information against the type of solid waste exchanged, except for company location, where no "No" responses were recorded.

The response patterns in Table 4.7 reveal some key insights. The majority of respondents did not share information on emission inventory (73.2%), synergy operating costs (51.02%), or technical knowledge and reuse pathways (73.2%). This suggests that many industries either do not maintain detailed emission inventory records or are unwilling to disclose this information, likely due to the fact that emissions reporting at the facility level is not yet mandatory and presents both technical and policy challenges. Additionally, the reluctance to share operational costs and technical knowledge reflects concerns over competitive advantage and the safeguarding of proprietary processes.

A small number of large-scale industries in agro-processing and metal and allied sectors dealing in nutrient value and energy value waste in the study maintained an emission inventory, likely due to their focus on regulatory compliance and enhancing sustainability. However, the majority of industries were reluctant to share this information with other collaborators. This reluctance aligns with findings from Hashimoto et al. (2010), who observed that the exchange of waste heat and slag between cement plants and steel mills, alongside the use of waste materials as alternative fuels, significantly reduced CO2 emissions. Despite these benefits, concerns about competition and protecting proprietary information likely limited the willingness to share details about emission inventories.

Table 4.7: Presentation of results from chi-square analysis of the four distinct type of solid waste material (Nutrient value Fibre cellulose, Energy and Element value) and seven categories of type of information

		Type of solid waste				Total		*X*2 (df)	P
		Element value	Energy value	Fibre & cellulose	Nutrient				
		N	N	N	N	N	%		
Information on Type of Waste								3.178 (3)	.365
	NO	0	0	1	0	1	2.4		
	YES	11	5	9	15	40	97.6		
Amount of Waste								4.709 (3)	.194
	NO	5	0	5	4	14	34.1		
	YES	6	5	5	11	27	65.9		
Waste quality								4.784 (3)	.188
	NO	4	0	4	2	10	24.4		
	YES	7	5	6	13	31	75.6		
Emission Inventory								2.394 (3)	.495
	NO	7	3	9	11	30	73.2		
	YES	4	2	1	4	11	26.8		
Supply patterns								1.662 (3)	.645
	NO	5	1	5	5	16	39.0		
	YES	6	4	5	10	25	61.0		
Operating cost of synergies								3.535(3)	.316
	NO	6	1	7	7	21	51.2		
	YES	5	4	3	8	20	48.8		
Technical knowledge and re-use pathways								2.579(3)	.461
	NO	10	3	7	10	30	73.2		
	YES	1	2	3	5	11	26.8		

Regarding the operating costs of synergies, over half of the respondents (51.02%) and moreso those dealing in fibre and cellulose waste material chose not to disclose this information, possibly due to concerns over maintaining a competitive advantage. This withholding of information may limit the formation of synergies, as noted by an officer from the Kenya Association of Manufacturers (KAM), who indicated that confidentiality surrounding business operations is a significant barrier to collaboration. Behera et al. (2012) demonstrated in their study of the Ulsan Eco-Industrial Park in South Korea that sharing operational costs is crucial, as industrial symbiosis can lead to cost reductions for participating firms.

The limited sharing of technical knowledge and reuse pathways, with 73.2% withholding this information ,particulary for those in element value solid waste material reuse, also reveals challenges related to trust and collaboration. This lack of information exchange could stem from industries safeguarding their technological processes or simply being unaware of reuse technologies, as observed in studies by Chen and Ma (2015) and Shi and Chertow (2017). Enhancing technological capacity and fostering research and development (R&D) are key strategies for addressing these limitations and promoting the growth of industrial symbiosis networks.

Conversely, the data shows that information sharing on waste types was high, with a 97.6% response rate. Only one industry, a sugar factory, did not share waste type information, as it operated in a closed-loop system, practicing symbiosis only within its facility. The high response rate indicates the critical role of waste type information in enabling industries to identify potential synergies for reuse. This finding is supported by Marconi et al. (2018) and Geng et al. (2012), who highlighted that detailed information on waste types is essential for identifying material matches and facilitating collaboration between industries. The more specific the data, the easier it becomes for industries to recognize and leverage waste streams for symbiotic exchanges.

For information related to the amount of waste generated, 65.9% of respondents shared this data. This is likely due to the necessity of matching waste output from one industry with the input requirements of another, ensuring complementarity in material flows. However, a notable gap is the absence of centralized databases containing waste data. Paquin and Howard-Grenville (2012) emphasized that such information is vital for determining whether a symbiotic exchange will have a meaningful impact. Developing databases that facilitate waste matching across industries would greatly enhance synergies within the network.

Waste quality information was shared by 75.6% of respondents, with variations across waste categories. In industries dealing with nutrient value waste, particularly those reusing by-products for consumption, waste quality is a crucial factor. For example, 13 respondents in the nutrient value category shared detailed information on waste quality. In contrast, industries exchanging energy value waste were less concerned with quality, likely because these materials do not require reprocessing. This highlights the complex relationship between waste quality and operational factors in industrial symbiosis, as identified by studies like those of Yenipazarli (2019), Low et al. (2018), and Yeo et al. (2019).

Regarding supply patterns, 61% of respondents shared this information. Supply pattern data are crucial for maintaining continuous transactions and ensuring the consistent availability of by-products. Turken and Geda (2020) argued that understanding supply patterns allows industries to plan logistics and establish secure partnerships. While information sharing varied across different types of waste, no statistically significant association between information type and types of solid waste material exchanged was found. Therefore, the study failed to reject the null hypothesis. This finding suggests that other factors might influence information exchange. Although the sample size may limit the statistical power of this study, the findings still highlight the importance of information exchange in forming synergies.

This study contributes to the existing literature by showing that while the type of information shared is critical, industries need to overcome barriers related to business confidentiality to facilitate trust and collaboration in industrial symbiosis. Other studies, such as those by Massard and Erkman (2007) and Patricio et al. (2022), have similarly identified the role of information flows in identifying synergies and creating new opportunities. Moving forward, the focus should be on creating open channels of communication, particularly regarding technical knowledge and cost-sharing, to enhance the effectiveness of industrial symbiosis networks.

4.5 Symbiotic Intensity and amount of solid waste material reused

Eight categories of symbiotic interactions were observed (Figure 8). Most (34%) of the symbionts fell under category 2,1, i.e., two actors exchanging 1 type of solid waste material. 3,1 and 4,2 each had a representation of 17% of symbionts.

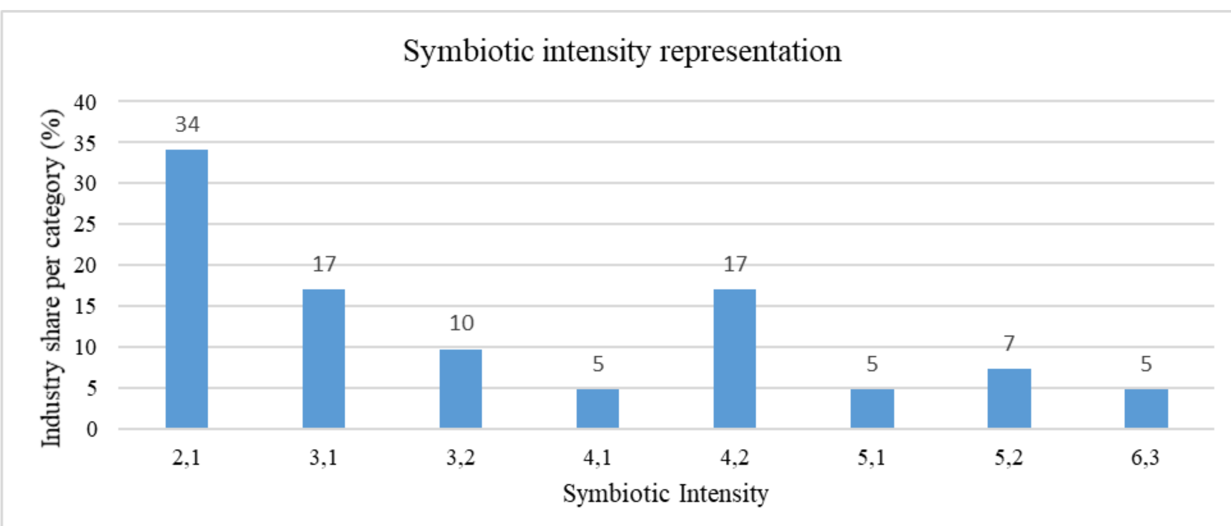


Figure 9: Symbiotic intensity and industry share per category in percentage.

The categories least represented (5%) were 4,1, 5,1, and 6,3, as shown in Figure 8. These results indicate that the intensity of symbiosis is low. Many actors pair in twos, most likely because the pairing actor sufficiently meets their resource needs and, as such, there is no need for further connections. The exchange of mainly 1 type of waste, as seen in most categories, was associated with the type of product made out of the solid waste material obtained, which in most cases was one product. The maximum number of materials exchanged was 3, but very few industries had this exchange level. This alluded to limited innovation pathways and poor sharing of technical information in the network. Yang (2022), in his study on evaluating the symbiotic efficiency of China's Provinces, established that scientific research and the quality of the talents provided have a substantial positive impact on the symbiotic efficiency. These results on symbiotic intensity form the basis for monitoring the further growth of the network. Due to the uniqueness of actors in any network in terms of exchange content of exchange and social structure, comparisons of performance or growth cannot be made with other networks. Van Berkel (2009) noted that symbiotic intensity primarily considers the organisational complexity of the industrial ecosystem and that it is case specific. However, a 6,3 symbiotic intensity was reported in Gladstone (Australia) comprising, that is, three symbiotic projects between 6 firms. Considering that symbiosis within the County is self-organised, and that there is not much-coordinated planning of the location of industries, the intensity of the practice remains low; thus, complementariness by scale and sector should be considered in expanding such networks.

To further illustrate the connectedness of the exchanges according to (Fig 8) The 3-D network visualization was generated using gephi-a network visualization software as shown in (Fig 9) Despite the various clusters within the networks, it was observed that industries formed more complex and aggregated networks based on the commonality of ‘connector’ actors. Figure 9 shows the entire symbiotic network of industries in Kisumu County, showing the 41 firms establishing 62 connections amongst them. The graph density was established to be 0.038, indicating that a small fraction of the possible connections in the network were actually present. This implies that the network is relatively sparse and not as tightly connected as it could be. The industries in agro-processing industries have the highest degree of centrality in the network (out-degree and in-degree centrality: appendix 12), indicating that these industries are the most important concerning their influence on exchanges between other actors in the network.

Earlier, it was established that the majority of the industries in the county belong to the agro-processing sector, and hence, this result is consistent with what we had established earlier in the study. Removing these pivotal actors from the network can result in significant reuse in the symbiotic intensity of the network. This inference is supported by Chopra and Khanna (2014) study, which sought to understand the resilience of IS networks in Kalundborg based on the disruption scenarios. He found that with the removal of the Asnae power plant, only 7 of the 20 previously existing synergistic water flows were maintained (Chopra & Khanna, 2014). The large-scale agro-processing industries can be considered anchor “tenants” of symbiosis in the County. Their role in shaping and orienting the practice of IS is critical within the network as their influence and impact ripples through to other industries regardless of the scale of operation.

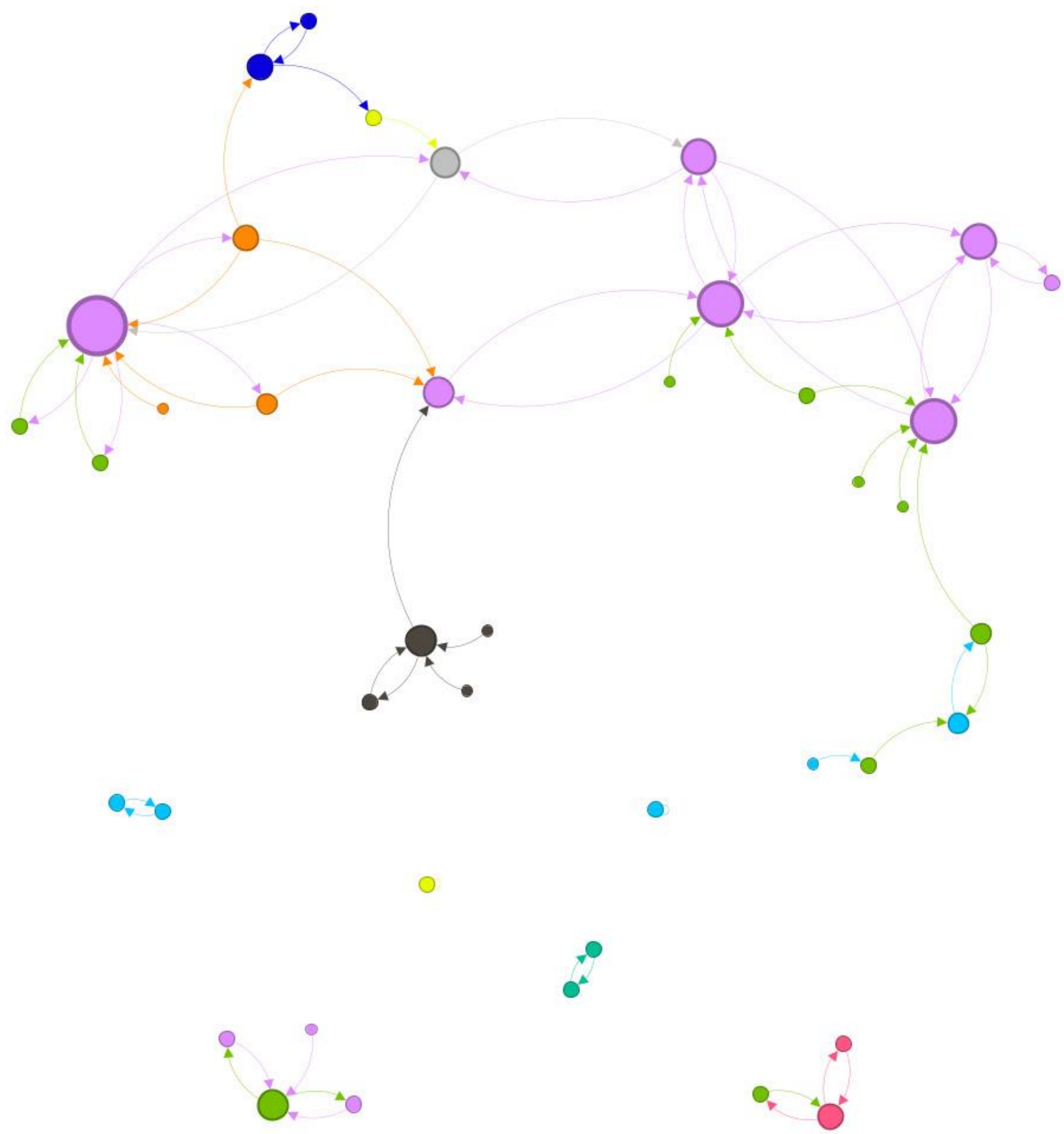


Figure 10: Symbiotic network showing exchanges of solid waste material amongst the different industry sectors.

