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BIOCHAR PRODUCTION AS A SUSTAINABLE WASTE MANAGEMENT OPTION

BY

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DECLARATION

I, Donald Daniel Nortey, hereby declare that this thesis titled “Biochar Production as a Sustainable Waste Management Option” except for the references that have been duly acknowledged is an original work carried out entirely by me under the supervision of Prof. Jesse Sey Ayivor and Dr. Ted Yemoh Annang, University of Ghana. I confirm that this thesis has neither in whole nor in part been presented for another degree elsewhere.

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DEDICATION

This thesis is dedicated to my sister Krystle Nortey, and my parents.

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ABSTRACT

Current management practices of Municipal Waste in Ghana have not yielded the expected results, negatively impacting the environment and human health. This thesis seeks to assess the sustainability of biochar production as a Municipal Solid Waste Management option. The study employed the pillars of sustainable sanitation to guide this assessment. Biochar production to sustainably manage waste will add value and extend shelf life of materials classified as waste. These capabilities allow for the transformation of organic waste into an essential resource with multiple applications including carbon sequestration, energy production, soil amendments, among others. The research employed a random sampling method to gather information on household waste management behavioural patterns, as well as knowledge and awareness of biochar, through the administration of questionnaires. In addition, a purposive sampling approach was used to select key informants from government institutions and agencies. These informants were interviewed using a structured guide to obtain information on biochar production and its applications. Findings from the study indicated that many households mixed their waste, and as such, there is a pressing need for aggressive implementation of source separation at the household and community level, to enable the organic component of Municipal Solid Waste feedstock be easily extracted for biochar production. At the institutional level, even though the biochar option was appreciated, there were gaps related to its production processes including its potential feedstocks, products, and co-products. As such intense sensitization and awareness efforts are needed to emphasize the sustainability the technology could provide. This, in turn, could influence policy development and potentially transform waste management in Ghana. With this, meaningful progress can be made towards the sustainable management of municipal waste, while expanding waste management pathways that support the transition from a "Collect-Aggregate-Dump" approach to an "Extract-Repurpose-Reuse" Model.

LIST OF ABBREVIATIONS AND ACRONYMS

AD	Anaerobic Digestion
BMP	Best Management Practice
CCAC	Climate and Clean Air Coalition
CEC	Cation Exchange Capacity
CIMMYT	International Maize and Wheat Improvement Center
EPA	Environmental Protection Agency
FAO	Food and Agriculture Organization of the United Nations
FFVW	Food, Fruit and Vegetable Waste
GHG	Greenhouse Gases
GPP	Ghana Poultry Project
HR	Heating Rate
IPCC	Intergovernmental Panel on Climate Change
ISWM	Integrated Solid Waste Management
MESTI	Ministry of Environment, Science, Technology and Innovation
MW	Municipal Waste
MSW	Municipal Solid Waste
PAH	Polycyclic Aromatic Hydrocarbons
RDF	Refuse-Derived Fuels
RO	Recycled Organics

ROU	Recycled Organics Unit
SSA	Sub-Saharan Africa
SDGs	Sustainable Development Goals
SOC	Soil Organic Carbon
SWM	Solid Waste Management
USEPA	United States Environmental Protection Agency
WAAPP	West Africa Agriculture Productivity Programme

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background to the Study

Waste is a human phenomenon and has existed since the dawn of time. It has been defined variously. The Oxford Learner's dictionary defined waste as "materials that are no longer needed and are disposed of." The Waste Management Law (Art 1.1) also defined waste as "any material, object, or substance which the holder disposes, intends to, or is forced to discard." Whilst the Basel Convention (1994) defined waste as "any deficient, non-usable or product without use, that its owner has decided to eliminate or dispose." There is a key feature common to all these definitions of any material described as "waste"; that is substances that have no further use and are likely to be ejected or discarded, essentially substances that cannot further serve the intended use or purpose.

The onset of human development, industrial advancement, and rapid urbanization are some factors that have resulted in increased consumption of resources to keep up with rapid growth and population development (Rabbani, Heidari, Farrokhi-Asl, & Rahimi, 2018). The culmination of these factors has resulted in the generation of high volumes and more complex waste materials.

Municipal Solid Waste encompasses everyday waste generated from organic materials, disposal of plastic bottles, cans, cardboard, and residual waste. It however does not include hazardous, industrial, or toxic waste materials (EPA, 2018). Efforts aimed at tackling the ever-growing volumes of waste, specifically Municipal Solid Waste, have been generally underwhelming.

Annually, our planet generates about 2.01 billion tons of Municipal Solid Waste, (Statistica, 2023), and that figure is anticipated to reach 3.40 billion in about 30 years. These are produced by major cities including households, commercial and industrial sectors who generate 2000 tonnes of mixed Municipal Waste (MW) per day, of which about 80% is collected and disposed of at open dump sites and/or at the limited number of landfills available. About 68% of this volume is organic in nature (CCAC,2014).

It is projected that between 150 kg and 200 kg per capita of Municipal Solid Waste are generated in Ghana annually, with the regional capitals together generating over 2 million tonnes per year (Nketiah et. al. 2022). In Accra alone, approximately 900,000 metric tonnes of Municipal Solid Waste are generated annually (Oteng-Ababio,2024).

Municipal Solid Waste in Ghana is generally unsorted (Kuleape et al.2014) and ends up at dump sites and landfills in various locations within and on the outskirts of urban centres. According to Godfrey et al. (2019), good waste collection services are often found in urban centres while suburbs and peri urban areas are left to handle their waste materials how they deem appropriate. Despite this, the phenomenon of waste being dumped on sidewalks, open fields, and stormwater drains is commonplace in urban areas (McElligot et al. 2011; N. Scarlat et al. 2015).

Developing countries in Africa, Asia and Latin America lack the requisite technology and infrastructure to manage their waste volumes (IPCC,2011). As such, the norm is for waste to be aggregated, transported and dumped at landfill sites and dump sites within and sometimes on the outskirts of city centres (Agyepong, 2011; McElligot et al. 2011; N. Scarlat et al.

2015). In some instances, open burning or waste incineration is resorted to as a waste management option.

Ineffective waste management systems in Africa, coupled with the careless disposal of waste, are resulting in significant economic, social, and environmental challenges. Current practices are causing waste to leak into the environment. Moreover, the uncontrolled dumping of waste in urban areas increases the risk of disease, flooding, and pollution. Research indicates a correlation between living close to open dump sites and a rise in diseases such as cholera, malaria, typhoid fever, dengue, and Zika virus (Okot-Okumu, 2012).

Godfrey et al. (2019) reported that 125 million tonnes per year of Municipal Solid Waste was generated in Africa in 2012, of which 81 million tonnes (65%) were from Sub-Saharan Africa and projected to grow to 244 million tonnes per year by 2025. According to Godfrey et al. (2019), the composition of Municipal Solid Waste from Africa according to recorded data was shown to be predominantly organic in composition, contributing 57% of all waste produced on the continent.

The aim of sustainable waste management is to convert waste into a resource, while keeping the leftover waste and environmental pollution within the capacity that local and global ecosystems can handle (van Vliet, 1996). Approaches for the sustainable management of Municipal Solid Waste include separating and utilizing the organic component through value addition, extending its shelf life, and essentially transforming it into a resource again. Two examples of such sustainable waste management options are composting and biochar production.

According to the United States Environmental Protection Agency (2023), composting is a controlled, aerobic biological process in which microorganisms break down organic waste materials such as food scraps and plant residues into a stable, nutrient-rich product called compost. This process generates heat and is essential for sustainable organic waste management. Similarly, Oazana et al. (2018) defined composting as an anaerobic biological decomposition process that produces thermophilic temperatures due to biologically exothermic heat. It serves as a reliable waste treatment method, effectively recycling the organic proportion of solid waste and potentially reducing the volume of organic matter entering overcrowded landfills by as much as 30% (Khater, 2015).

According to Lehmann et al. (2006), biochar is a porous and stable carbon-rich co-product of the pyrolysis process with soil amendments, long-term carbon sequestration, waste management and energy production properties. Tomczyk et al. (2020) also defined biochar as a pyrogenous, organic material synthesized through pyrolysis of different biomass i.e. plant or animal waste. This option shows that it can be derived from a few sources including waste, with various uses and applications like soil amelioration, carbon sequestration and energy production.

Unlike composting which targets the agricultural sector by improving soil fertility, biochar targets several industries with uses spanning from soil amendments, long term carbon capture and storage, waste management and energy production (Lehmann et al. 2006). The versatile nature and far-reaching applications of biochar give it an advantage over other sustainable waste management options.

Opting for biochar production for sustainable waste management would target the organic waste component, which is the bulk of waste extraction from Municipal Solid Waste. In this view, the bulk of Municipal Solid Waste that ends up at landfill sites is reduced; organic waste materials are repurposed with added value and extended shelf life, allowing them to be utilized for other purposes.

The Sustainable Development Goals (SDGs) are the guiding framework of how humans live, work, interact, and co-exist with the environment. Indeed, issues relating to the management of waste materials fall under several sub-categories of the SDGs. For instance, SDG 6 captures issues relating to Clean Water and Sanitation. Waste management is a key aspect of environmental management, involving the handling of materials that have been qualified to have no further purpose. The underestimation or complete abandonment of the repercussions of poor waste management schemes could potentially derail from this SDG.

Another Sustainable Development Goal (SDG) of importance is SDG 7, i.e. Affordable and Clean Energy. The application of biochar in various sectors - including green, clean, and sustainable energy, provides an avenue and an encouraging factor for its use in managing Municipal Solid Waste. This aligns with the broader objective of repurposing and converting waste into a valuable resource for human societies.

However, it is important to contextualize this within the Ghanaian setting. Currently, biochar production in Ghana is not entirely smokeless due to the adoption of crude and outmoded techniques and technologies, and the absence of advanced, low-emission technologies. As a result, the claim of biochar being a green and clean energy source must be treated with caution. Efforts are ongoing to explore ways to reduce or capture smoke emissions during production, but until such technologies are accessible and widely adopted in Ghana, the environmental benefits of biochar must be critically assessed against its current production realities.

Sustainable Development Goals 11 and 12, i.e. Sustainable Cities and Communities (SDG 11), and Responsible Production and Consumption (SDG 12) respectively are also of relevance here. Value addition to the organic component of Municipal Solid Waste extends its shelf life and has the potential to reduce waste volumes likely to be ejected into the environment. Thus, essentially repurposing the organic component of Municipal Waste for other applications and uses within our cities and communities whilst taking responsibility for the management of waste that is usually discarded.

Also, SDG 13 (Climate Action) which encapsulates climate change, and its impact is strongly highlighted here. Efforts made to tackle the daunting consequences of climate change can be mitigated with biochar. Through the valorization and repurposing of the organic component of municipal solid waste, carbon that would typically be released into the atmosphere through decomposition can instead be sequestered in biochar. This would not only reduce atmospheric carbon dioxide but also serve as a viable carbon sink for emissions generated by decomposing organic waste. The introduction of biochar would thereby enhance carbon sequestration within the carbon cycle.

The combination of SDGs 6, 7, 11, 12 and 13 influences the standard and quality of life on land, as reflected in SDG 15: Life on Land. These SDGs are intricately meshed within the fabric of human society and our existence on Earth. As such the sustainable management of Municipal Waste using biochar production is an avenue that aligns with the sustainability framework.

Production of biochar from organic waste ensures that the organic composition of Municipal Solid Waste destined for landfill is Reduced, Recovered, Reused, Repurposed, or Recycled. This application of the "Rs of Sustainability" with respect to biochar production and use guarantees the application of core sustainability principles in areas of waste management and sanitation.

The prospect of biochar holds great promise for developing countries, especially considering the growing volumes of waste they produce annually. The implementation of this intervention would seek to enhance waste management and serve as a critical resource in areas such as soil improvement and an alternative to traditional biomass (firewood and charcoal).

The primary focus of the study is therefore to evaluate the feasibility of biochar production as a sustainable waste management option.

1.2 Problem Statement

Waste management in Ghana remains a persistent environmental and public health challenge, especially in rapidly urbanizing cities such as Accra, Kumasi, and Tamale. According to the World Bank (2018), Ghana generates approximately 12,710 tonnes of Municipal Solid Waste

(MSW) daily, with urban areas accounting for over 70% of this volume. Yet less than 40% of this waste is properly collected and disposed of, leading to widespread illegal dumping, open burning, and environmental degradation.

Current waste management practices marked by erratic collection systems and indiscriminate dumping and burning have proven ineffective. These practices pose significant economic, social, and environmental risks, including disease outbreaks such as malaria, cholera, and typhoid fever. Such outcomes are often direct consequences of uncontrolled waste spillages into the environment, which exacerbate public health vulnerabilities and urban decay.

Several factors contribute to the inefficiency of Ghana's waste management system. These include inadequate infrastructure, limited financial and human resources at the municipal level, poor enforcement of environmental regulations, and a general lack of public awareness around waste segregation, recycling, and sustainable disposal methods (Boadi & Kuitunen, 2005; Amoah & Kosoe, 2014). The informal waste sector dominates recovery efforts, often operating under hazardous and unregulated conditions. While this sector plays a crucial role in waste collection, its informality limits the scope for safe and sustainable recycling and reuse initiatives.

A significant opportunity lies in the composition of Ghana's waste stream. Approximately 60% of MSW is organic in nature (D. Yirenya-Tawiah et al., 2020), and in certain contexts such as market waste, the organic fraction approaches 100%. This presents a valuable opportunity for targeted interventions. Managing the organic components more efficiently would significantly reduce the volume and complexity of residual waste, and in some cases, could address the entire waste stream.

As Ghana's urban population is projected to exceed 60% by 2030 (UN-Habitat, 2020), the pressure on already strained waste infrastructure is expected to intensify. Addressing this growing crisis calls for innovative, inclusive, and sustainable waste management strategies. Among the promising alternatives is the application of biochar production, which offers a sustainable approach to managing organic waste. Beyond waste reduction, biochar has multiple co-benefits: it contributes to energy production, carbon sequestration, soil enhancement, and water purification.

The lack of urgency and innovation in addressing Ghana's waste management challenges requires immediate policy and technological reform. A coordinated, multi-stakeholder approach—emphasizing waste-to-resource strategies such as composting, recycling, and especially biochar production holds the potential to transform waste from an environmental liability into a sustainable asset. By integrating community engagement, regulatory frameworks, and circular economy principles, Ghana can move towards a more resilient and efficient waste management system.

Biochar production offers a valuable opportunity to utilize the large volume of organic waste present in the Municipal Solid Waste (MSW) stream. This approach not only makes MSW more manageable but also enables the conversion of its organic fraction into biochar for sustainable applications.

Various applications of biochar including an alternative to traditional biomass (firewood and charcoal) and as a soil enhancement agent make biochar production a venture that should be strongly considered for Sub-Saharan countries, especially Ghana. It could also provide relief to the dwindling rainforests which communities depend heavily on for wood fuels and charcoal.

Ghana is yet to explore, much more consider such a sustainable alternative waste management approach (Yeboah et al. 2022). As such, there is a glaring research gap in biochar production as a sustainable waste management approach conducted in Ghana and this research aims to precisely fulfil this. The core of this research is to assess the prospects of biochar production as a sustainable Municipal Solid Waste Management option. This research will thus contribute to the body of knowledge on sustainable Municipal Waste management in the Ghanaian setting.

1.3 Research Objectives

The general objective of the study is to assess the feasibility of biochar production as a sustainable Municipal Solid Waste management option.

1.3.1 Specific Objectives

The following specific objectives are set to achieve the general objective:

1. Examine the environmental issues related of biochar production.

2. Examine the socio-cultural acceptability of biochar use.

3. Analyse the financial viability of deploying biochar as a MSW management option.

4. Determine the technological sustainability and constraints underpinning biochar production.

5. Examine the institutional issues hindering biochar production to manage MSW volumes.

1.4 Research Questions

In view of the general objective, the following research questions become important:

1. What are the environmental benefits of biochar production compared to current waste management practices?

2. What are the socio-cultural factors likely to affect biochar production?

2.1 How does public knowledge and attitudes about biochar production influence their willingness to accept it and use?

3. What are the potential revenue streams, industries and economic benefits of biochar production can provide?

4. What are the technological constraints in operationalizing biochar production for waste management?

5. Are there any policy frameworks that consider the application of biochar production to manage MSW streams?

CHAPTER TWO

2.0 LITERATURE REVIEW

This chapter is on the review of existing literature related to the field of study. It focuses on key concepts and terminologies relating to the study including biochar, its applications, pyrolysis, and Municipal Solid Waste (MSW). This will be investigated comprehensively and in detail as they have appeared in various schools of work. This will be backed by literature from various persons and schools of thought who have embarked on projects related to the topic of study. The review aimed to identify gaps that provided the basis for the research questions of this study.

2.1 Sustainable Municipal Waste Management

Municipal Solid Waste (MSW) management is a significant global environmental issue. The shift towards sustainability and the circular economy has transitioned MSW management from basic disposal to recycling and resource recovery (Ayeleru et al. 2018). The most appropriate strategy involves integrating recycling, treatment, and disposal technologies, with choices depending on the region's technological and socio-economic context. (Iqbal, A., Liu, X., & Chen, G. H. (2020)).

Besides landfilling, Municipal Solid Waste (MSW) can be converted into valuable products or energy through recycling and incineration. Optimization models have been developed to design optimal supply chain networks for sustainable MSW management, focusing on both economic objectives by minimizing cost and environmental objectives through emission reduction.

For a waste management system to be regarded as sustainable, it must fulfill three criteria: environmental effectiveness, economic affordability, and social acceptability (Seadon, 2010). Increasing awareness of both the present and future effects of solid waste management services has led responsible authorities prioritizing these facets of sustainability.