Key Agroprocessors Energy Sector Food and Beverage Metal and Allied Leather and textiles

Plastics Building and construction Chemical &allied Timber Paper and board

The 3-D network visualization showed a highly interconnected network with a prominent cluster connecting the majority of the actors in the network. Four smaller clusters of 2-4 actors and a single standalone node. Actors in the smaller clusters were disconnected from the primary network industry because their activities were strategically aligned to complement each other. Therefore, there was no need to outsource by-products outside the cluster. It seems possible that this observation was due to the few industries that were noted to reuse the inorganic materials under the element value waste type. The majority of the other industries belonged to the more extensive cluster of those reusing organic solid waste material. Similar findings were demonstrated by Chertow *et al.* (2008), who reported that anchor actors provided resources and expertise in reusing a byproduct, facilitating the establishment of a network. Van Beers *et al.* (2007) attributed the developments in Kwinana and Gladstone in Australia to widespread enthusiasm and commitment to achieve greater regional synergies. (Shi & Chertow, 2017) established that the change in growth from 2 internal to 11 internal and external symbiotic exchanges in the Guitang Group of industries in China was partly explained by the institutionalization of research and development (R&D) and technology-oriented leadership, which facilitated the transfer and dissemination of technical information and created more channels for reuse of by-products from sugar processing (Shi & Chertow, 2017). This network shows the potential to grow more complex and cohesive symbiotic networks that can be done through enhanced cooperation amongst actors. It can be inferred that symbiotic networks are established based on the type of waste exchanged by actors, and the structure and strength of the network are influenced by industries through which most resources flow.

4.5.1 The amount of solid waste material reused in the network

Annually, the total amount of solid waste material reused within the symbiotic networks of the 41 industries was established to be 560,115.7 tons (Table 4.8). This represented the amount of valuable waste material that was diverted from landfills. The mean amount reused in the network was (μ=13661.4 tons), and the standard deviation (= 28316.724 tonnes) indicated a high variation in the amount of waste reused by industries.

A considerable range observed (Min = 2 tonnes, Max= 148568 tonnes) can be explained by industry scales where small-scale industries reuse smaller amounts of waste compared to large-scale industries.

Table 4.8: Summation, mean, standard deviation, range, minimum, and maximum amount of waste exchanged in the entire network annually in tonnes

	N	Range	Minimum	Maximum	Sum	Mean	Std. Deviation
Amount of waste	41	148568	2	148570	560115.7	13661.40	28316.724

The annual tonnage recorded (560115.7 tonnes) represents almost four times the daily solid waste generated within Kisumu. The current data highlight that the environmental benefits of the symbiotic practice are substantive. Kisumu City generates roughly 400 tonnes of solid garbage daily (County Goverment of Kisumu, 2018).

Despite the 5,2 symbiotic cluster having a representation of 7% in the exchange network (Fig 8), the highest amount of solid waste material (221,960 tonnes = 38.02%) was reused in this category, as shown in (Table 4.9).

Table 4.9: Symbiotic intensity, amount of solid waste material reused and amount of solid waste material in percentage

Symbiotic intensity	Amount of solid waste material reused (tons)*	Proportion of waste (%)
2,1	46055	8.2
3,1	62385	11.14
3,2	20230	3.61
4,1	375	0.07
4,2	62525	11.16
5,1	43760	7.81
5,2	212960	38.02
6,3	111785	19.96
Total	560075	100

*Values rounded to the nearest five.

In contrast, the 2,1 group, which made up 34% of the network, reused only 46,055 tons (8.2%) of the total waste. This discrepancy highlights that higher symbiotic intensity—defined by the number of waste types and actors involved—leads to greater waste reuse. The clusters with higher symbiotic intensity, such as 5,1, 5,2, and 6,3, accounted for 64.98% of the total waste reused, despite representing only 17% of the network. This correlation between symbiotic intensity and waste reuse aligns with the findings of Menato et al. (2017), who demonstrated that larger companies tend to create more symbiotic flows due to their greater capacity and resource availability.

A key informant from the Kisumu County Department of Environment emphasized that solid waste management remains a central issue in the county. As more industries pursue ISO-14001 certification, which emphasizes environmental management, the waste management practices at the industry level are likely to improve. The informant also noted the need for greater collaboration between the county government and industries to enhance the effectiveness of industrial symbiosis. This finding suggests that by increasing the participation of industries in symbiotic networks, especially those with higher capacity for waste reuse, the county can significantly improve its waste management outcomes and contribute to sustainable economic development.

4.5.2 Influence of symbiotic intensity on the amount of solid waste reused

The third question in this study sought to determine the influence of symbiotic intensity on amount of solid waste-material reused in the network. The symbiotic intensity was conceptualized as the number of actors and the number of types of solid waste material exchanged. Multiple regression predicted the relationship between symbiotic intensity and the amount of waste exchanged in the network. The results of multiple linear regression are presented in Table 4.10. From this data, we can see that the variation of 11.3% (Adjusted R square = 0.113) in the amount of solid waste reused can be explained by the number of actors and the number of types of solid waste exchanged in the symbiotic network.

The number of actors and the number of types of solid waste exchanged in symbiotic networks only explained 11.3% of the variation in the amount of solid waste reused. This indicates that the model in this study could not explain 88.7% of the observation variation. The unstandardized coefficients for the multiple linear regression model show that the constant regression equation was 2.009, and the coefficients of the number of actors in the network and the number of types of solid waste material exchanged were 0.324 and 0.243, respectively. The Beta column of the standardized coefficients compares each variable's contribution to the multiple regression model. The contribution of the 'Number of actors in a network" (0.308) appeared to be greater than that of the "Number of types of solid waste material exchanged' (0.114). This was also reflected in the contribution of each variable when the other one was kept constant.

Table 4.10: Presentation from results of multiple linear regression symbiotic intensity (Number of actors; Number of types solid waste material exchanged) and the amount of solid waste material reused

Model		Unstandardized coefficients		Standardized Coefficients			Correlations
		B	Std. Error	Beta	t	Sig.	Part
1	(Constant)	2.009	.496		4.053	<.001	
	Number of actors	.324	.221	.308	1.468	.150	.219
	Number of types of solid waste material exchanged	.243	.448	.114	.541	.591	.081

Dependent variable: the amount of solid waste reused (log_10)
Adjusted R^2=.113;
F=3.548;
df (2,38);
p=.039

The multiple linear regression model for predicting the amount of solid waste reused based on the number of actors and number of types of waste exchange can be expressed as follows:

$$Y = b_0 + b_1 X_1 + b_2 X_2 + \varepsilon$$

Y represents the amount of solid waste being predicted.

X_1 represents the number of actors

X_2 represents the number of types of solid waste exchanged.

b_0 is the intercept or constant term.

b_1 is the regression coefficient of number of actors

b_2 is the regression coefficient of number of types of solid waste material reused.

ε represents the error term, which accounts for the variability in the amount of solid waste reused that is not explained by the predictors. Therefore,

$$Y = 2.009 + 0.324\, X_1 + 0.243\, X_2 + \varepsilon$$

The semi-partial contribution of the variables in the column Correlations "Part" explained the unique contribution of each variable. In this case, the highest unique contribution was from the number of actors in a network (0.219) compared to the number of types of solid waste material (0.81). It was also established that the significance of these factors was not statistically significant (number of actors in a network $p=0.150$) and (Number of types of solid waste material exchanged: $p = 0.591$). However, the model's results were statistically significant ($F = 3.548$, $p = 0.039$, $\alpha = 0.05$) according to the analysis of the variance test of the combined effect of the two variables. Symbiotic intensity influenced the amount of solid waste material reused in the network, and as such, the coefficients in the equation for symbiotic intensity cannot be zero.

The low variation effect (11.3%) seen in the model could be explained by what was observed by the low symbiotic intensity that was observed in the network (Fig 8), where the majority of the symbiotic industries were in the 2,1 and 3,1 clusters. The coefficients indicate that the two variables used to measure symbiotic intensity positively influenced the amount of solid waste material. It implies that if the number of actors in a symbiotic group increases by one, holding the number of types of solid waste material exchanged constant, then the amount of solid waste reused would increase by 324 tons. On the other hand, if the number of actors in the network is kept constant, then increasing the number of types of material exchanged by one would increase the amount of solid waste material reused by 243 tons. This study established that symbiotic intensity statistically significantly influenced the amount of waste reused in the network (p=0.039). Given the findings (p=0.039), we reject the null hypothesis.

Furthermore, the findings established the unique contribution of each variable in the model and demonstrated that increasing the number of actors in the network will have more impact on waste reuse than increasing the number of types of waste being exchanged. This finding may be explained by a characteristic of the established symbiotic network where it was observed that the number of industries in collaboration was between 2 to 6 industries in exchange. Additionally, the amount of waste exchanged was more in the higher clusters despite having lesser representation in the network. On the other hand, the number of types of waste industries could exchange only four, and only 5% of the sampled industries exchanged up to 3 types of waste; the majority exchanged 2 or 1 type. A note of caution is due here; these types of waste were established through a regrouping system where individual waste streams were grouped into categories based on the values attached. This was necessary for the statistical analysis.

The broader literature also emphasizes caution when comparing different industrial systems, as each network has unique characteristics ((Van Berkel, 2009). This taken into account, it is encouraging to note that other studies have looked at the amount of waste reused in the network annually and hence diverted from landfills, such as by Berkel *et al.*, (2009) who established that in Kawasaki Japan, 14 documented symbioses with key material exchanges divert at least 565 000 tons of waste annually from incineration or landfill. Dong *et al.*.(2013) established that in Liuzhou, China, there were three symbiosis activities between industries with an annual waste exchange of more than 2 million tons/year, whereas in Jinan, China, had seven symbiotic links between industries, with a total waste exchange of more than 8 million tonnes/y.

This finding corroborates the ideas of Chertow and Lombardi (2005) who suggested that a higher symbiotic intensity can increase resource efficiency as more materials and energy are reused or repurposed within the network, reducing waste and promoting sustainability. Only 11.3% of the variation was explained by the model, meaning other factors drive symbiotic exchanges that were not examined. This observation broadly supports some of the research work which has put a caution on symbiotic intensity not to be considered sufficient to assess the benefits or impacts of industrial symbiosis networks fully, and other factors and indicators may need to be considered as well: economic factors such as input cost reduction (Van Beers *et al.*, 2007). knowledge and technology (Boons *et al.*, 2011), diversity of industries, geographical proximity, facilitating entities, legislation, plans, and policies (Neves *et al.*, 2019). Before this study, it was difficult to predict how symbiotic intensity influences the amount of waste reused in the network. The findings of this study offer insightful contributions to the current literature and lay the groundwork for future research on the relationship between symbiotic intensity and the amount of waste reused in the network.

CHAPTER FIVE

SUMMARY, CONCLUSIONS & RECOMMENDATIONS

5.1 Introduction

The study was designed to explore the influence of industrial symbiosis on solid waste reuse in the manufacturing sector in Kisumu County. Three research questions were postulated based on the three specific objectives to examine this concept. The findings, conclusions, and recommendations for each specific objective have been summarized in the following sections.

5.2 Summary of the Findings

In objective one, which determined the influence of geographical proximity (distance between actors in the network) on types of solid waste material exchanged, the study found that the ideal radius for exchange in the four types of waste was 4.5km. However, there was a variance in the ideal distance when each waste type was examined independently (element value = 6.5 Km, Energy value = 2.65 km, Fibre & cellulose value = 4.8 km). Only nutrient value waste had similar results with the overall distance (4.5 km). Regarding the entire data set, geographic proximity did not significantly influence the type of solid waste material exchanged ($p = 0.687$; $p>0.05$). The study failed to reject the null hypothesis. The same was established when the significance of the geographical proximity on each waste type, 'Nutrient value' waste material being the reference category: solid waste material ($p= 0.298$), Energy value element value ($p =0.327$), and Fibre&Cellulose value ($p=0.535$). A note of caution is due here since, compared to other studies, the current study area had a sample size of 41, much smaller than other studies that covered wider regions with a sample size of 600+. This could limit the generalizability of this result.

Objective two sought to establish the relationship between information flows (type and frequency of communication) and types of solid waste material exchanged. The results showed variation in frequency communication within the cases; overall, it was established that 56.1% of cases communicated when necessary, 29.3% weekly and 14.6% daily. Analysis based on waste type categories showed a statistically significant relationship between the frequency of communication and the type of solid waste material exchanged (p=0.013). The study rejected the null hypothesis regarding frequency of communication. The second part of the analysis that examines the relationship between the type of information shared and the type of waste exchanged did not show a statistically significant relationship between the two variables**:** information on type of waste generated (p=0. 365), Amount of waste generated (p=0. 194), Waste quality (p=0. 188), Emission inventory (p=0. 495), Supply patterns (p=0. 181), Operating costs of synergies (p=0.316), Technical knowledge (p=0. 461). Therefore, the study failed to reject the null hypothesis for the type of information shared, indicating no significant association. The study did not have enough statistical power to detect a significant relationship between the type of information and the type of waste exchanged.

One of the most significant findings to emerge from this study is that there was a statistically significant relationship (p=0.039) between symbiotic intensity and solid waste reuse in the network. Given the findings (p=0.039), we reject the null hypothesis. The symbiotic intensity was conceptualized as the number of actors in a network and the number of types of waste exchanged. Symbiotic intensity explained 11.3% of the variation in the amount of solid waste material reused. The model showed a positive relationship between symbiotic intensity and the amount of waste reused. Increasing the number of actors in a symbiotic cluster by one would increase waste reuse by 324 tons while keeping the number of types of solid waste material exchanged constant. Conversely, if the number of actors in the network is kept constant, then increasing the number of types of material exchanged would increase the amount of solid waste material reused by 243 tons. The amount of solid waste material reused in the network annually was established to be 5,60075 tonnes.

5.3 Conclusions

The study concludes that while proximity plays a role in facilitating exchanges, it may not be a decisive factor in determining the types of solid waste exchanged within industrial symbiosis in Kisumu County. Since proximity is not a decisive factor in waste exchanges, industries do not necessarily need to be co-located to facilitate effective waste exchanges. This provides flexibility in planning industrial locations and allows for regional collaboration between distant industries, potentially expanding the scope of industrial symbiosis networks beyond immediate neighbors. To mitigate the impact of distance and enhance exchanges, investments in efficient transportation and logistics infrastructure are crucial. This study challenged the traditional theories of industrial symbiosis which emphasize the importance of geographical proximity in facilitating material exchanges between industries. This implies that the theoretical understanding of IS may need to consider broader factors beyond physical closeness.

Based on the findings of objective two, the study concludes that the frequency of communication between actors in a symbiotic relationship was significantly associated with the type of solid waste material exchanged, highlighting that frequent communication enhances the development of symbiotic exchanges. This implies that communication frequency is crucial for building and fostering effective industrial symbiosis networks. Practically, this finding suggests that targeted interventions, such as facilitating face-to-face interactions and implementing e-communication technologies, are needed to enhance communication frequency among network actors, thereby promoting more successful waste exchanges. Theoretically, while the study did not find a significant association between the type of information shared and the type of waste exchanged, it partially validated the importance of diverse information types in fostering synergies. This suggests the need for further exploration of how accessible, comprehensive information databases could stimulate new industrial symbiosis activities, potentially extending the reach of waste reuse initiatives.

Lastly, the study concludes that symbiotic intensity significantly influences solid waste reuse, with a greater impact observed from increasing the number of actors within a network compared to increasing the types of waste exchanged. This finding enhances our understanding of how network composition affects waste reuse, highlighting the importance of expanding the number of participants to boost the efficiency of industrial symbiosis (IS). The practical implication is that strategies to facilitate IS networks should focus on integrating more complementary industries to maximize the potential for waste reuse. The theoretical contribution of this study is the development of a predictive model that demonstrates how symbiotic intensity, characterized by the number of industries and resource flows, can be used to estimate the performance of a symbiotic network. This model provides valuable insights for planning and optimizing IS initiatives, offering a framework for scaling up the positive impacts of industrial symbiosis on solid waste management.

5.4 Recommendations

Since the study found no significant influence of proximity, policymakers could improve data collection and monitoring efforts related to waste reuse across the region. This data can assist industries in identifying suitable partners for waste exchange and also help policymakers track the effectiveness of industrial symbiosis initiatives across different proximities. The study also recommends that the road infrastructure should also be improved to facilitate better movement of solid waste material within the network of existing symbiotic industries even if they are not in close proximity.

The study recommends that targeted interventions be developed to create more avenues for frequent and fast communication between actors in a network. This can include face-to-face interactions and the use of electronic communication technology. This should be done while integrating key stakeholders, including research institutions, who will offer technical feasibility of possible symbiotic exchanges in the network. The creation of information databases will be critical in the growth of IS, as it can help foster synergies between actors in a network and yield symbiotic activities in new spheres.

Finally, the study recommends that practitioners and facilitators of IS networks prioritize increasing the number of complementary industries in the network to spur the growth and impact of IS networks. Additionally, the use of policy instruments and incentives that will create an enabling environment to accelerate the establishment of more industries that will promote symbiotic exchanges in the manufacturing sector with the ultimate goal of zero waste production processes is recommended. Future development plans can utilise the model developed in this study to predict the performance of a symbiotic network (solid waste reuse) based on the number of industries and the number of resource flows.

5.5 Areas for further research

More research on a regional scope could shed more light on the geographical proximity and the type of solid waste material exchanged. Furthermore, the effectiveness of other factors beyond geographical proximity, such as economic incentives, regulatory frameworks, and policy support, in promoting industrial symbiosis in developing countries can be investigated.

Considerably, more work will need to be done to determine how information flows influence IS. Firstly, exploring the effectiveness of different communication channels, such as face-to-face interactions and e-communication technology, in promoting frequent and fast communication among actors in a network. Secondly, To enhance replicability, future research would need a larger sample size or more refined methods to increase statistical power, ensuring that significant relationships can be detected more reliably.

Further modeling work will have to be conducted to determine the contribution of other factors, such as technology, innovation, and policy support, to the relationship between symbiotic intensity and solid waste reuse.

REFERENCES

Alfaro, J., & Miller, S. (2014). Applying industrial symbiosis to smallholder farms: Modeling a case study in Liberia, West Africa. *Journal of Industrial Ecology, 18*(1), 145-154.

Ashton, W. (2008). Understanding the organization of industrial ecosystems: A social network approach. *Journal of Industrial Ecology*, *12*(1), 34-51.

Awuor, F. O., Oloko, M., Onditi, A. L., & Agong, S. G. (2021). From a Waste Cemetery to a Waste Hospital: Recreating Kisumu City's Waste Management System.

Ayres, R. U., & Ayres, L. (2002). *A handbook of industrial ecology*. Edward Elgar Publishing.

Baruch, Y. (1999). Response Rate in Academic Studies-A Comparative Analysis. *Human Relations*, *52*(4), 421-438.

Behera, S. K., Kim, J.-H., Lee, S.-Y., Suh, S., & Park, H.-S. (2012). Evolution of 'designed'industrial symbiosis networks in the Ulsan Eco-industrial Park:'research and development into business' as the enabling framework. *Journal of Cleaner Production, 29*, 103-112.

Belhadi, A., Kamble, S. S., Zkik, K., Cherrafi, A., & Touriki, F. E. (2020). The integrated effect of Big Data Analytics, Lean Six Sigma and Green Manufacturing on the environmental performance of manufacturing companies: The case of North Africa. *Journal of Cleaner Production, 252*, 119903.

Berkel, R. V., Fujita, T., Hashimoto, S., & Fujii, M. (2009). Quantitative assessment of urban and industrial symbiosis in Kawasaki, Japan: ACS Publications.

Boons, F. (2008). Self-organization and sustainability: The emergence of a regional industrial ecology. *Emergence: complexity and organization*, *10*(2), 41-48.

Boons, F., Montalvo, C., Quist, J., & Wagner, M. (2013). Sustainable innovation, business models and economic performance: an overview. *Journal of Cleaner Production, 45*, 1-8.

Boons, F., Spekkink, W., & Mouzakitis, Y. (2011). The dynamics of industrial symbiosis: a proposal for a conceptual framework based upon a comprehensive literature review. *Journal of Cleaner Production, 19*(9-10), 905-911.

Bowersox, D. J., Closs, D. J., & Stank, T. P. (2003). How to master cross-enterprise collaboration. *SUPPLY CHAIN MANAGEMENT REVIEW, V. 7, NO. 4 (JULY/AUG. 2003), P. 18-27: ILL*.

Branca, T. A., Colla, V., Algermissen, D., Granbom, H., Martini, U., Morillon, A., Pietruck, R., & Rosendahl, S. (2020). Reuse and recycling of by-products in the steel sector: Recent achievements paving the way to circular economy and industrial symbiosis in Europe. *Metals, 10*(3), 345.

Brent, A. C., Oelofse, S., & Godfrey, L. (2008). Advancing the concepts of industrial ecology in South African institutions: science policy. *South African Journal of Science*, *104*(1), 9-6.

Brundtland, G. H. (1985). World commission on environment and development. *Environmental policy and law*, *14*(1), 26-30.

Cárcamo, E. A. B., & Peñabaena-Niebles, R. (2022). Opportunities and challenges for the waste management in emerging and frontier countries through industrial symbiosis. *Journal of Cleaner Production, 363*, 132607.

Chertow, M., & Ehrenfeld, J. (2012). Organizing self-organizing systems: Toward a theory of industrial symbiosis. *Journal of Industrial Ecology*, *16*(1), 13-27.

Chertow, M. R. (1999). *Industrial symbiosis: a multi-firm approach to sustainability.* Paper presented at the Eighth International Conference of the Greening of Industry Network.

Chertow, M. R. (2000). Industrial symbiosis: literature and taxonomy. *Annual review of energy and the environment*, *25*(1), 313-337.

Chertow, M. R. (2007). "Uncovering" industrial symbiosis. *Journal of Industrial Ecology, 11*(1), 11-30.

Chertow, M. R., Ashton, W. S., & Espinosa, J. C. (2008). Industrial symbiosis in Puerto Rico: Environmentally related agglomeration economies. *Regional studies, 42*(10), 1299- 1312.

Chertow, M. R., & Lombardi, D. R. (2005). Quantifying economic and environmental benefits of co-located firms: ACS Publications.

Chopra, S. S., & Khanna, V. (2014). Understanding resilience in industrial symbiosis networks: Insights from network analysis. *Journal of environmental management, 141*, 86-94.

Cook, R. D. (1979). Influential observations in linear regression. *Journal of the American Statistical Association, 74*(365), 169-174.

Costa, I., Massard, G., & Agarwal, A. (2010). Waste management policies for industrial symbiosis development: case studies in European countries. *Journal of Cleaner Production, 18*(8), 815-822.

County Goverment of Kisumu. (2018). *Kisumu integrated solid waste management plan*. Kisumu: Kisumu County Press.

County Government of Kisumu. (2020). Kisumu Sustainable Mobility Plan. Kisumu County.

County Government of Kisumu. (2020). Kisumu County Solid Waste Management Policy. Kisumu County.

County Government of Kisumu. (2023). Kisumu County Integrated Development Plan (CIDP) III 2023-2027. Kisumu County.

Damgaard, A., Takou, V., Ramin, E., & Andersen, M. M. (2019). *Identifying industrial ecology options for an industrial park—case of Ruaraka, Kenya*. Paper presented at the Abstract from 17th international waste management and landfill symposium, Santa Margherita di Pula, Italy.

Davenport, T. H., & Prusak, L. (1998). *Working knowledge: How organizations manage what they know*. Harvard Business Press.

Dianati, K., Schäfer, L., Milner, J., Gómez-Sanabria, A., Gitau, H., Hale, J., Langmaack, H., Kiesewetter, G., Muindi, K., & Mberu, B. (2021). A system dynamics-based scenario analysis of residential solid waste management in Kisumu, Kenya. *Science of the Total Environment, 777*, 146200.

Domenech, T., Bleischwitz, R., Doranova, A., Panayotopoulos, D., & Roman, L. (2019). Mapping Industrial Symbiosis Development in Europe_ typologies of networks, characteristics, performance and contribution to the Circular Economy. *Resources, conservation and recycling, 141*, 76-98.

Domenech, T., & Davies, M. (2011). Structure and morphology of industrial symbiosis networks: The case of Kalundborg. *Procedia-Social and Behavioral Sciences, 10*, 79- 89.

Dong, L., Zhang, H., Fujita, T., Ohnishi, S., Li, H., Fujii, M., & Dong, H. (2013). Environmental and economic gains of industrial symbiosis for Chinese iron/steel industry: Kawasaki's experience and practice in Liuzhou and Jinan. *Journal of Cleaner Production, 59*, 226-238.

Ehrenfeld, J., & Gertler, N. (1997). Industrial ecology in practice: The evolution of interdependence at Kalundborg. *Journal of Industrial Ecology, 1*(1), 67-79.

European Union. (2018). SWITCH Africa Green final report: Promoting sustainable consumption and production in six African countries (2014-2018).

Fraccascia, L., & Yazan, D. M. (2018). The role of online information-sharing platforms on the performance of industrial symbiosis networks. *Resources, conservation and recycling, 136*, 473-485.

Frosch, R. A., & Gallopoulos, N. E. (1989). Strategies for manufacturing. *Scientific American, 261*(3), 144-153.

Gajendran, R. S., & Joshi, A. (2012). Innovation in globally distributed teams: The role of LMX, communication frequency, and member influence on team decisions. *Journal of Applied Psychology, 97*(6), 1252.

Gelman, A., & Hill, J. (2006). *Data analysis using regression and multilevel/hierarchical models*. Cambridge university press.

Geng, Y., Fu, J., Sarkis, J., & Xue, B. (2012). Towards a national circular economy indicator system in China: an evaluation and critical analysis. *Journal of Cleaner Production, 23*(1), 216-224.

Gibbs, D., & Deutz, P. (2007). Reflections on implementing industrial ecology through eco-industrial park development. *Journal of Cleaner Production, 15*(17), 1683-1695.