"The concept Sustainable Waste Management should aim to continually improve the environment, provide direct health benefits, support economic productivity, and provide safe, dignified and secure employment" (E. Selin, 2013). Effective sustainable management of municipal solid waste (MSW) demands a comprehensive understanding of waste streams, material balance, and flow, along with the knowledge and engagement of stakeholders (Vidanaarachchi et al. 2006).

Consequently, establishing a Municipal Solid Waste (MSW) management system that relies only on economic considerations is insufficient. Recent literature on MSW management reveals that a significant amount of research is directed towards developing countries such as India (Suthar, Rayal, & Ahada, 2016), Bangladesh (Shams, Sahu, Rahman, & Ahsan, 2017), and Nigeria (Abd'Razack, Medayese, Shaibu, & Adeleye, 2017).

Achieving good governance in Sustainable Municipal Solid Waste Management (MSWM) requires involvement from the government, waste generators, and the private sector. Clear laws and regulations, coupled with proper financial planning through public-private partnerships and privatization, are also essential (Ansori et al. 2022). Generating revenue from the Municipal Solid Waste system, raising awareness, and empowering the community can foster a sense of ownership and responsibility (Abdulhamid, Ali, & Semhar, 2024).

Beyond landfills, options like recycling and incineration can convert MSW into valuable products or energy. (Li et al. 2015).

A key aspect of Integrated Solid Waste Management (ISWM) is a comprehensive approach that incorporates waste prevention, recycling, composting, and disposal. To build an effective system, it is vital to implement strategies that minimize waste, enhance recycling, and manage solid waste in ways that protect human health and the environment. Integrated Solid Waste Management also requires an assessment of local conditions and community needs to identify and integrate the most appropriate waste management practices (USEPA 2002). Important activities in ISWM include waste prevention, recycling, composting, controlled combustion, and disposal in well-designed, constructed, and managed landfills. Each of these activities demands careful planning, financing, collection, and transportation (USEPA 2002).

Major cities in transition and developing countries face growing challenges in managing solid waste sustainably. Despite various treatment options, these cities need an Integrated Municipal Solid Waste Management (IMSWM) system to select and invest in appropriate treatments based on waste composition and quantity (ElSaid & Aghezzaf, 2020). Landfill and incineration as traditional waste management strategies due to their cost-effectiveness and simplicity, though they require high management levels to mitigate negative impacts.

Modern Sustainable Municipal Waste Management (MSWM) now captures the pillars of sustainability including environmental protection, social equity, and economic stability. Pollutant partitioning to understand the movement of hydrophobic colloids in different environments such as marine, groundwater, and soil, which is crucial for selecting sustainable

MSW management options and incorporating cleaner production methods in waste management significantly enhances environmental sustainability and cleaner bio-resources by addressing potential environmental depletion. (Bello, A. S., Al - Ghouti, M. A., & Abu - Dieyeh, M. H. (2022)).

Proper handling and management of MSW, involving collection, segregation, and treatment, are essential. Strategic planning is necessary for a sustainable MSW management system for future development (Öztaş & Bektaş, 2022). Transitioning to a circular economy can significantly reduce waste disposal. Key strategies in circular economy models, such as source reduction, source separation, and recycling, align with the United Nations Sustainable Development Goals (SDGs).

2.2 Municipal Solid Waste Composition supporting Organic Composition

Globally, more than 30% of food that is fit for human consumption is wasted or lost during the production process before it reaches consumers (Loizia et al. 2019). Studies show that Municipal Solid Waste (MSW) constitutes a significant portion of waste generated in market areas, ranging from 20% to 40% (Masó & Blasi 2008; Okot-Okumu and Nyenje 2011; Solomon 2011). Additionally, markets generate considerable amounts of food, fruit, and vegetable waste (FFVW), which is often greater than what households produce. This type of waste can create problems in landfills due to its rapid decomposition (Chandrappa and Das, 2012).

In 2016, a study piloted in South Africa found that the organic components of municipal solid waste (MSW) collected from households, restaurants, and a fruit and vegetable market in Johannesburg comprised 34%, 14%, and 93% by weight, respectively (Masebinu et al. 2018). Lim et al. (2017) emphasize that food, fruit, and vegetable waste (FFVW), which represents a considerable portion of market waste (MW), is a key component of Municipal Solid Waste (MSW) in Malaysia. Kitinoja and Kader (2015) note that post-harvest losses—due to issues like improper handling, insufficient packaging, high temperatures during transportation, and delays in marketing—are major contributors to the significant amounts of organic waste found in market waste.

Research shows that vegetable losses in West Africa are considerable, with rates between 70% and 80%, while fruit losses range from 50% to 70%. The high organic content and easily biodegradable characteristics of market waste highlights its potential for affordable energy generation, which could enhance access to energy and related services (Mohan et al. 2009; Palaiogeorgou et al. 2017). Furthermore, studies in several high- and middle-income countries have examined the use of organic waste from market sources. For example, Palaiogeorgou et al. (2017) discovered that carbohydrate-rich food, fruit, and vegetable waste (FFVW) can serve as fermentation feedstocks to produce 2,3-butanediol (BDO). Additionally, Masebinu et al. (2018) explored the potential for biogas production through the anaerobic digestion (AD) of fruit and vegetable waste sourced from the Johannesburg market in South Africa.

In Sub-Saharan Africa, around 37% of all food produced is lost or wasted (FAO, 2011). Markets in Ghana are no exception, generating significant amounts of waste that are almost entirely organic. The significant quantities of organic waste are linked to inadequate post-harvest storage systems, as many markets lack proper storage facilities (FAO, 2011). For instance, at the retail level, agricultural products in poor packaging experience a drastically shortened shelf life (Adom, 2018), resulting in higher levels of organic waste in the market.

The waste composition in Ghana primarily consists of organic materials (60%), followed by plastics (14%), paper (5%), metals (3%), and glass (3%). Major cities generate about 2,000 tonnes of mixed municipal waste each day, with 80% of this waste being collected (Cofie et al. 2009). However, waste management authorities in many Ghanaian cities struggle with various challenges, including limited funding, negative public attitudes, insufficient infrastructure, lack of equipment, and inadequate maintenance practices (Addae et al. 2021). In Kumasi, for instance, around US$491,730 is spent monthly on solid waste collection and disposal (Alhassan et al. 2020).

Most studies in Ghana have primarily focused on household waste (Asase 2011; Miezah et al. 2015; Ofori-Boateng et al. 2013). In comparison, Municipal Waste (MW) appears to be a less explored area, with limited data on its generation and composition. To effectively valorise MW, it is essential to have reliable information about waste properties, making characterization crucial for assessing material recovery potential and identifying the sources of different waste components (Abur et al. 2014; Pagliaccia et al. 2019).

Additionally, the environmental assessment of sustainable waste management systems does not depend only on the physical characteristics of waste but also on the chemical properties of its individual compositions. There is a scarcity of studies examining the chemical properties of Municipal Waste (MW) in Ghana.

Moreover, periodic waste characterization is underrepresented in the current waste data for Ghana, even though it is crucial for tracking periodic changes in waste composition. Fisgativa et al. (2016) highlighted the periodic effects on characteristics of food waste, pointing out the issues in optimizing the renewable energy supply chain, as feedstock availability varies with the seasons while energy demand remains steady year-round.

Similarly, Shi et al. (2017) discovered that the presence of moisture in domestic waste in Kétao, Togo, was ten times higher during wet seasons than in dry seasons. Additionally, MW is considered a promising feedstock for resource recovery technologies, as it is generated in large quantities, unlike household waste, which is typically produced in smaller amounts at various locations.

2.3 Potential Uses of the Organic Component of Wastes

2.3.1 Composting

Composting is an anaerobic biological decomposition process that produces thermophilic temperatures due to biologically exothermic heat (Oazana et al. 2018). It serves as a reliable waste treatment method, effectively recycling the organic proportion of solid waste and potentially reducing the volume of organic matter entering overcrowded landfills by as much as 30% (Khater, 2015).

In Jordan, the application of organic residues for fertilizers has recently gained attention from local authorities. Sources of organic waste include waste materials derived from agricultural and industrial activities, the organic fraction of Municipal Solid Waste (MSW), and animal manure (Ammari et al. 2012; Abbassi et al. 2015). Given the country's potential for producing raw materials and the low organic matter content in its soil, composting can play a significant role in Solid Waste Management (SWM) and improve soil fertility (Al-Nawaiseh et al. 2021).

Diverting organic materials from Municipal Solid Waste to composting presents various economic and environmental advantages. These include reducing the volume and weight of raw materials and greenhouse gas emissions (Abu Qdais et al. 2019), lowering leachate production, decreasing the costs associated with disposing of organic residues, and generating income by using compost as a substitute for more costly materials like chemical fertilizers and peat (Proietti et al. 2016; Wei et al. 2017).