Government of Kenya. (2012). *Micro and Small Enterprises Act, No. 55 of 2012*. Kenya Gazette Supplement No. 219 (Acts No. 55). Government Printer

Graedel, T. E., & Lifset, R. J. (2016). Industrial ecology's first decade. *Taking stock of industrial ecology*, 3-20.

Grant, G. B., Seager, T. P., Massard, G., & Nies, L. (2010). Information and communication technology for industrial symbiosis. *Journal of Industrial Ecology, 14*(5), 740-753.

Gutberlet, J., Kain, J. H., Nyakinya, B., Oloko, M., Zapata, P., & Zapata Campos, M. J. (2017). Bridging weak links of solid waste management in informal settlements. *The Journal of Environment & Development*, *26*(1), 106-131.

Halstenberg, F. A., Steingrímsson, J. G., & Stark, R. (2017). *Material reutilization cycles across industries and production lines*. Springer International Publishing.

Hartwick, J., & Barki, H. (2001). Communication as a dimension of user participation. *IEEE transactions on professional communication, 44*(1), 21-36.

Hashimoto, S., Fujita, T., Geng, Y., & Nagasawa, E. (2010). Realizing CO2 emission reduction through industrial symbiosis: a cement production case study for Kawasaki. *Resources, conservation and recycling, 54*(10), 704-710.

Hein, A. M., Jankovic, M., Feng, W., Farel, R., Yune, J. H., & Yannou, B. (2017). Stakeholder power in industrial symbioses: A stakeholder value network approach. *Journal of Cleaner Production*, *148*, 923-933.

Hewes, A. K., & Lyons, D. I. (2008). The humanistic side of eco-industrial parks: champions and the role of trust. *Regional studies, 42*(10), 1329-1342.

Hocking, J. B., Brown, M., & Harzing, A. W. (2007). Balancing global and local strategic contexts: Expatriate knowledge transfer, applications, and learning within a transnational organization. *Human Resource Management: Published in Cooperation with the School of Business Administration, The University of Michigan and in alliance with the Society of Human Resources Management, 46*(4), 513-533.

Holgado, M., Benedetti, M., Evans, S., Baptista, A., & Lourenço, E. (2018). Industrial symbiosis implementation by leveraging on process efficiency methodologies. *Procedia CIRP, 69*, 872-877.

Homans, G. C. (1958). Social behavior as exchange. *American journal of sociology*, *63*(6), 597-606.

Hoornweg, D., & Bhada-Tata, P. (2012). What a waste: a global review of solid waste management.

Irma Becerra-Fernandez, R. S. (2001). Organizational knowledge management: A contingency perspective. *Journal of management information systems, 18*(1), 23-55.

Jacobsen, N. B. (2006). Industrial symbiosis in Kalundborg, Denmark: a quantitative assessment of economic and environmental aspects. *Journal of Industrial Ecology, 10*(1-2), 239-255.

Jensen, P. D., Basson, L., Hellawell, E. E., Bailey, M. R., & Leach, M. (2011). Quantifying 'geographic proximity': experiences from the United Kingdom's national industrial symbiosis programme. *Resources, conservation and recycling, 55*(7), 703-712.

Johnson, M. P. (2017). Knowledge acquisition and development in sustainability-oriented small and medium-sized enterprises: Exploring the practices, capabilities and cooperation. *Journal of Cleaner Production, 142*, 3769-3781.

Kamndaya, M., Ren, J., & Li, B. . (2015). The application of industrial symbiosis in Africa: The case of Zanzibar. *Journal of Cleaner Production, 103*, 496-504. doi: 10.1016/j.jclepro.2014.09.061

Kaza, S., Yao, L., Bhada-Tata, P., & Van Woerden, F. (2018). *What a waste 2.0: a global snapshot of solid waste management to 2050*. World Bank Publications.

Kenya Association of Manufacturers. (2015). Industrial Symbiosis: Opportunities for Resource Efficiency and Competitiveness in Kenya's Manufacturing Sector.

Kenya Circular Economy Network. (2021). Kenyan Circular Economy Trends & Opportunities.

Kenya National Bureau of Statistics. (2019). 2019 Kenya population and housing census: Volume I: Population by county and sub-county.

Khisa, K., Oguge, N., & Obiero, S. A. (2018). Mainstreaming the culture of eco-industrial parks (EIPs) in Kenya for the sustainable realization of the country's vision 2030. *Journal of International Business Research and Marketing, 3*(6), 7-21.

Korhonen, J. (2001). Four ecosystem principles for an industrial ecosystem. *Journal of Cleaner Production, 9*(3), 253-259.

Kosmol, L. (2019). *Sharing is caring-information and knowledge in industrial symbiosis: a systematic review.* Paper presented at the 2019 IEEE 21st Conference on Business Informatics (CBI).

K'oyoo, E. O., Onyango, L., & Midheme, E. (2022). Assessing community perception of post- mine brownfield's effects on the physical environment in Kisumu, Kenya. *Afr. Res. J. Educ. Soc. Sci, 9*, 58-70.

Lombardi, P., Giordano, S., Farouh, H., & Yousef, W. (2012). Modelling the smart city performance. *Innovation: The European Journal of Social Science Research, 25*(2), 137-149.

Low, J. S. C., Tjandra, T. B., Yunus, F., Chung, S. Y., Tan, D. Z. L., Raabe, B., Ting, N. Y., Yeo, Z., Bressan, S., & Ramakrishna, S. (2018). A collaboration platform for enabling industrial symbiosis: Application of the database engine for waste-to-resource matching. *Procedia CIRP, 69*, 849-854.

Lowe, E. (2002). Introduction to eco-industrial parks and networks. *Cited September, 8*.

Lu, C., Wang, S., Wang, K., Gao, Y., & Zhang, R. (2020). Uncovering the benefits of integrating industrial symbiosis and urban symbiosis targeting a resource-dependent city: a case study of Yongcheng, China. *Journal of Cleaner Production, 255*, 120210.

Lütje, A., Willenbacher, M., Möller, A., & Wohlgemuth, V. (2019). Enabling the identification of industrial symbiosis through ict.

Mangan, A., & Olivetti, E. (2010). By-product synergy networks: Driving innovation through waste reduction and carbon mitigation. *Sustainable development in the process industries: Cases and impact*, 81-108.

Marconi, M., Gregori, F., Germani, M., Papetti, A., & Favi, C. (2018). An approach to favor industrial symbiosis: The case of waste electrical and electronic equipment. *Procedia Manufacturing, 21*, 502-509.

Martin, M. (2013). *Industrial Symbiosis in the Biofuel Industry: quantification of the environmental performance and identification of synergies.* Linköping University Electronic Press.

Mascarenhas, L. C., Ness, B., Oloko, M., & Awuor, F. O. (2021). Multi-criteria analysis of municipal solid waste treatment technologies to support decision-making in Kisumu, Kenya. *Environmental Challenges, 4,* 100189.

Massard, G., & Erkman, S. (2007). *A regional industrial symbiosis methodology and its implementation in Geneva, Switzerland.* Paper presented at the 3rd International Conference on Life Cycle Management.

Mattila, T. J., Pakarinen, S., & Sokka, L. (2010). Quantifying the total environmental impacts of an industrial symbiosis-a comparison of process-, hybrid and input−output life cycle assessment. *Environmental science & technology*, *44*(11), 4309-4314.

Memon, M. A. (2010). Integrated solid waste management based on the 3R approach. *Journal of Material Cycles and Waste Management, 12*, 30-40.

Menato, S., Carimati, S., Montini, E., Innocenti, P., Canetta, L., & Sorlini, M. (2017). *Challenges for the adoption of industrial symbiosis approaches within industrial agglomerations.* Paper presented at the 2017 international conference on engineering, technology and innovation (ICE/ITMC).

Mirata, M., & Emtairah, T. (2005). Industrial symbiosis networks and the contribution to environmental innovation: The case of the Landskrona industrial symbiosis programme. *Journal of Cleaner Production, 13*(10-11), 993-1002.

Munala, G., & Moirongo, B. (2017). The need for an integrated solid waste management in Kisumu, Kenya.

Neves, A., Godina, R., Azevedo, S. G., & Matias, J. C. (2019). *Environmental, economic, and social impact of industrial symbiosis: Methods and indicators review.* Paper presented at the Industrial Engineering and Operations Management II: XXIV IJCIEOM, Lisbon, Portugal, July 18–20 24.

NEW, C. O. (2018). Creating a circular economy in new west: pilot test of the National Industrial Symbiosis Program (NISP®).

Nicholson, C. Y., Compeau, L. D., & Sethi, R. (2001). The role of interpersonal liking in building trust in long-term channel relationships. *Journal of the Academy of Marketing Science, 29*, 3-15.

Nthambi, M., Nyikal, R., & Mburu, J. (2013). Determinants of households choice of solid waste management options in Kibera slum, Kenya. *Journal of International Real Estate and Construction Studies*, *3*(2), 143.

Nyaluogo, K. O. (2016). A study of solid waste management: a case study of Kisumu City (Bachelor of Science in Civil Engineering). Nairobi: University of Nairobi

Ojijo, A. D. (2023). Solid Waste Value Addition and Sustainable Development in Kisumu County, Kenya. *International Journal of Research and Analysis in Commerce and Management, 2*(1).

Oni, O. O., Nevo, C. M., Hampo, C. C., Ozobodo, K. O., Olajide, I. O., Ibidokun, A. O., Ugwuanyi, M. C., Nwoha, S. U., Okonkwo, U. U., & Aransiola, E. S. (2022). Current status, emerging challenges, and future prospects of industrial symbiosis in Africa. *International Journal of Environmental Research, 16*(4), 49.

Paquin, R. L., & Howard-Grenville, J. (2012). The evolution of facilitated industrial symbiosis. *Journal of Industrial Ecology, 16*(1), 83-93.

Park, J.-G., & Lee, J. (2014). Knowledge sharing in information systems development projects: Explicating the role of dependence and trust. *International Journal of Project Management, 32*(1), 153-165.

Patricio, J., Axelsson, L., Blomé, S., & Rosado, L. (2018). Enabling industrial symbiosis collaborations between SMEs from a regional perspective. *Journal of Cleaner Production, 202*, 1120-1130.

Pires, A., Martinho, G., Rodrigues, S., & Gomes, M. I. (2019). *Sustainable solid waste collection and management*. Springer.

Raafat, T., Trokanas, N., Cecelja, F., & Bimi, X. (2013). An ontological approach towards enabling processing technologies participation in industrial symbiosis. *Computers & Chemical Engineering, 59*, 33-46.

Ramin, E., Bestuzheva, K., Gargalo, C. L., Ramin, D., Schneider, C., Ramin, P., Flores-Alsina, X., Andersen, M. M., & Gernaey, K. V. (2021). Incremental design of water symbiosis networks with prior knowledge: The case of an industrial park in Kenya. *Science of the Total Environment, 751*, 141706.

Ronoh, I. J. (2020). *Geothermal Fluid for Industrial Use in the KenGen Green Energy Park, Kenya.* Paper presented at the Proceedings of the 45th workshop on Geothermal Reservoir Engineering; Stanford, California, USA.

Rweyendela, A. G., & Mwegoha, W. J. (2021). Industrial symbiosis in Tanzania: A case study from the sugar industry. *African Journal of Science, Technology, Innovation and Development*, *13*(5), 595-606.

Schlueter, R. (2017). Solid waste management in the developing world: the role of local government in Kisumu, Kenya.

Shi, L., & Chertow, M. (2017). Organizational boundary change in industrial symbiosis: Revisiting the Guitang Group in China. *Sustainability, 9*(7), 1085.

Sibanda, L. K., Obange, N., & Awuor, F. O. (2017). *Challenges of solid waste management in Kisumu, Kenya.* Paper presented at the Urban Forum.

Siddique, R., Khatib, J., & Kaur, I. (2008). Use of recycled plastic in concrete: A review. *Waste Management*, *28*(10), 1835-1852.

Skvoretz, J., & Lovaglia, M. J. (1995). Who exchanges with whom: structural determinants of exchange frequency in negotiated exchange networks. *Social Psychology Quarterly*, 163-177.

Staber, U. (2001). The structure of networks in industrial districts. *International journal of urban and regional research, 25*(3), 537-552.

Standard Media. (2019, March 6). Kisumu firms raided over Lake Victoria pollution. Standard Media.

Standard Media. (2021, February 8). Kisumu rated best in mobile connectivity. Standard Media.

The Star. (2019, 23 April). Kisumu firm on the spot over pollution and skewed employment, The Star.

Turken, N., & Geda, A. (2020). Supply chain implications of industrial symbiosis: A review and avenues for future research. *Resources, conservation and recycling*, *161*, 104974.

UNIDO. (2017). *Industrial Development Report 2018: Demand for Manufacturing: Driving Inclusive and Sustainable Industrial Development*. United Nations Industrial Development Organization.

Van Beers, D., Bossilkov, A., Corder, G., & Van Berkel, R. (2007). Industrial symbiosis in the Australian minerals industry: the cases of Kwinana and Gladstone. *Journal of Industrial Ecology, 11*(1), 55-72.

Van Berkel, R. (2009). Comparability of industrial symbioses. *Journal of Industrial Ecology, 13*(4), 483-486.

Van Berkel, R., van Beers, D., & Bossilkov, A. (2006). *Regional resource synergies for sustainable development: The case of Kwinana.* Paper presented at the Mater. Forum.

Van Capelleveen, G., Amrit, C., & Yazan, D. M. (2018). A literature survey of information systems facilitating the identification of industrial symbiosis. *From science to society: New trends in environmental informatics*, 155-169.

Velenturf, A. P. (2016). Promoting industrial symbiosis: empirical observations of low-carbon innovations in the Humber region, UK. *Journal of Cleaner Production, 128*, 116-130.

Velenturf, A. P. (2017). Initiating resource partnerships for industrial symbiosis. *Regional Studies, Regional Science, 4*(1), 117-124.

Velenturf, A. P., & Jensen, P. D. (2016). Promoting industrial symbiosis: Using the concept of proximity to explore social network development. *Journal of Industrial Ecology, 20*(4), 700-709.

Velenturf, A. P., & Purnell, P. (2017). Resource recovery from waste: Restoring the balance between resource scarcity and waste overload. *Sustainability, 9*(9), 1603.

Were, A. (2016). Manufacturing in Kenya: Features, challenges and opportunities. *International Journal of Science, Management and Engineering, 4*(6), 15-26.

Yang, J. (2022). An empirical study evaluating the symbiotic efficiency of China's provinces and the innovation ecosystem in the high-tech industry. *Complexity, 2022*.

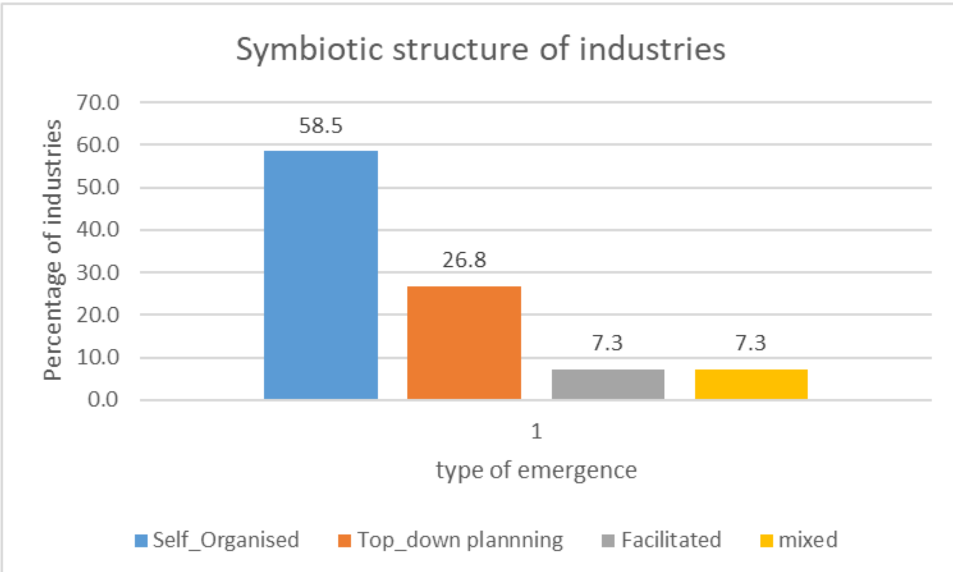
Yenipazarli, A. (2019). Incentives for environmental research and development: Consumer preferences, competitive pressure and emissions taxation. *European Journal of Operational Research, 276*(2), 757-769.

Yeo, Z., Masi, D., Low, J. S. C., Ng, Y. T., Tan, P. S., & Barnes, S. (2019). Tools for promoting industrial symbiosis: A systematic review. *Journal of Industrial Ecology, 23*(5), 1087-1108.

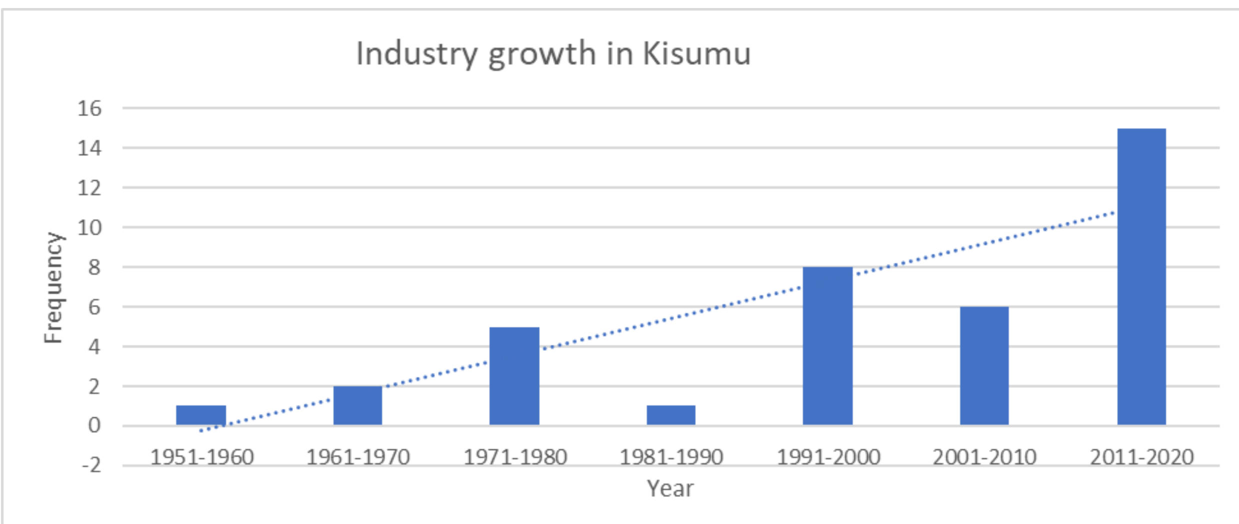
Yu, F., Han, F., & Cui, Z. (2015). Evolution of industrial symbiosis in an eco-industrial park in China. *Journal of Cleaner Production, 87*, 339-347.

APPENDICES

Appendix 1 Symbiotic structure of IS in Kisumu County



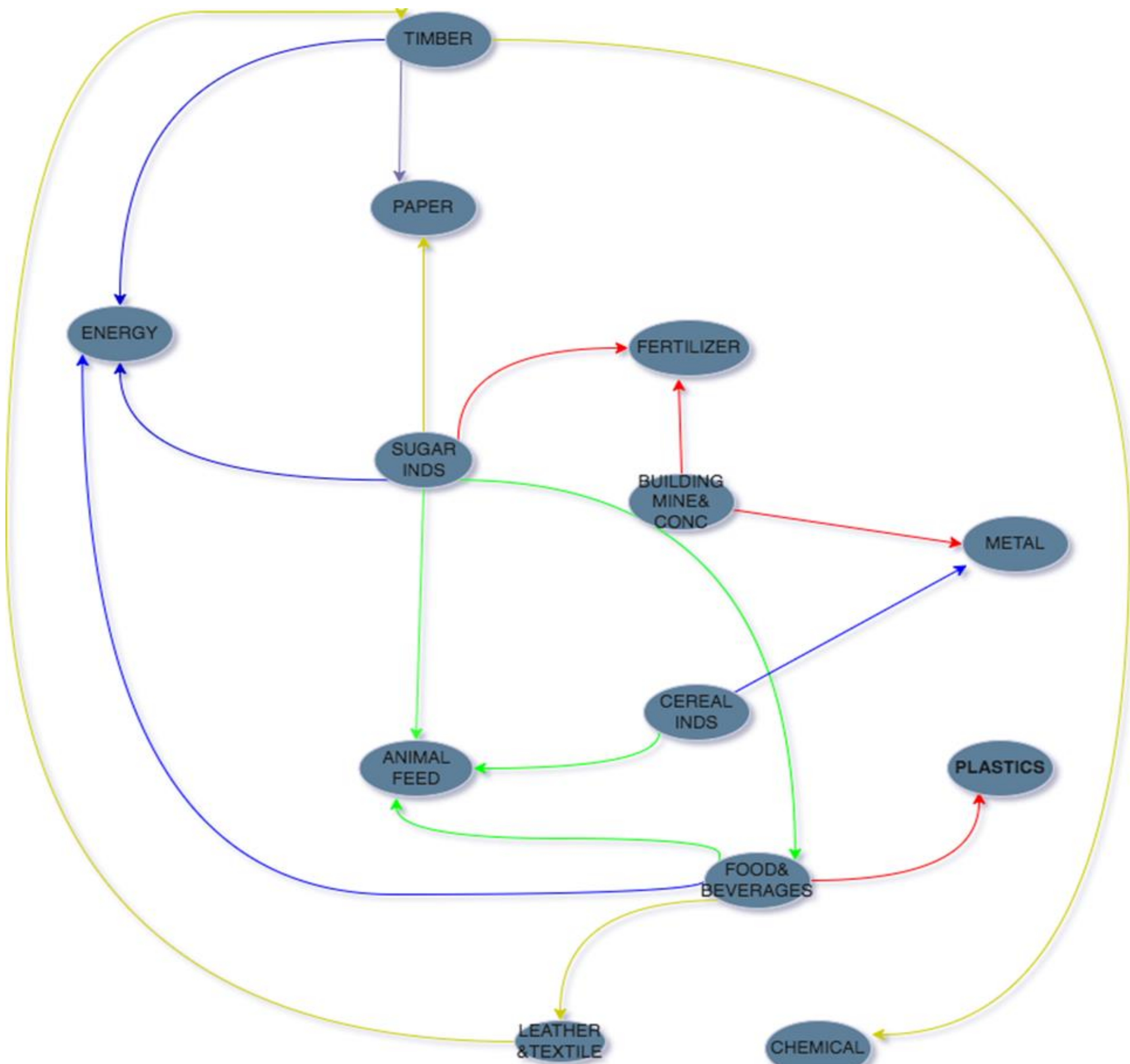
Appendix 2 Growth of industries in Kisumu County from 1951 – 2020



Appendix 3 Waste streams from various industrial processes

INDUSTRIAL SECTOR	LINE PROCESS	WASTE STREAMS
Agroprocessors	Sugar processors	Baggasse, Molasses, Filter Mud and ash, Slurry
	Cereal processors	Maize germ, Wheat Pollard, Rice bran and husks, peanut skins and hulls
	Animal feed processors	Substandard raw input
	Fertilizer manufacturers	Substandard outputs
Food and beverage	Meat processors	Hides and skins, blood bones, gut content, substandard carcass
	Bakery	Crumbs, stale goods, plastic packaging
	Alcohol manufactures(beverage)	Spent grain and hops, Glass packaging
	Soft drinks	Glass and plastic packaging
Energy sector	Briquette/Biogas manufactures	substandard outputs
Building mining and construction	Cement manufactures	Lime waste, kiln dust, fly ash
	Concrete manufactures	substandard outputs, cement bags
Chemical and allied	Alcohol manufactures (industrial)	
	Paint manufactures	Paint waste, sludge
Metal and allied	Steel manufactures	Scrap, mill scale sludge
	Scrap recyclers	Nonmetallic components of scrap
Timber paper and board	Timber processors	Saw dust, barks and shavings
	Paper manufactures	sludge
Leather and textile	Leather processors	Offcuts, shavings and trimmings
	Textile and garment manufactures	Foam,material trimmings
Plastics	Plastic recyclers	Plastics waste, Plastic Expanded Polyethlene

Appendix 4: Symbiotic exchange of solid waste material based on reuse value amongst different industry sectors



KEY

Energy_value waste materials

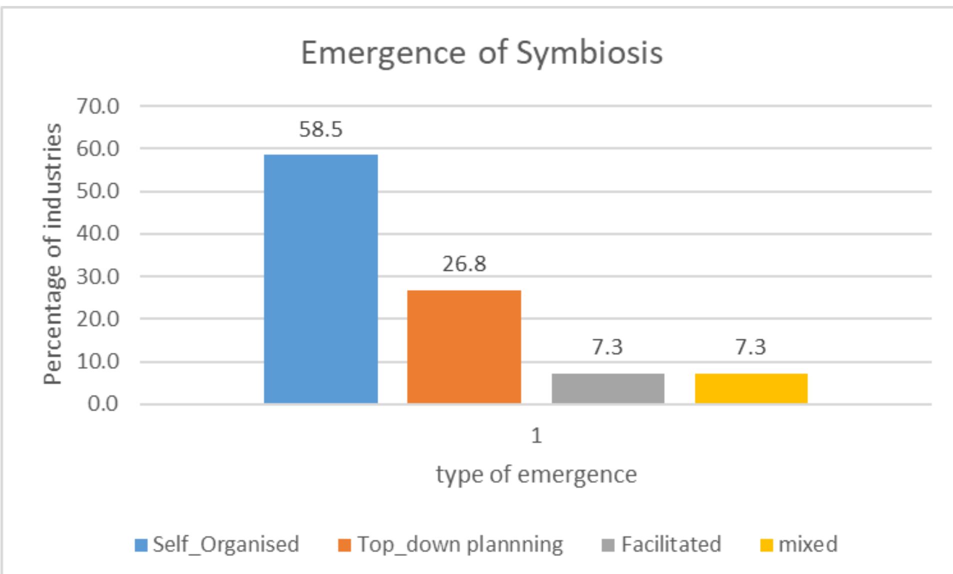
Nutrient_value waste materials

Fibre&Cellulose_value waste materials

Appendix 5: Type of solid waste material according to reuse value

Reuse Value	Solid Waste Material
Nutrients	Molasses maize germ, wheat pollard, rice bran, peanut skins, spent grain, hops, bread crumbs, blood, bones
Energy	Baggasse, rice husks, slurry, peanut hulls, sawdust, timber shavings.
Elements	Plastics, glass, metal, lime, filter mud and ash, sludge, paint waste
Fibre &Cellulose	Paper, hides and skins, fabric and leather offcuts

Appendix 6: Emergence of Industrial Symbiosis in Kisumu County



Appendix 7: IS classification in Kisumu County based on Chertows's 2000 model

IS Type	**Number of industries represented**
Type 1 (Recyclers)	2
Type 2(Within facility)	14
type 3 (Eco-industrial park)	0
Type 4(Not co-located)	14
Type 2 and 4 (mix)	11
Type 5(Virtually)	0
Sample size	**41**