Despite the numerous environmental and economic benefits of adopting composting as a mainstream waste management solution, several technical and socio-economic issues still exist. Key concerns include the contamination of feedstock and final compost with heavy metals and microplastics, as well as the reliability of the compost's quality and safety. To mitigate these issues, it is crucial to establish comprehensive management practices, governing guidelines, and efficient enforcement of policy plans.

According to Saft and Elsinga (2006), anaerobic digestion of organic waste produces methane (CH_4) and carbon dioxide (CO_2). Composting can help reduce Greenhouse Gas

(GHG) emissions by decreasing the volume of virgin waste sent to landfills, thereby minimizing anaerobic digestion and the associated production of CH_4 and CO_2.

In a similar vein, Adani et al. (2004) found that composting results in GHG emissions are about 82% lower than those from landfill disposal. Efficient treatment of these organic-rich waste components is essential for recovering their nutrients and/or converting them into value-added products, which helps lessen their environmental impact. Nutrients can be extracted from waste using various methods, including biological treatment (Karimi et al. 2018).

2.3.2 Biogas Production

Research has shown that organic waste, such as Municipal Solid Waste (MSW), green waste, and yard waste, can be harnessed for bioenergy production (Daioglou et al. 2016; Tyagi and Lo, 2013). Anaerobic digestion is a process that not only recovers energy from organic materials but also allows for nutrient recycling when the digestates are applied to agricultural land. Since the Industrial Revolution, the linear economy has been the prevailing production model in modern society, built on a consumer-oriented approach that relies on natural resources. This model follows a straightforward sequence of production, consumption, and final disposal, which has been viewed as the rational way to foster economic growth (Rekleitis et al. 2020).

In this context, a variety of microorganisms, including bacteria, yeast, and filamentous fungi, are utilized to biologically treat organic waste (Liang et al. 2014). Among these, filamentous fungi have attracted considerable attention in industrial production of various value-added products, such as enzymes, pigments, organic acids, and other metabolites (Ferreira et al.

2016; Gmoser et al. 2017), owing to their ability to thrive on diverse organic-rich substrates (Lauryn et al. 2016).

To lower the costs associated with large-scale fungal product production and address the environmental impacts of industrial waste, there has been growing interest in using industrial byproducts and waste as cultivation media for fungi. These fungi can produce and secrete a range of enzymes, such as proteases and lipases, enabling them to degrade and utilize different substrates (Ferreira et al. 2016). Additionally, filamentous fungi can generate metabolites like ethanol, carboxylic acids, pigments, and antibiotics (Gmoser et al. 2017). Furthermore, the rich protein, fatty acid, and vitamin content of fungal biomass makes it a viable option for human food and animal feed.

2.3.3 Animal Feed

Traditionally, fermented fungal foods such as miso, tofu, and tempeh are popular in Eastern and Southeastern Asian countries, including Japan, China, and Indonesia (Lenartsson et al. 2012). The nutrient composition of fungal biomass makes it a promising option for supplementing or replacing conventional animal feeds, particularly fish feed.

In aquaculture, fish production is directly linked to the nutrients provided by fish feed (Tacon et al. 2008). Feeding expenses significantly affect overall production costs, accounting for 30% to 60% of total costs in intensive and semi-intensive farming systems (Azaza et al. 2009). To support healthy fish growth, diets must include adequate protein levels (Khan et al. 2012; Naz & Javed, 2013).

Fishmeal is commonly favoured in traditional fish diets due to its high protein content, palatability, digestibility, and well-balanced amino acid profile (Yildirim et al. 2014). However, fishmeal is an expensive ingredient because of its high demand from various animal farming industries (Kristofersson et al. 2006). As the aquaculture industry continues to expand, the demand for fishmeal rises, leading to increased prices. Additionally, overfishing has detrimental effects on fish stocks in the pelagic zones of natural waters (Luo et al. 2012). Consequently, to advance toward more sustainable aquaculture practices, it is essential to explore renewable and affordable alternatives that can partially or completely replace fishmeal.

2.3.4 Soil Amendment

Inefficient agricultural management practices can cause valuable topsoil to be lost due to erosion from water, wind, or tillage. Industries like mining, oil and gas extraction, and quarry frequently involve the removal of surface soil layers, leading to a substantial reduction in the soil organic matter pool. This disruption compromises the exposed soil's ability to regenerate organic matter through net primary production, as it faces altered conditions related to nutrients, water, and temperature.

The loss of soil organic matter reduces water-holding capacity and leads to increased runoff due to decreased porosity (higher bulk density) and lower infiltration rates. This also negatively affects soil microbial activity. Intergenerational equity underscores the importance of providing future generations with the same or ideally improved environmental quality as the current generation. Therefore, degraded soils that remain un-reclaimed pose a disservice to future generations.

Given that organic matter is vital for soil productivity, it influences nearly all its physical, chemical, and biological properties—successful land reclamation relies on recreating a topsoil rich in organic matter to support productivity (Akala and Lal, 2000). Even though importing topsoil can restore these horizons, this method is often expensive and impractical, and it depletes resources from degraded areas. If importing topsoil is not feasible, the addition of organic amendments may serve as a suitable alternative. There are various forms of organic ameliorants (Larney and Pan, 2006), including fresh, aged, or composted manure, biosolids, pulp and paper mill sludges, and food processing wastes. These materials are readily available in the large quantities required for many land reclamation projects.

For centuries, humans have added organic matter, including livestock manure and human waste, to soils, resulting in enhanced soil fertility and increased crop yields (Montgomery, 2007). The positive impacts of organic amendments on the chemical, physical, and biological properties of degraded soils are well-established in the literature (Pascual et al. 1999; Stewart et al. 2000).

An in-depth review of land surface reclamation by Sims et al. (1984) emphasized the overarching role of organic amendments, especially sewage sludge, in addressing negative properties of the rooting area. However, these amendments are often seen negatively as waste products, linked to undesirable features such as odor, excessive nitrogen and phosphorus, heavy metals, pathogens, toxins, and other contaminants that may leach into surface or groundwater (Larney et al. 2011). Sims et al. (1997) questioned how to assess the quality of soils intentionally amended with these wastes and by-products, as many view such practices as simply treating soil as a dumping ground for agricultural or industrial waste. Still, when applied carefully, organic amendments can play a vital role in soil reclamation.

Soils are resilient and can capitalize on these products primarily through their contribution to soil organic matter. Additionally, using organic amendments helps divert materials from increasingly overloaded landfill sites. A frequent question is whether fertilizers can reclaim soils as effectively as organic amendments. While fertilizers provide essential nutrients like nitrogen, phosphorus, potassium, and other micronutrients, they do not contribute to organic matter.

In contrast, organic amendments supply both nutrients and organic matter, offering more extensive avenues for enhancing soil physicochemical, and biological properties, which are vital for the success of any attempt to reclaim the soil. For example, research showed that the addition of biosolids was more effective in improving soil quality and fertility on reclaimed copper mine tailings in British Columbia compared to traditional inorganic fertilizers (Gardner et al. 2010). Reid and Naeth (2005a, b) found comparable results in establishing vegetation cover in Northwest Territories of Canada, where biosolids and composted papermill sludge outperformed fertilizers.

Organic matter, a fundamental component of healthy soils, plays a key role in soil carbon flux and carbon sequestration. The decomposition of organic matter contributes to the release of carbon dioxide, a potent greenhouse gas. However, through effective land management practices, organic matter can also be manipulated to enhance carbon sequestration. A study by Paustian et al. (2016) stresses on the potential for soil organic matter management to significantly increase carbon storage in agricultural systems, providing an avenue for climate change mitigation.

Carbon sequestration in soil through organic matter preservation and enhancement has emerged as a promising strategy for climate change mitigation. Research by Sanderman et al. (2017) emphasizes that carbon sequestration in soils shows promising signs of offsetting a significant portion of global greenhouse gas emissions. The sequestered carbon not only mitigates climate change but also enhances soil fertility, nutrient cycling, and water retention. Moreover, a study by Lal (2020) demonstrates the broader benefits of carbon sequestration, including improved ecosystem services, enhanced resilience to extreme events, and reduced soil erosion. Besides mitigating emissions from waste disposal at municipal landfills, adding composted organic material to soil improves nutrient availability, increases water-holding capacity, and can sequester additional carbon from the atmosphere (Hargreaves et al. 2008).

Applying compost is considered a best management practice (BMP) for reducing runoff and soil erosion due to its low technology and maintenance requirements, cost-effectiveness, and the significant benefits achieved from a single application (Pachauri et al. 2014). Incorporating organic matter into soils is a widely used management technique in cropping systems to enhance net primary productivity and has also been suggested for grazed grassland ecosystems to promote plant growth and increase belowground carbon storage (Smith et al. 2008). Soil carbon sequestration, as observed in natural ecosystems, refers to the net increase in carbon storage in soils and plants, which is derived from atmospheric CO_2 and plant photosynthesis (Lal, 2018).