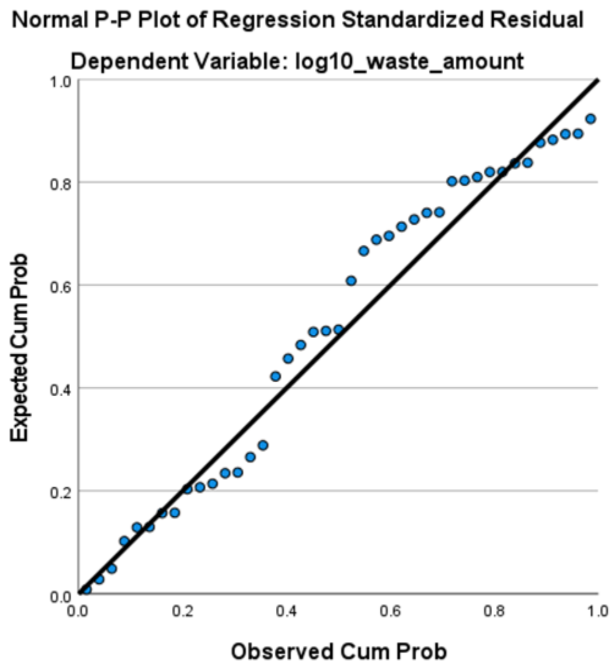
Appendix 8:Test for normality

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
log10_waste_amount	.151	41	.019	.948	41	.061

a. Lilliefors Significance Correction

Appendix 9 Test for Linear Relationship Between Independent and dependent variables (Probability-Probability plot)

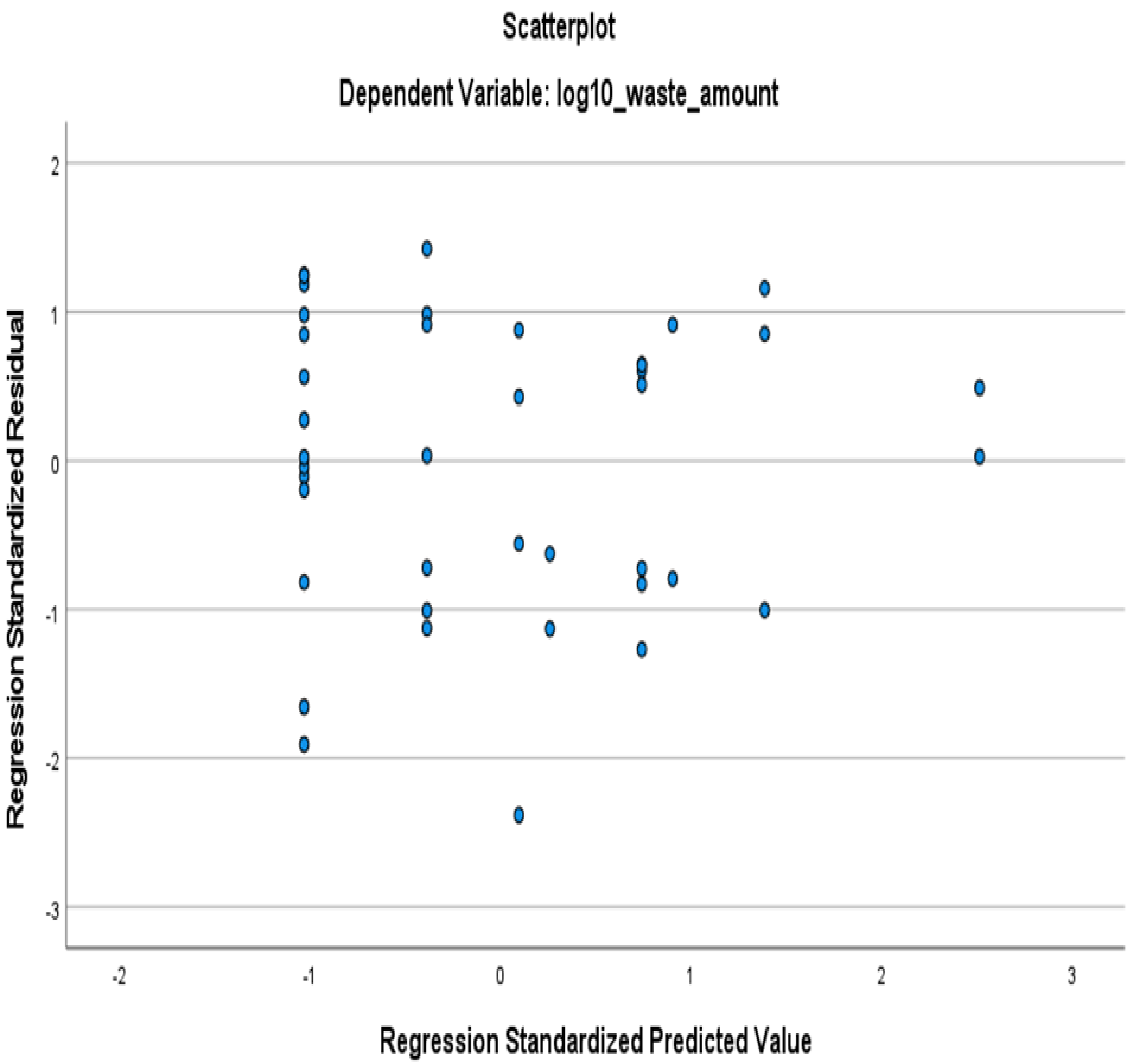


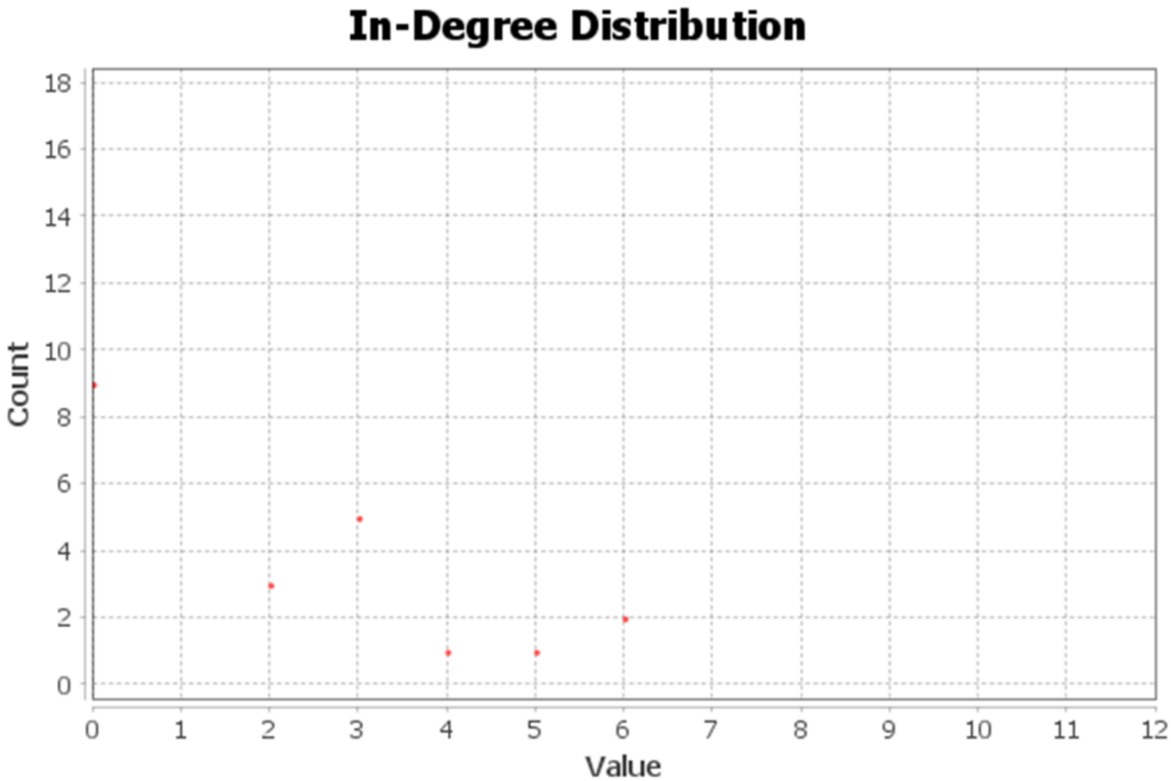
Appendix 10: Residual statistics

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	2.5753	4.3559	3.0926	.50218	41
Std. Predicted Value	-1.030	2.516	.000	1.000	41
Standard Error of Predicted Value	.246	.570	.310	.090	41
Adjusted Predicted Value	2.4935	4.3474	3.0928	.50426	41
Residual	-2.84071	1.69934	.00000	1.16219	41
Std. Residual	-2.382	1.425	.000	.975	41
Stud. Residual	-2.492	1.456	.000	1.011	41
Deleted Residual	-3.10801	1.77476	-.00016	1.25078	41
Stud. Deleted Residual	-2.688	1.479	-.007	1.030	41
Mahal. Distance	.724	8.179	1.951	2.035	41
Cook's Distance	.000	.195	.026	.036	41
Centered Leverage Value	.018	.204	.049	.051	41

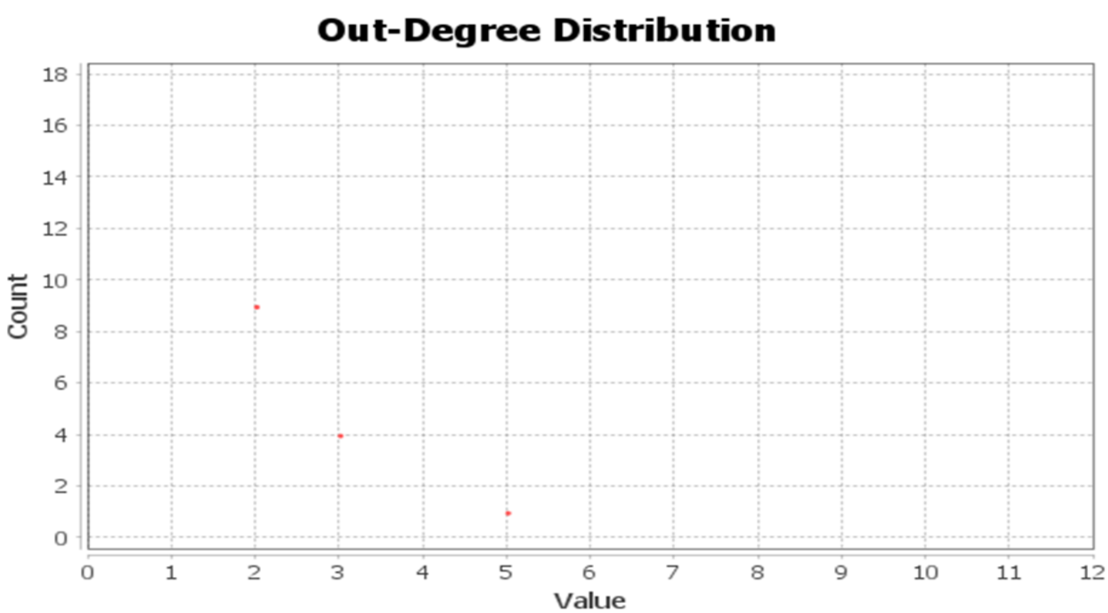
a. Dependent Variable: log10_waste_amount

Appendix 11 Test for Linear Relationship between Independent and dependent variables (scatter plot)





Appendix 12: Degree of centrality in the network



Parameters:

Network Interpretation: directed

Results:

Density: 0.038

Appendix 13: Sample data

Sample No	Industry Codes	Industry Sector	Company Size	Type of Waste exchanged	Amount of waste exchanged (tonnes/year)
1	IS1	Agro-processing	Large	Bagasse, filter mud/Ash, Mollases	87315
2	IS2	Agro-processing	Large	Bagasse and filter mud/ash, Mollases	11900
3	IS3	Agro-processing	Large	Baggasse	400
4	IS4	Agro-processing	Medium	Food waste	90
5	IS5	Agro-processing	Large	Wheat and maize milling byproducts	64000
6	IS6	Agro-processing	Large	Bagasse and filter cake	4510
7	IS7	Agro-processing	Medium	Rise husks and bran	391
8	IS8	Agro-processing	Medium	Cereal milling byproducts	110
9	IS9	Agro-processing	Medium	Rice bran, fish mill,	75
10	IS10	Agro-processing	Large	wheat and maize by-products	43360
11	IS11	Agro-processing	Medium	Filter mud/ash	336
12	IS12	Food and Beverage	Large	Fish Skins and Bones	148570
13	IS13	Food and Beverage	Medium	Meat waste	300
14	IS14	Food and Beverage	Large	Slurry	50
15	IS15	Food and Beverage	Small	peanut hulls and skin	17300
16	IS16	Food and Beverage	Large	spent grains, spent hops and surplus yeast	11600
17	IS17	Food and Beverage	Medium	Mollases	800
18	IS18	Food and Beverage	Large	plastics	400
19	IS19	Food and Beverage	Large	Bread waste	300