Compost breaks down much more slowly than fresh organic residues, with a mean residence time typically several times longer than that of un-composted organic matter. This slower decomposition leads to reduced mineralization and a greater potential for long-term carbon storage in soils (Ryals, 2018). Composted products derived from recycled organics (RO) provide additional opportunities to enhance soil organic carbon (SOC) in various agricultural systems. Recycled organics encompass compostable materials like garden waste, food scraps, residual wood and timber, biosolids, and agricultural by-products (ROU, 2001), all of which are high in organic carbon.

2.3.5 Biochar Production

Biochar is produced by so-called thermal decomposition of organic material under limited supply of oxygen (O_2), and at relatively low temperatures below <700°C (Lehmann & Joseph, 2009).

There is compelling evidence that biochar is more stable than any other soil amendment (Lehmann & Joseph, 2009), It also improves nutrient availability beyond the effects of fertilizers (Lehmann & Joseph, 2009). These essential characteristics of stability and nutrient retention make biochar more efficient than other organic materials in the soil. This implies that biochar is simply not another form of compost or manure; it is considerably better at enhancing soil quality than other soil ameliorants (Lehmann & Joseph, 2009).

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2.4 The Concept of Biochar

The concept of biochar has existed for a very long time, with various schools of thought representing it in one way or another in literature. The concept of biochar takes root in biomass and bioenergy. Biomass is well-recognized as the world's longest-standing energy. (Van-Loo and Koppejan, 2008).

Singh (1996) discusses bioenergy and biomass in detail, describing it as a renewable and concentrated form of readily available solar energy. It is derived from materials such as agro-wastes and forest residues which are widely spread throughout the world. Singh (1996) then continues to estimate about 200 million tonnes of organic matter are produced annually.

Biomass is simply recycled CO_2 with solar energy and is in varying and beneficial forms such as agriculture, sericulture, forest, animal, and fish products and residues, aquatic mass, algae and microorganisms, manure and household, community and industrial organic wastes and runoffs.

Mohan et al. (2006) defined biomass to mean complicated biological, organic, or nonorganic solid material that can be derived from both living and dead organisms. It can be transformed using various processes including biochemical, chemical, and thermochemical processes (Demirbas et al. 2009). Heat transformation of biomass has obtained unique traction since it advances to beneficial products while also contributing to providing solutions to challenges of pollution arising from biomass buildup (Rocha et al. 1999).

Duku et al. (2012) as well as Shuma (2012) postulate the waste generated in agricultural settings and urban environments can serve as the source material for biomass. This material can be converted into charcoal briquettes and used for domestic cooking as an option or replacement for wood-derived charcoal (Vest, 2003; Mwampamba et al. 2012).

Various types of waste, such as animal manure, wastepaper, sludge, and various industrial wastes, are also treated as biomass because just like naturally obtained biomass, these waste materials are also a mixture of organic and non-organic compounds and can be treated and converted to derive energy (Tripathi et al. 2016). Biomass, specifically for electricity or for alternative fuels, can be obtained using several feedstocks, each with specific advantages and disadvantages (Demirbas, 2008). Unlike other energy forms, biomass is readily available. It is estimated that the current annual growth of biomass on Earth is approximately equal to 10 times of the combined global yearly energy consumption. This assumes that only 1% of products and output was used for energy. This alone shows the immense prospect for research and development and further future applications (Demirbas, 2004).

Woody biomass (firewood), used as a major source of energy for cooking and heating in many parts of the world, comprised and estimated 10% of the world's energy use as of 2009 (Van-Loo and Koppejan, 2008). Firewood primarily includes the remnants from forest and vegetation (Jafri et al. 2018). Biomass combustion is accountable for more than 90% of the global contribution to bioenergy; this is the primary technology used for bioenergy production.

Biomass can be categorized under the three matter states. These are biofuel (liquid) which comprises of biodiesel, biogas (gas) and biochar (solid) (Decker et al.2000; Das et al. 2014; Tripathi et al. 2016). The three states of biomass have their respective and distinct processes that aid in their production and extraction. The fraction of singular output is heavily dependent on a series of variables including the residence time, range of temperature, and pressure, etc (Brewer, 2012; Cheah et al. 2016; Lewandowski et al. 2010).

Van-Loo and Koppejan, (2008) postulated that biomass can be processed into bioenergy (heat or electricity) or energy vessels (gas, oil or char) by different thermochemical and biochemical processing technologies The liquid products produced are known as bio-oil (Bridgewater and Peacocke 2000; Granatstein et al. 2009; Huber 2008; Mason et al. 2009; Lehmann et al. 2004), while the solid output is referred to as biochar (Babinszki et al. 2021; Farghali et al. 2022). Pyrolysis products are an oil; a cocktail of hydrocarbons, synthetic gas; a mixture of hydrocarbon gases and biochar (Lewandowski et al. 2010; Verheijen et al. 2010). Arkham et al. (2016) backs this assertion by establishing in his study that biomass pyrolysis generates gas, liquids, and solid products. The gas can serve as an energy provider to power the pyrolysis process, whilst the bio-oil can be used as a substitute for several uses where fuel oil can be applied, as well as a feedstock for chemical production. Again, the bio-oil can be converted into gas to produce clean ash free syngas.

In contrast to fossil fuels, the energy derived from the three products of pyrolysis is carbon neutral or even carbon negative, making them promising energy sources for the future (Laird, 2008). Additionally, while the combustion of firewood, paper, and plastic waste is known to emit dioxins, there is no experimental evidence supporting dioxin emissions from the pyrolysis of conventional biomass feedstocks and their co-products (Sohi et al. 2009; Verheijen et al. 2010).

Biochar is a porous and stable carbon-rich co-product of the pyrolysis process that has diverse uses including soil amendments and long-term carbon sequestration, waste management and energy production (Lehmann et al. 2006). Lehmann (2006) also established the production of biochar being obtained from various source materials such wood, manure, or leaves, is heated in an enclosed receptable with little to no air being present. This process he defined as the thermal decomposition of organic matter under limited supply of oxygen under temperatures not exceeding 700 degrees.

2.5 Biochar Production and its Uses

2.5.1 Biochar Production; Pyrolysis

Biochar is manufactured using the process of pyrolysis. It is recognized as the earliest known method of biomass thermal processing. It backdates to prehistoric Egypt (Mohan et al. 2006). Pyrolysis constitutes one of the several other technologies used to convert energy from biomass (Bridgewater, 2003).

Pyrolysis is a thermal degradation process producing heat, bio-oil, syngas, and biochar in the absence of oxygen (Spokas et al. 2012). The process has established itself as the most promising thermochemical technique to produce energy from biomass (Tripathi et al. 2016). Leinweber and Schulten (1999), reported that the term pyrolysis is linked to critical methods to determine the organic chemistry of organic substances or bioenergy systems that absorb the off-gases released during the charring process and used to produce syngas, hydrogen, bio-oils, heat and electricity (Bridgwater et al. 1999).

On the contrary, the term 'burning' is typically used when char is absent, with the organic substrate being completely converted to ash that does not contain any organic C (carbon). Usually, substances identified as 'ash' have some component amount of char or biochar being present. This substantially influences ash characteristics and behavioural patterns in technology and the environment.

According to Hersh et al. (2019), focusing on the thermochemical production processes, pyrolysis technology is projected to see a drastic growth because of the higher yield methods of production and pristine output in terms of carbon constituent and steadiness. Hersh (2019) categorized pyrolysis as one of the effective methods of extracting superior biochar and bio-oil from biomass; specifically, slow pyrolysis is described as an economical transformation technique for biochar production because of the high operational output and output quality according to Rosas et al. (2015). The challenging gasification technology has seen intensified demand due to the expanding requirement of electricity in energy distribution systems (Hersh et al. 2019).

Pyrolysis of dry lignocellulosic materials (including woody biomass, crop residues, and other plant-based substances) involves three main paths (Shafizadeh, 1982; Varhegyi et al. 1994; Antal and Grønli, 2003): the formation of biochar and gases, the production of liquids and tar, and the processes of gasification and carbonization. When biological materials are thermally decomposed in low-oxygen conditions, they primarily produce a solid byproduct.

Various feedstocks and thermal processes can be used to create biochar. These feedstocks include organic materials such as manure, rendering wastes, and lignocellulosic biomass, which is preferred and recommended due to its abundance. Thermal degradation methods include hydrothermal conversion, torrefaction, slow pyrolysis, fast pyrolysis, and gasification among other combinations. Common thermal conversion technologies in bioenergy systems are direct combustion, liquefaction, gasification, and pyrolysis.

Direct combustion, which involves burning biomass to generate heat and results in wood ash as a byproduct, is the most frequently used method of complete oxidation (Obernberger and Thek, 2010). Liquefaction, which converts biomass into a liquid biofuel under low temperature and high pressure (Van-Loo and Koppejan, 2008), also produces a considerable amount of wood ash. Biomass gasification, however, yields combustible gases like carbon monoxide and hydrogen, along with minor traces of other gases, through controlled partial combustion of biomass at high temperatures and pressures.