20	IS20	Food and Beverage	Large	Bread waste	39680
21	IS21	Energy	Small	Baggage	17136
21	IS22	Energy	Small	bagasse	24472
22	IS23	Energy	Medium	bagasse	11864
24	IS24	Building, mining &const	Large	Super calcium fertiliser, slurry	1766.5
25	IS25	Building and const	Large	Concrete material	0.2
26	IS26	Chemical and allied	Medium	timber shavings/wood waste	40
27	IS27	Chemical and allied	Large	Powder pigments	5
28	IS28	Metal and Allied	Medium	Scrap Metal	15401
29	IS29	Metal and Allied	Large	Scrap Metal, cole ash, husks and sludge	9780
30	IS30	Metal and allied	Large	Scrap metal	4
31	IS31	Metal and Allied	Medium	Scrap metal	9780
32	IS32	Timber	Large	Wood waste	870
33	IS33	Timber	Medium	Wood waste	154209
34	IS34	Paper and boards	Medium	Bagasse	
35	IS35	Textile and Leather	Large	Off-cut foam, fabric, plastic Expanded Polyethene	280
36	IS36	Textile and Leather	Medium	Fabric offcuts	36
37	IS37	Textile and Leather	Medium	Leather offcuts	300
38	IS38	Textile and Leather	Large	Off-cut foam, fabric, plastic Expanded Polyethene	220
39	IS39	Textile and Leather	Small	fish Skins	4
40	IS40	Plastic and Rubber	Small	plastics	40
41	IS41	Plastic and Rubber	Large	plastics	11457

Linkage No.	Distance (km)	Linkage No.	Distance (km)	Linkage No.	Distance (km)
1	0.4	41	0.6	81	6.2
2	2.6	42	2.9	82	5.8
3	2.6	43	4.4	83	14
4	0.62	44	5.8	84	0
5	0.3	45	7.5	85	6.5
6	1.304	46	5.15	86	6.5
7	107	47	0.4	87	45.1
8	0.5	48	1	88	0.55
9	2.2	49	119	89	51.9
10	36.56667	50	40.13333	90	26.0125
11	8.9	51	14	91	3.2
12	14	52	2.2	92	8.5
13	5	53	8.1	93	26.8
14	4.5	54	2.4	94	5.7
15	9.1	55	1.3	95	4.8
16	6.2	56	1.85	96	3.6
17	180	57	8	97	1.9
18	9.4	58	4.8	98	3.433333
19	5	59	6.4	99	4.8
20	1.3	60	0.3	100	6.3
21	48.925	61	6.6	101	0.6
22	0.5	62	1.8	102	9.4
23	14	63	4.5	103	121
24	7.25	64	2.1	104	43.66667
25	0.55	65	7.4	105	0.6
26	2.7	66	4.2	106	3.4
27	8.7	67	8.1	107	4.2
28	9	68	0.45	108	0.4
29	5.2375	69	0.8	109	7.4
30	2.3	70	121	110	10
31	26	71	2.6	111	4.5
32	14.15	72	87		
33	1.3	73	3.8		
34	3	74	2.6		
35	2.15	75	3.8		
36	3	76	22		
37	4.5	77	118		
38	26	78	8.7		
39	4.5	79	114		
40	9.5	80	4.2		

		Type of information Exchanged								
Sample No	Industry Codes	Amount of Waste	Type of Waste	Waste quality	Emission Inventory	Supply patterns	Company location	operating costs of synergies	Technical knowledge and re-use pathways	Frequency of Communication
1	IS1	YES	YES	YES	YES	YES	YES	YES	YES	Daily
2	IS2	NO	YES	NO	NO	YES	YES	NO	NO	as need arises
3	IS3	YES	YES	YES	NO	NO	YES	NO	NO	as need arises
4	IS4	NO	YES	NO	NO	YES	YES	NO	NO	as need arises
5	IS5	YES	YES	YES	NO	NO	YES	YES	NO	Weekly
6	IS6	YES	YES	YES	YES	YES	YES	YES	YES	as need arises
7	IS7	NO	YES	YES	NO	YES	YES	NO	NO	as need arises
8	IS8	YES	YES	YES	NO	NO	YES	YES	NO	Daily
9	IS9	YES	YES	YES	NO	NO	YES	YES	NO	Weekly
10	IS10	YES	YES	YES	NO	YES	YES	NO	NO	Weekly
11	IS11	YES	YES	YES	YES	NO	YES	YES	YES	Weekly
12	IS12	NO	NO	YES	NO	NO	YES	NO	NO	daily
13	IS13	NO	YES	NO	NO	NO	YES	NO	NO	daily
14	IS14	YES	YES	YES	NO	YES	YES	YES	YES	as need arises
15	IS15	NO	YES	YES	NO	YES	YES	NO	NO	as need arises
16	IS16	YES	YES	YES	YES	YES	YES	NO	YES	Weekly
17	IS17	YES	YES	YES	NO	YES	YES	YES	NO	as need arises
18	IS18	YES	YES	YES	YES	NO	YES	NO	NO	as need arises
19	IS19	YES	YES	YES	NO	YES	YES	NO	NO	Weekly
20	IS20	YES	YES	YES	YES	NO	YES	YES	YES	as need arises
21	IS21	YES	YES	YES	YES	YES	YES	YES	NO	Daily
21	IS22	YES	YES	YES	NO	YES	YES	YES	YES	Weekly
22	IS23	YES	YES	YES	NO	YES	YES	YES	NO	Daily
24	IS24	NO	YES	NO	NO	NO	YES	NO	NO	As need arises
25	IS25	NO	YES	YES	YES	NO	YES	NO	NO	As need arises
26	IS26	NO	YES	YES	NO	NO	YES	YES	NO	As need arises
27	IS27	YES	YES	NO	NO	NO	YES	NO	NO	As need arises
28	IS28	NO	YES	YES	NO	YES	YES	NO	NO	As need arises
29	IS29	YES	YES	YES	YES	YES	YES	YES	NO	As need arises
30	IS30	YES	YES	YES	YES	YES	YES	YES	NO	As need arises
31	IS31	NO	YES	YES	NO	YES	YES	NO	NO	As need arises
32	IS32	NO	YES	NO	NO	YES	YES	YES	NO	weekly
33	IS33	NO	YES	NO	NO	YES	YES	NO	YES	weekly
34	IS34	YES	YES	YES	NO	YES	YES	YES	YES	as need arises
35	IS35	YES	YES	YES	YES	NO	YES	NO	NO	as need arises
36	IS36	YES	YES	YES	NO	NO	YES	NO	YES	weekly
37	IS37	YES	YES	NO	NO	YES	YES	NO	NO	weekly
38	IS38	YES	YES	YES	NO	NO	YES	NO	NO	as need arises
39	IS39	NO	YES	YES	NO	YES	YES	YES	NO	weekly
40	IS40	YES	YES	NO	NO	YES	YES	YES	YES	as need arises
41	IS41	YES	YES	NO	NO	YES	YES	YES	NO	as need arises

Appendix 14: Solid- material generation rates

Processing /Manufacturing	Solid material Yields (% of weight raw material)	Reference
Maize	Maize germ=5%, maize bran= 35%	Papageorgiou, M., & Skendi, A. (2018).
Rice	rice husk (20%), rice bran (8%) and rice germ (2%)	Esa et.al (2013)
Wheat	Wheat bran, mildings (25%-30%) Wheat germ for (2%-3%)	(Huang et. al, 2014)
Sugar	Bagasse(30-34 tonnes), molasses (3-4 tonnes) filter cake (5-6 tonnes) yield per 100 tonnes of cane	(Santos et.al, 2020)
Peanut	Peanut meal (500-700kg per 1000kg processed) skin 35-45 g per kg of raw peanut, peanut hull (230-250g)	Zhao, X., Chen, J., & Du, F. (2012)
Beer	Floating kernels(4%), barley malt sprouts spent grain (85%)	Papageorgiou, M., & Skendi, A. (2018).
Meat, Poultry, Fish	Hides (4% - 11%) Bones (15% - 16%), Feathers (7%-8%), Blood meal(3.2%-3.7%)	Jayathilakan et.al,(2012
Steel	BF slag (250kg) , SMS slag, mill scale and scrap (28kg), fly ash (142kg), refractory wastes (17kg)	Chakravarty, T. K., & Panigrahi, S. K. (1996).
Leather	Raw trimming (120 kg)Fleshings (70 – 230 kg) Tanned splits (115 kg) Trimming + Shavings (100 kg), Buffing dust (2 kg) Trimmings (32 kg) per tonne of raw hide	Chakraborty, R., & Sarkar, S. K. (1998)

Appendix 15: Questionnaire

QUESTIONNAIRE ON THE INFLUENCE OF INDUSTRIAL SYMBIOSIS ON SOLID WASTE REUSE IN MANUFACTURING INDUSTRIES IN KISUMU COUNTY, KENYA.

I am Adalla Morelly, a Master's student at Maseno University undertaking an academic study on the ‘influence **of industrial symbiosis on solid waste in manufacturing industries in Kisumu County, Kenya’** Anonymity and confidentiality of both the respondent and the company is upheld in this research study, which means that no identification will be captured and that the information collected here about the company will NOT be disclosed. The information obtained will strictly be used for only academic purposes.

Official Use:
Date ………………………………. Questionnaire number ………………….
GPS Coordinates ………………….

SECTION A: Company profile

Q1. In which sector does your industry belong?

[ ] Building, mining and construction

[ ] Metal and allied sector

[ ] plastics and rubber collectors

[ ] paper and paper board

[ ] motor vehicle assemblies and accessories

[ ] Chemical and allied sector

[ ] Energy, electrical and electronic

[ ] Food and beverage

Q2. Which year did the industry begin production?……………………………

Q3. How many employees are currently employed in your industry?

[ ] less than 10 people.

[ ] 10-49 people.

[ ] 50-99 employees.

[ ] More than 99

Q4. Do you practice reuse as a waste management strategy in your industry?

[ ] Yes [ ]No

SECTION B: Geographical proximity and solid waste-material (by-product) exchanges.

Q5. Please list all the stages of production and their respective solid waste materials generated.

Production stage	Waste-material generated
1.	
2.	
3.	

Q6. Are waste materials (by-products) reused in your production processes?

[ ] Yes [ ] No

If **YES**, which type of solid waste material and where is it used?

Fill the table(s) below appropriately where applicable.

1. Re-use within the industry

Type of Solid Waste-material/byproduct generated from your production operations	What is the solid waste material used for

2. **Re-use at a different industry** (*this question refers to by-products/solid waste material obtained from your industry to be used elsewhere either by another industry, which is located elsewhere*)

Type of solid waste material obtained from your industry	Approximate distance from your industry to the other industries	What is the solid waste material used for

If **NO** response above, why?

[ ] no technological know-how on how to reuse solid waste.

[ ] no infrastructural capacity

[ ] Other industry which could use the waste is located too far, making it not cost-effective.

[ ] do not know which other company can reuse the solid waste-material

[ ] any other.

Specify………………………………………………………………………..

Q7. Do you collect solid waste -material **from other industries** for use in your industry?

[ ] Yes [ ] No

If YES, which type of waste material do you obtain, and how far is the other industry from where you source the material

Type of solid waste material sourced	Approximate Distance from your company

If NO, why?

[ ] Sufficient supply within your production facility

[ ] Distance between the facilities is not economically viable to favour exchanges

[ ] No working relationship between facilities

[ ] No technical know-how for re-use by-products generated

[ ] Other. Specify……………………………………………………….

Q8. Which year did you begin cooperating with other companies for solid-waste (byproduct) exchange? ………………………………………………..

Q9. On a scale of 1 to 5, how would you rate the importance of physical distance when it comes to collaborative exchanges amongst facilities? **1-slightly important, 2-important, 3-Fairly important, 4-Very important, 5-Extremely important**

……………………………………………………………………………………………………

…

Q10. List the benefits and/or challenges you have experienced regarding your physical location and that of industries you collaborate with

BENEFITS, E.g. reduction of transportation costs, narrowed mental distance, increased production, closer working relationship

…………………………………………………………………………………………………

…………………………………………………………………………………………………

CHALLENGES Eg. Delayed deliveries, increased costs

……………………………………………………………………………………………………

……………………………………………………………………………………………………

Q10. What considerations are factored in regarding the distance between your industry and the other industries you collaborate with?

[ ] Regular/consistent supply of solid-waste material

[ ] Efficiency and timeliness in the delivery of solid-waste material

[ ] Acquisition of solid-waste material on credit

[ ] Membership to similar associations for manufacturers

[ ] Common interest/ tariffs

SECTION C: Information flows and waste-material exchanges.

Q12. Do you engage in information sharing with other industries? [ ] Yes [ ] No

If YES

(i)What type of information is exchanged? (*Indicate with □ to mean "exchanged" and □ to mean "not exchanged"*)

Type of information exchanged	Response
Amount of produced and required resources	
Resource types	
Waste quality	
Waste composition	
Emission inventory	
Supply patterns	
Company location and cooperation willingness	
Operating costs of synergies (transport, material purchasing) and potential savings	
Goals, principles, experiences and best practices	
Technical knowledge, re-use pathways	

(ii) What is the purpose of the exchange? (*Tick appropriate reasons*)

[ ] Identification of potential synergies

[ ] Assess the compatibility of resources

[ ] Assess the compatibility of (companies' supply chain systems, technology)

[ ]Others(specify)

……………………………………………………………………………………………..

……………………………………………………………………………………………..

If NO, why? (*Tick appropriate reasons*)

[ ]Lack of trust

[ ]Confidentiality concerns

[ ]Lack of motivation to engage in the process

[ ]Difficulty in communication of expert knowledge

[ ]Lack of contacts and relationships to obtain knowledge of share information

[ ]Lack of information in terms of a database on waste/byproducts or surplus resources

Q13.Please rank the above responses from most influencing factor to least influencing factor

RANK	FACTOR (As per responses given above)
1. Most influencing factor	
2.	
3.	

Q14. Which companies have you engaged with in terms of information exchange, and for how long has the relationship existed

Company	From	To

Q15. Are there companies you have had to disengage with?

[ ] Yes [ ] No

If YES, why? ....

…………………………………………………………………………………………

…………………………………………………………………………………………

Q16. Tick the appropriate option from the list below that best describes how you come into a collaborative relationship with the facilities in your network

[ ] Self-organized

[ ] Top-down planning (Symbiosis by design)

[ ] Facilitated (third party involved, e.g. research institutions, government agencies, associations such as KAM, consultants) specify ………………………………………….................................