Pyrolysis of biomass to produce biochar is considered a net-negative carbon process because it sequesters carbon rather than releasing it into the atmosphere (Kong et al. 2014). Although the carbonization process generates a notably strong odour, it does not necessitate highly complex engineered systems and is not restricted to wood. Slow pyrolysis is particularly effective for biochar production, typically yielding about 35% of biochar by weight from dry biomass. This process is also closely linked to charcoal production (Tripathi et al. 2016).

Fast pyrolysis is known to be the most efficient method for generating biofuels, whereas gasification excels in producing syngas and is typically employed for generating heat and energy (Cheah et al. 2016). It is noteworthy that most research studies focused on pyrolysis technologies focused more on the liquid and syngas product. (Chen D. et al. 2014); this fixation on syngas is attributed to the fact that the oil and syngas products were deemed more valuable; and the yields and composition of pyrolysis oil and syngas are mainly changing with temperature. As a result of high heating rates and short residence times, fast pyrolysis tends to yield higher proportions of oils.

In contrast, slow pyrolysis generally produces higher quantities of biochar due to its slower heating rates and longer residence times (Daful and Chandraratne, 2018). Additionally, biomass pyrolysis can lead to the formation of phytotoxic and potentially carcinogenic compounds, depending on factors such as feedstock type, feedstock contamination, and pyrolysis conditions (Ndriangu et al. 2019).

The process of biochar production has often been likened to that of charcoal production, a process spanning back to the early civilization of humankind (Harris, 1999; Karaosmanoglu et al. 2000; Demirbas, 2004a). Using 'biochar' rather than 'charcoal' to refer to fuel is likely to distinguish it from coal. Although coal and charcoal are produced through different processes and possess different chemical and physical properties, there are occasional situations where their properties might appear similar or overlap. Despite this, the term ‘charcoal’ is long established in popular language and scientific literature and has also been used to represent charred organic matter as a source of energy. A glaring similarity between biochar and char is the fact that pyrolysis-produced biochar contains high energy which in some cases is comparable to the coal used in industries as feedstock for fuel (Fu et al. 2012; Mohanty et al. 2014).

The term ‘charring’ can refer to either the process of making charcoal or the formation of char from fires. Although 'char' is frequently used interchangeably with 'charcoal,' it can sometimes denote material that has been charred to a lesser extent than charcoal, typically as a byproduct of pyrolysis (Schmidt and Noack, 2000). "Activated carbon" describes substances likened to biochar and coal that are treated with steam or chemicals at temperatures over 700°C to boost their surface area. This treatment enhances their utility for industrial purposes, including filtration (Boehm, 1994).

The term ‘black C’ is also associated with biochar and includes all carbon-rich residues produced by fire or heat. This encompasses fossil fuels like coal, gas, and petrol, as well as biomass. 'Black C' covers the solid carbonaceous byproducts of combustion and heat, including soot. It includes a wide range of charred materials, from char and charcoal to biochar, soot, graphitic black C, and graphite (Schmidt and Noack, 2000). Despite this broad classification, clear distinctions are made based on their uses. Biochar differs chemically from other organic matter primarily due to its higher proportion of aromatic carbon and condensed aromatic structures, compared to other components like lignin (Schmidt and Noack, 2000). The condensed aromatic structures of biochar can vary, including amorphous carbon at lower pyrolysis temperatures, turbostratic carbon at temperatures between 600–700°C, and graphite carbon (Keiluweit et al. 2010; Nguyen et al. 2010).

In biochar production, the process usually produces more energy than it consumes, depending on the moisture level of the feedstock (Lehmann et al. 2006). The heat, oil, and gas generated can be recovered and repurposed for various uses, including electricity generation. A sustainable model for biochar production primarily utilizes waste biomass, such as green waste from municipal landscaping, forestry, or agricultural byproducts (e.g., bagasse and other residues from agricultural processing).

2.5.2 Applications and Use of Biochar Production

The term 'biochar' is a relatively current development, emerging with carbon sequestration and soil management issues (Lehmann et al. 2006). Some publications establish and use 'biochar' as the suitable term where charred organic matter is mixed into soil deliberately, with the sole purpose of improving soil properties. This is a distinguishing factor separating biochar from charcoal used for heating or for fuel purposes, as a screen, a reducing agent in ironmaking, or as a dying agent used in the textile industry.

Lehmann and Joseph (2009) establish four balancing and usually collaborative objectives which have motivated biochar applications. These applications have fallen under managing the environment: improving soil properties (for improved productivity as well as reduced pollution); managing wastes; managing climate change, and energy generation, which must independently or collaboratively provide social, financial benefits. As a result, these systems can vary widely in scale and design. They may involve different production methods that either produce energy in addition to biochar or focus solely on biochar. These systems can range from small household units to large bioenergy power plants.

Most of the literature focuses biochar's application mainly in soil fertility improvement used in the manner of a liming effect, enrichment in volatile matter and the growth of pore volume pollution remediation due to high CEC and specific surface area carbon sequestration due to carbon and ash content, etc. However, (Lehmann and Joseph, 2009) highlights its critical relevance in other overlooked applications such as its application as renewable fuel. Notwithstanding, other applications of biochar have also been established including its successful use in textile dye removal (Mui et al. 2010; Rangabhashiyam et al. 2013), applications in road construction and as an admixture (Wang et al. 2019), as an adsorbent for air and water, and as a catalyst to remove tar or produce biodiesel (J.S. Cha et al. 2016).

2.5.2.1 Biochar Application for Soil Amendment

Although there is increasing interest in using biochar in agriculture, its current application is still relatively limited. The market potential for biochar could expand if it proves effective as a soil amendment for enhancing soil quality and boosting crop yields (Day et al. 2004). Biochar's key advantage is its nutrient value, which benefits plants either directly or indirectly by improving soil conditions and enhancing fertilizer efficiency. For example, biochar can reduce nutrient leaching by retaining nutrients in the soil, leading to better nutrient uptake by plants and increased crop production (Gonzaga et al. 2021).

The "Green Revolution," spearheaded by Nobel Laureate, Norman Borlaug at the International Centre for Maize and Wheat Improvement (CIMMYT) in Mexico during the 1940s, greatly enhanced agricultural productivity in Latin America and Asia. This success was achieved through advancements in agricultural technology, including improved crop varieties, better irrigation, and increased use of fertilizers and pesticides. Recently, there has been a push for a "Doubly Green Revolution" that integrates sustainable soil management practices (Tilman, 1998; Conway, 1999). Biochar presents a valuable opportunity to advance this vision by supporting sustainable agroecosystem practices. As input costs, such as for fertilizers, continue to rise, maintaining adequate soil organic matter becomes crucial, and biochar can provide a long-term solution for this (Kimetu et al. 2008; Steiner et al. 2007).

The Green Revolution in Africa has not been as successful as in other regions (Evenson and Gollin, 2003), mainly because of the exorbitant price of agrochemicals (Sanchez, 2002) and other factors (Evenson and Gollin, 2003). Biochar presents a unique avenue to enhance soil fertility and efficiency of nutrient-use by utilizing locally available and renewable materials in a sustainable manner. Adopting biochar management does not require additional resources but rather optimizes the use of existing ones in a more efficient and environmentally friendly way. Farmers in resource-constrained agroecosystems can produce biochar from organic residues and biomass fuels, achieving a rapid return on investment without compromising energy output.

Biochar has its roots stemming from the "Terra Preta" soils of the Amazon, which are notable for their exceptional fertility. These dark-colored soils, reaching depths of up to 2 meters, have sustained agricultural practices in the Amazon for centuries (Sombroek et al. 2003; Neves et al. 2004). One reason Amazonian Terra Preta soil which are rich in biochar-like pyrogenic carbon, maintain high fertility compared to surrounding infertile soils is their ability to retain nutrients effectively (Glaser et al. (2001)). Another benefit of biochar is its capacity to address soil constraints that limit plant growth, such as using lime to reduce soil acidity, which improves fertilizer efficiency and boosts plant production. Steiner et al. (2008) reported that applying 5 tonnes of biochar per hectare led to a 7% reduction in fertilizer needs. Furthermore, Gaunt and Lehmann (2009) indicated that the long-term carbon storage observed in Terra Preta soils suggests that biochar can persist in the soil for hundreds to thousands of years. Due to its scalability and adaptability to various soil types and uses, biochar is a flexible and globally applicable carbon management strategy.

Soil degradation and loss are happening at alarming rates in both developed and developing countries (Stocking, 2003; IAASTD, 2008), severely affecting soil ecosystem functions (Matson et al. 1997). Many regions experience declining soil productivity despite heavy agrochemical use, with additional negative consequences for soil and water resources (Foley et al., 2005; Robertson and Swinton, 2005). Biochar offers a significant opportunity to enhance sustainable soil management by building on current best practices to boost soil productivity and reduce environmental harm. Instead of replacing existing soil management methods, biochar should be viewed as a crucial addition that aids in creating sustainable land use practices, thus contributing to a truly green "Biochar Revolution."

According to Bassey et al. (2022), sequestering carbon in soil is a powerful strategy for mitigating climate change. Recently, there has been growing recognition of the benefits of converting atmospheric carbon into biochar and applying it to soil. Using biochar as a soil amendment is an effective method for climate change mitigation, as it not only sequesters carbon but also brings additional advantages for agriculture and the environment. Biochar incorporated into soil helps to reduce N_2O and CH_4 emissions, offers effective management of agricultural waste, improves soil sustainability, and decreases the need for fertilizers, among other benefits (Majumder et al. 2019; Wang et al. 2019).

While global research and development of biochar for environmental management is a relatively recent trend, its use and study have long histories in certain regions. For instance, Trimble (1851) reported observations of ‘evidence upon almost every farm in the county in which I live, of the effect of charcoal dust in increasing and quickening vegetation’. Preliminary scientific investigations by Retan (1915) and Tryon (1948) explored biochar’s effects on seedling growth and soil chemistry. In Japan, biochar research notably increased in the early 1980s (Kishimoto and Sugiura, 1980, 1985). Biochar has also been recommended for horticultural purposes for some time, such as in potting mixes (Santiago and Santiago, 1989).

Additionally, Morley discussed biochar in the inaugural issue of The National Greenkeeper in 1927 that ‘charcoal acts as a sponge in the soil, absorbing and retaining water, gases and solutions. He even remarks that ‘as a purifier of the soil and an absorber of moisture, charcoal has no equal’ (Morley, 1929), and charcoal products are being marketed for turf applications in a 1933 issue of the same magazine.

Biochar has a long history as a soil modifier (Brewer, 2012). Early Japanese farmers used unique manure called ‘‘haigoe’’, which was prepared by adding human waste to rice husk biochar and applying it to fields some time before planting crops (Shakya and Agarwal, 2017).

Moreover, the addition of biochar may affect the biological community composition of soil, as demonstrated for the ‘Terra Preta’ soils in the Amazon (Lehmann et al. 2011). Soil is a complex material and comprises minerals, soil organic matter, water, and air. These fractions greatly influence soil texture, structure, and porosity (Baghdadi and Zribi, 2016). These properties subsequently affect air and water movement in the soil layers and thus the soil’s ability to function (Naga Raju et al. 2017). Therefore, soil physicochemical properties have a great influence on the soil quality.

Biochar generally increases carbon sequestration in soil (Sohi et al. 2010), reduces the emission of ammonia and carbon dioxide (Cabeza et al. 2018), lowers soil compactness, optimizes compost (Liang et al. 2010), improves water retention and the sorption of heavy metals, increases the availability of micronutrients for plants and rises the pH of soils (Van Zwieten et al. 2010). Biochar also stimulates the growth of rhizosphere microorganisms and mycorrhizal fungi (Głuszek et al. 2017). These bacteria and fungi may also promote plant growth (Compant et al. 2010).

Justus Liebig describes a practice in China where waste biomass was mixed and covered with soil and set on fire to burn over several days until a black earth is produced, which reportedly improved plant vigour (Liebig, 1878, p452). According to Ogawa (undated), biochar is described by Miyazaki as 'fire manure' in an ancient Japanese text on agriculture dating from 1697 (pp91–104).

Despite these early descriptions and research, global interest in biochar only began in the past few years. The basis for the strong recent interest in biochar in this regard is twofold. First, the discovery that biochar-type substances are the explanation for high amounts of organic C (Glaser et al. 2001) and sustained fertility in Amazonian Dark Earths locally known as Terra Preta de Indio (Lehmann et al. 2003a).

Biochar has consequently been frequently connected to soil management practised by ancient Amerindian populations before the arrival of Europeans, and to the development of complex civilizations in the Amazon region (Petersen et al. 2001). This proposed association has found widespread support through the appealing notion of Indigenous wisdom rediscovered. Irrespective of such assumptions, fundamental scientific research on Terra Preta has also provided critical fundamental information on the working of soils, in general, and particularly on the effects of biochar (Lehmann and Joseph, 2009).

Unequivocal proof has become available showing that biochar is not only more stable than any other amendment to soil but that it increases nutrient availability beyond a fertilizer effect (Lehmann and Joseph, 2009), but that these basic properties of stability and capacity to hold nutrients are fundamentally more effective than those of other organic matter in soil. This means that biochar is not merely another type of compost or manure that improves soil properties but is much more efficient at enhancing soil quality than any other organic soil amendment. This ability is rooted in specific chemical and physical properties, such as the high charge density (Liang et al. 2006), that result in much greater nutrient retention (Lehmann et al. 2003b), and its particulate nature (Skjemstad et al. 1996; Lehmann et al. 2005) in combination with a specific chemical structure (Baldock and Smernik, 2002) that provides much greater resistance to microbial decay than other soil organic matter (Shindo, 1991; Cheng et al. 2008).

Although the processes may not fully be understood, studies have proposed that enhanced root growth, mycorrhizal fungi and production of waxes and mucilages bind soil particles together (Mukherjee and Lal, 2013). The highly stable organic carbon in biochar plays an important responsibility in improving soil aggregation and aggregate stability. Enhanced microbial diversity including enzyme-related processes and respiration have been seen with biochar-altered soils Steiner et al, 2008). Overall, alterations in soil structure due to biochar application may enhance soil moisture retention, infiltration, and consequently reduce runoff and erosion.

These and other comparable examinations have helped to make a convincing case for biochar as a critical tool for environmental management. They have provided the breakthrough that has brought already existing – yet either specialized or regionally limited – biochar applications and isolated research efforts to a new level.

2.5.2.2 Biochar Application to Produce Energy

Biochar, when used as a replacement for coal, is a charred by-product created through the thermochemical pyrolysis of biomass in low (controlled oxygen) or zero oxygen environments at temperatures below 700°C. Under these conditions, thermal bond cleavage and polycondensation reactions transform the biomass into biochar. Additionally, biochar is produced as a by-product when Municipal Solid Waste (MSW) is converted for energy use.

The primary methods for converting MSWs into energy include thermal conversion, biochemical conversion, and physicochemical conversion (Gumisiriza et al. 2017). Direct combustion involves burning biomass in its dry form to generate heat for basic purposes like cooking (Clini et al. 2008). Gasification, on the other hand, is a process where solid waste materials undergo partial combustion at higher temperatures (700–1500°C) and lower pressures with limited or no oxygen (Mohan et al. 2014).

A sustainable biofuel offers two significant benefits: it is produced from renewable resources and has a reduced environmental impact compared to fossil fuels. For biochar production, potential feedstock includes a wide range of biomass sources such as wood waste, agricultural residues, forestry by-products, the organic component of Municipal Solid Waste, and animal manures (Duku et al. 2011).

The organic component of Municipal Solid Waste (MSW) makes up a significant portion, estimated to contribute 50% of the total waste stream. Another report by D. Yirenya-Tawiah et al.2020 approximated that 60% of MSW being organic in nature. While these materials are often regarded as waste, they are valuable resources that can be utilized to produce biochar, a renewable energy alternative (Arkham et al. 2016).

According to the International Energy Agency, global energy demand is expected to double by 2035 (IEA, 2012). Currently, most of this demand is met by non-renewable energy sources, such as fossil fuels, which are leading contributors to Greenhouse Gas (GHG) emissions.

The conversion of biomass through thermochemical processes has become increasingly important in response to rising global energy demands and the need to mitigate environmental pollution (Tekin et al. 2013). Various thermal methods are employed to transform renewable feedstocks into valuable fuels and chemicals (Gercel and Gercel, 2007). Key thermochemical techniques for converting biomass into biofuels and other bio-based products include pyrolysis, carbonization, and gasification (Duku et al. 2011).

Gasification involves the partial combustion of solid waste materials at high temperatures (700–1500°C) and low pressures with minimal or no oxygen, resulting in the production of syngas—a mixture of hydrogen (H_2), carbon monoxide (CO), and carbon dioxide (CO_2) (Mohan et al. 2014). However, the process of capturing syngas poses challenges due to the high costs associated with its storage and maintenance. Additionally, the formation of coke and tar can lead to significant fouling of the gasifier chambers during operation (Matsakas et al. 2017).

Capturing energy during biochar production and subsequently using the biochar from pyrolysis as a soil amendment offer mutually beneficial outcomes. This approach not only supports the sustainability of biomass production (Lehmann, 2007a) but also helps in reducing overall emissions (Gaunt and Lehmann, 2008).

Although applying biochar to soil might lower the energy efficiency of pyrolysis-based bioenergy, the emission reductions from adding biochar to soil often surpass the benefits of using it purely as a fuel (Gaunt and Lehmann, 2008). As such, focusing on biochar can be particularly effective for addressing environmental issues rather than concentrating solely on energy production.