……………………………………………………………………………………………………..

Q17. Which methods do you employ to facilitate information sharing with other companies?

[ ] Face –Face meetings specify techniques used starting with the most frequently used, e.g. worKShops, round table meetings, focus group discussions

……………………………………………………………………………………………

……………………………………………………………………………………………

[ ] ICT-related methods. Specify techniques used, starting with the most frequently used, e.g. Telephone/mobile phone, e-mails, Social media forums, blogs and websites.

[ ] Through a third party, who is the custodian of information submitted. Specify the third party involved, e.g. research institutions, government agencies, associations such as KAM, consultants.

Q18. How often do you engage in information sharing? Give more details of the type of information.

[ ] daily [ ] weekly

[ ] as need arises

……………………………………………………………………………………………

……………………………………………………………………………………………

Q19.Is your database digitized? [ ] YES [ ] NO

Q20. How do you go about opportunity identification for synergies?

[ ] accidental discovery

[ ] coordinated searches

[ ] worKShops organized by industry, associations or County govt

[ ] others. Specify…………………………………………………………

Q21 Do you have access to an ICT system database where you do searches for opportunity identification

SECTION D: Symbiotic intensity and amount of waste-material reused in the network

Q22. What amount of raw material is processed annually ………………………. (Tonnes per year)

Raw material	**Amount per year (tonnes/ year)**
E.g Sugarcane	34,000

Q22. What is the approximate amount of solid waste material (by-product) reused within your facility. Where not applicable indicate

Type of soild waste material reused within facility	Amount per year (tonnes/ year)

Outsourced-solid waste material	Company from which solid waste material is outsourced	Amount per year (tonnes/ year)

Q23. Fill in the table appropriately to give approximate amount of solid waste material picked from your industry to be reused in another industry located elsewhere.

Solid waste material picked from your facility	Which industry picks the solid waste material	Amount per year (Tonnes/ year)

Q24.Rank the industries you collaborate with in terms of most depended on to least depended on

…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………
………………………………

Q25. How would you rate the connectedness of the network you have

1. Very Weak 2. Weak 3. Strong 4. Very Strong.

THE END! THANK YOU!

Appendix 16: Key informant interview guide

Key informant from Kenya Association of Manufactures

1. What is your role with regards to bringing industries together?
2. **How do you recruit and retain members in the association and how many industries are registered members in Kisumu?**
3. What channels do you use to mobilize members for training, information sharing and capacity building?
4. What does information sharing entail and how do the industries benefit from this?
5. How often do you organize these forums?
6. What benefits have these industries drawn from being members of your association?
7. What is the stand of KAM with regards to environmental protection?
8. Has the association driven projects on waste reuse in industries?
9. Has there been advocacy on industrial symbiosis? How has this been done?
10. What's the uptake of industrial symbiosis and what are the challenges?

Key informant from County Department of Environment

1. What is the current state of solid waste management in the County?
2. With reference to industries as a significant generator of solid waste, how has the department partnered with industries to promote cleaner production systems?
3. Is there data on industries and their waste output? What kind of data is available?
4. Do you bring industries to work collaboratively in solid waste management **i.e.** network brokerage, how is it done?
5. **What proportion of industries are ISO 140001 certified?**
6. Is there a County policy in place on solid waste management?
7. What is the role of the department in ensuring cleaner production systems are in place?
8. What challenges have you faced in attempt of getting industries to reduce their solid waste generation?

Key informant from Department of Energy and Industrialization

1. In terms of scale how the industries are apportioned either small, medium or large enterprises?
2. How do you go about partnering with industries on knowledge and technology transfer?
3. Are their programs you have run on diversification of products from individual raw inputs?

4. Has your department profiled industries within the County?
5. Is waste output a data set in an industries profile?
6. Are industries located in such a manner to promote collaboration amongst them and improve efficiency?

Key informant from Department of Physical Planning lands and Urban Development

1. Are industries within the County zoned? What do you consider when zoning
2. With reference to road infrastructure, are industries currently located in a manner that they can promote transport efficiency?
3. Prior to one setting up an industrial facility, especially those near the city centre of the County, what considerations does the department look at?
4. Are there plans to set up SEZ/industrial parks within the County?
5. What challenges has the department faced in the planning of SEZ?

A key informant from NEMA –County office

1. How has NEMA ensured the integration of solid waste management considerations in industries' production systems?
2. Are incentives/subsidies given to industries with low to zero waste production systems?
3. What is the nature of technical support you offer to industries?
4. What strategies have been put in place to ensure the greening of industries within Kisumu County?
5. **In the last 5 years, how many Environmental cases have been filed at the Environmental Tribunal Court on pollution due to solid waste dumping from industries?**
6. How would you rate Kisumu County industries regarding rational utilization and management of environmental resources?

Appendix 17 List of manufacturing industries in Kisumu County

NO	NAME	PRODUCT
1.	SILVERPC	Dried vegetables
2.	Pendeza weaving	Tables, clothes, bedspreads, shirts and dresses
3.	Peche foods	Chilled Nile, perch fillets, frozen Nile
4.	Fish Processors (2000) Ltd	Headless and gutted
5.	East African Sea Food Ltd	Headless and gutted
6.	Roak Enterprises	Steel doors, windows, irrigation sprinklers
7.	Swan Industries	Biscuits, baking powder
8.	Spectre International Ltd	Ethanol, yeast CO2
9.	Nyanza Ginnery Ltd	Cotton seed cake, oil, cotton
10.	Alisam Products Dev & Design	Fish leather, fish leather shoes, belts, jackets and hats
11.	Free Kenya	Dried mushrooms and fresh mushrooms
12.	Agrochemical and Food Co. Ltd	Extra Neutral Alcohol, baker’s yeast, bottled spirit CO2
13.	Kibos sugar & allied industry	Sugar molasses
14.	Kibos distillers	Extra neutral alcohol
15.	Nyawal animal feeds Co-op Society	Fish fillets, fish mash
16.	Chuma industrial engineers	Green biofuel
17.	Yala riverside dairy	Yoghurt
18.	Asumbi enterprises	Metal products, e.g. gates, doors, windows, wheelbarrows etc
19.	Belano Enterprises	Peanut butter, packed honey
20.	Mix foods & beverages.	Cricket cakes, cricket flour, roasted/fried foods
21.	Ogutu Posho Millers	Maize flour, wimbi flour
22.	Festo Fish Mongers	Fish fillet, packed omena, whole fish
23.	Zamanga foods	Peanut butter, packed honey, uji mix
24.	Pride Group Limited	Concrete/ballast
25.	Vyatu Limited	Plastic products(household goods)
26.	Maran holdings	Sorghum flour
27.	Kirkin Limited	Juice, jam, and hibiscus tea bags
28.	Kambu Industries	Maize flour(maize milling)
29.	Equator Bottlers Ltd	Soft drinks(soda)
30.	Highland Creamers and food	Processed milk and milk products
31.	Butali Sugar	Processed sugar
32.	Dominion Farms Ltd	Rice, sugar, vegetable oils

33.	Kisumu concrete	Aggregates/ballast and paving blocks
34.	UN WIN Ltd	Processing of fish flies for the export market.
35.	Transmara Sugar Co.	Sugar processing
36.	Karan biofuel	Briquettes
37.	Muhoroni Sugar Co.	Sugar
38.	Homa Line Co. Ltd	Lime, jaggery/brown sugar
39.	Lake Basin Devt. Authority(Migosi poultry)	Poultry
40.	Lakeside Millers	Rice milling
41.	Ndugu transport	Quarrying
42.	Janki Enterprises	Ballast
43.	Skylark Construction	Building blocks
44.	Farm Engineering Industries	Fabricators
45.	Anvi Emporium	Packing of acids/spirits
46.	Lake Quarry Ltd	Ballast
47.	Paramount Engineering	Steel structures
48.	Lake Feeds Manufacturer	Animal feeds
49.	Phoenix Matches	Match making
50.	Mayfair Bakery	Bread and confectionaries
51.	Modern Furniture	Furniture making
52.	United Millers-Bakery, flour mill, feed mill, printing press	Bread, maize, wheat flour, animal feeds, packaging materials
53.	Nyando Millers	Rice milling
54.	Lakeside Millers	Rice Milling
55.	Chemelil Sugar Co.	White and brown sugar
56.	Millennium millers	Animal feeds making
57.	Mombasa millers	Maize flour
58.	Steel Centre Ltd	Steel products
59.	Prime Steelmills Ltd	Twisted bars, nails, binding wires
60.	Abyssinia Iron and Steel	Twisted bars, nails, binding wires
61.	Kondele poultry	Poultry products
62.	Kisumu Innovators Ass.	Livestock feeds, Incubators, Weaning flour, ornaments, family porridge flour, hyacinth biofuels
63.	Tausi Enterprises	Medicated soaps
64.	Takawiri Enterprises	Hyacinth products
65.	Eosopo Enterprises	Cosmetics
66.	Kisumu Innovation	Tomatoe sauce(food processing)
67.	Midland tea	Herbal tea
68.	Garden of Hope	Water filters & maize seller
69.	Ariesco	Briquettes making machine
70.	Practical Action	Energy saving stoves
71.	Kisumu Leather Ass.	Industrial boots & balls

Appendix 18: School of Graduate Studies Approval

MASENO UNIVERSITY
SCHOOL OF GRADUATE STUDIES

Office of the Dean

Our Ref: MSC/NS/00064/2015

Private Bag, MASENO, KENYA
Tel:(057)351 22/351008/351011
FAX: 254-057-351153/351221
Email: sgs@maseno.ac.ke

Date: 6th January, 2020

TO WHOM IT MAY CONCERN

RE: PROPOSAL APPROVAL FOR MORELLY KATHY ADALLA — MSC/NS/00134/2017

The above named is registered in the Master of Science in Environmental Science degree programme in the School of Environment and Earth Science, Maseno University. This is to confirm that her research proposal titled "*Influence of Industrial Symbiosis on Solid Waste Reduction in Manufacturing Industries in Kisumu County.*" has been approved for conduct of research subject to obtaining all other permissions/clearances that may be required beforehand.

SCHOOL OF GRADUATE STUDIES MASENO UNIVERSITY 2020 P.O. BOX PRIVATE BAG, MASENO

f. Prof. J.O. Agure
DEAN, SCHOOL OF GRADUATE STUDIES

Maseno University *ISO 9001:2008 Certified*

Appendix 19: Maseno University Ethics Approval

MASENO UNIVERSITY ETHICS REVIEW COMMITTEE

Tel: +254 057 351 622 Ext: 3050
Fax: +254 057 351 221

Private Bag – 40105, Maseno, Kenya
Email: muerc-secretariate@maseno.ac.ke

REF: MSU/DRPI/MUERC/00817/19

Date: 17th June, 2021

TO: Morelly Kathy Adalla
PG/MSC/NS/00134/2017
Department of Environmental Science
School of Environment and Earth Sciences
Maseno University
P. O. Box, Private Bag, Maseno, Kenya

Dear Madam,

RE: Influence of Industrial Symbiosis on Solid Waste Reduction in Manufacturing Industries in Kisumu County, Kenya

This is to inform you that **Maseno University Ethics Review Committee (MUERC)** has reviewed and approved your above research proposal. Your application approval number is MUERC/00817/19.The approval period is 17th June, 2021 – 16th June, 2022.

This approval is subject to compliance with the following requirements;

i. Only approved documents including (informed consents, study instruments, MTA) will be used.
ii. All changes including (amendments, deviations, and violations) are submitted for review and approval by Maseno University Ethics Review Committee (MUERC).
iii. Death and life threatening problems and serious adverse events or unexpected adverse events whether related or unrelated to the study must be reported to Maseno University Ethics Review Committee (MUERC) within 24 hours of notification.
iv. Any changes, anticipated or otherwise that may increase the risks or affected safety or welfare of study participants and others or affect the integrity of the research must be reported to Maseno University Ethics Review Committee (MUERC) within 24 hours.
v. Clearance for export of biological specimens must be obtained from relevant institutions.
vi. Submission of a request for renewal of approval at least 60 days prior to expiry of the approval period. Attach a comprehensive progress report to support the renewal.
vii. Submission of an executive summary report within 90 days upon completion of the study to Maseno University Ethics Review Committee (MUERC).

Prior to commencing your study, you will be expected to obtain a research license from National Commission for Science, Technology and Innovation (NACOSTI) https://oris.nacosti.go.ke and also obtain other clearances needed.

Yours sincerely

MASENO UNIVERSITY APPROVED 17 JUN 2021 ETHICS REVIEW COMMITTEE

Prof. Philip O. Owuor, PhD, FAAS, FKNAS
Chairman, MUERC

MASENO UNIVERSITY IS ISO 9001 CERTIFIED

Appendix 20: NACOSTI Research Permit

REPUBLIC OF KENYA

NATIONAL COMMISSION FOR SCIENCE, TECHNOLOGY & INNOVATION

Ref No: **561373**

Date of Issue: **02/August/2021**

RESEARCH LICENSE

This is to Certify that Ms.. Morelly Kathy Adalla of Maseno University, has been licensed to conduct research in Kisumu on the topic: INFLUENCE OF INDUSTRIAL SYMBIOSIS ON WASTE REDUCTION IN MANUFACTURING INDUSTRIES IN KISUMU COUNTY for the period ending : 02/August/2022.

License No: **NACOSTI/P/21/12130**

561373

Applicant Identification Number

Director General

NATIONAL COMMISSION FOR SCIENCE,TECHNOLOGY & INNOVATION

Verification QR Code

NOTE: This is a computer generated License. To verify the authenticity of this document, Scan the QR Code using QR scanner application.