This strategy is well-suited to bioenergy's objectives, as bioenergy and pyrolysis have significant potential to ensure a sustainable supply of green energy in the future. Arkham et al. (2016) however stated the relevance of organic waste pyrolysis emphasizing that it will not only decrease the solid waste challenge but also reduce the reliance on non-renewable petroleum-based energy resources by offering a future sustainable energy resource. This assertion assumes that biochar alone cannot resolve the energy crisis or meet the growing global demand for energy. For example, Kim and Dale (2004) projected that ethanol from crop waste could potentially replace 32% of worldwide gasoline consumption at the time, but reaching this potential appears unlikely.

Additionally, a global assessment of bioenergy from forestry projected a theoretical excess supply of 71 EJ by 2050, beyond what is needed for other wood uses (Smeets and Faaij, 2006), compared to a global energy consumption of 489 EJ in 2005 (EIA, 2007). Even though biochar alone may not fully meet the future global energy demand, even a fraction of its potential could make a significant contribution to the overall energy solution.

While producing bioenergy solely from woody biomass (such as heat or biofuels) is technically feasible, it may face financial challenges (Stephen, 2013). These challenges stem from varying issues such as the pressure on feedstocks and the rapidly rising energy demand.

In regions that rely heavily on biomass energy, such as much of rural Africa and extensive regions in Asia and Latin America, pyrolysis bioenergy presents a more efficient method of energy production compared to traditional wood burning (Demirbas, 2004b). It also broadens the range of biomass resources that can be used for energy, including not only wood but also crop residues. A key benefit of pyrolysis is its ability to generate cleaner heat, which can enhance cooking technologies by reducing indoor smoke pollution, a common issue with conventional biomass burning (Bhattacharya and Abdul Salam, 2002; Bailis et al., 2005).

While existing scientific research on slow pyrolysis of Municipal Solid Waste (MSW) includes lab-scale experiments (e.g., Ryu et al., 2007; Phan et al., 2008; Velghe et al., 2011; Mitchell et al., 2013) and explores complex systems for mixed waste in industrialized countries (Chen et al., 2014) or low-cost methods for wood charring (Adam, 2009), there is limited information on the decentralized carbonization of various types of municipal organic solid waste in developing nations.

2.5.2.3 Biochar Application to Mitigate Climate Change

The Earth has faced severe and accelerating climate change due to increasing anthropogenic carbon dioxide (CO_2) emissions, which have been rising by over 3% annually since 2000 (Solomon et al. 2009; Raupach et al. 2007). Climate change and global warming have emerged as major issues over the past decade and are expected to remain significant challenges for many years.

Human activities account for around 25% of total greenhouse gas emissions (Cherubini and Stromman, 2011), and the current global CO_2 concentration of 385 ppm has exceeded the safe limit of 350 ppm (Rockstrom et al. 2009). As a result, the planet is experiencing severe environmental changes, including extreme weather events like floods and droughts, and land degradation, which pose immediate threats to biodiversity and productivity. Meanwhile, global demand for food and energy continue to escalate (Eriksen et al. 2009).

Carbon sequestration would involve the absorption and storage of carbon in soil to avert its emission in the atmosphere (Duku et al. 2011). Carbon sequestration: ‘‘The long-term storage of carbon in soils, vegetation, oceans and geological formations” (Kowalska et al., 2020) is an essential requirement for preserving Soil Organic Matter (SOM), which serves as a source of plant nutrients as well as a potential CO_2 sink (Hossain et al.,2017; Munera et al., 2020).

Soil characteristics, the environment, and land management all influence CO_2 exchange between soil and atmosphere (Hassouna et al. 2017; Söderqvist, 2019). The rate of soil carbon emission is strongly influenced by the amount and characteristics of additional organic materials, soil processes, and climatic factors, particularly temperature and water availability (Agehara & Warncke, 2005).

Stockmann et al. 2013 reported that soil contains approximately 2344Gt of organic carbon globally and is considered the largest terrestrial pool of organic carbon. According to the IPCC (2019), about 72 % of global warming is caused by carbon-dioxide as a major greenhouse gas. However, other gases like CH_4, N_2O and F-gases also contribute as well, but with miniscule contribution rates of 20%, 5%, and 3% respectively.

Adding biochar to soils has been described as a means of sequestering atmospheric carbon dioxide (CO_2) (Lehmann et al. 2006). For this to represent true sequestration, two requirements must be met. First and foremost, plants must be grown at the same rate as they are being charred because the actual step from atmospheric CO_2 to an organic C form is delivered by photosynthesis in plants. Yet, plant biomass that is formed on an annual basis typically decomposes rapidly. This decomposition releases the CO_2 that was fixed by the plants back to the atmosphere. In contrast, transforming this biomass into biochar that decomposes much more slowly diverts C from the rapid biological cycle into a much slower biochar cycle (Lehmann, 2007b). Biochar is highly resistant to decay thus storing the remaining carbon and preventing rerelease to the atmosphere (Lehmann 2007).

An effective implementation of biochar as a climate-change mitigation tool would however require an application of massive quantities of biochar into the environment (Biederman and Harpole, 2013), which may result in its exposure to non-target terrestrial and aquatic systems as wind and water can erode up to 50% of applied biochar material during application (Major et al. 2010). Such an occurrence has the tendency to alter biosystems, influencing biota and thereby influencing species populations in unique ecosystems. It is estimated that the implementation of this strategy to capture carbon has the potential to reduce current global carbon emissions by as much as 10 % (Woolf et al. 2010).

Co-production of biochar with bioenergy, with its subsequent application to the soil, has been suggested as one possible method to reduce atmospheric CO_2 concentration (Laird, 2008; Fowles, 2007; Lehmann, 2007; Lehmann et al. 2006). Biochar-based bioenergy can reduce the rate of current GHG emissions by fixing atmospheric carbon into the soil, thereby mitigating the problem of global warming in the long term (Campbell et al. 2008). Schmidt et al. (2018) argued that biochar is likely to gain importance in climate policy contexts in the approaching years due to its melding and synergistic applications.

The conversion of biomass carbon to biochar leads to sequestration of about 50% of the initial carbon compared to the low amounts retained after burning (3%) and biological decomposition (less than 10–20% after 5–10 years). Hence, biochar incorporated into agricultural soil can help to mitigate climate change through stable carbon storage and reduction of GHG emissions. Lehmann et al.2009 estimated that up to 4GGT of carbon can potentially be removed per year, which is equivalent to the carbon flux currently created through burning of all fossil fuels (Kong et al. 2014).

2.5.2.4 Biochar Application to Manage Wastes

The management of animal and crop wastes from agriculture poses a significant environmental burden that leads to pollution of ground and surface waters (Carpenter et al. 1998; Matteson and Jenkins, 2007). These wastes as well as other by-products are usable resources for pyrolysis bioenergy (Bridgwater et al. 1999; Bridgwater, 2003).

Not only can energy be obtained in the process of charring, but the volume and especially weight of the waste material is significantly reduced which is an important aspect, for example, in managing livestock wastes (Cantrell et al. 2007). Similar opportunities exist for green urban wastes or certain clean industrial wastes such as those from paper mills (Demirbas, 2002). At times, many of these waste or organic by-products offer economic opportunities, with a significant reliable source of feedstock generated at a single point location (Matteson and Jenkins, 2007).

Costs and revenues associated with accepting wastes and by-products are, however, subject to market development and are difficult to predict. In addition, appropriate management of organic wastes can help in the mitigation of climate change indirectly by decreasing methane emissions from landfill; reducing industrial energy use and emissions due to recycling and waste reduction; recovering energy from waste; enhancing C sequestration in forests due to decreased demand for virgin paper; and decreasing energy used in long-distance transport of waste (Ackerman, 2000).

Strict quality controls must be applied for biochar, particularly for those produced from waste, but also from other feedstocks due to the nature of material and the possibility of contamination by pollutants and other toxic substances. Pathogens that may pose challenges to direct soil application of animal manures (Bicudo and Goyal, 2003) or sewage sludge (Westrell et al. 2004) are removed by pyrolysis, which typically operates above 350°C and is thus a valuable alternative to direct soil application. Contents of heavy metals can be a concern in sewage sludge and some specific industrial wastes and should be avoided. However, biochar applications are, in contrast to manure or compost applications, not primarily a fertilizer, which must be applied annually. Due to the longevity of biochar in soil, accumulation of heavy metals by repeated and regular applications over long periods of time that can occur for other soil additions may not occur with biochar.

2.5.2.4.1 Biochar Application to Manage Municipal Solid Waste (MSW)

Chen D. et al. (2014) recognised MSW to mainly consist of paper, cloth material, yard waste (leaves and branches), food wastes, plastics and a small amount of leather and rubber, metals, glass, ceramic, earthen materials, and miscellaneous other materials. In another research study, Arkham et al. (2016) characterized solid waste into 11 different categories named as kitchen waste, yard trimmings (grass & wood, etc.), paper, diapers, textile, plastic, leather and rubber, metal, bottle, and glass, miscellaneous (ceramic, stone, and soil, etc) and domestic hazardous wastes.

Proportions of waste subjected to pyrolysis mainly include paper, cloth, plastics, and yard wastes. Highly wet food wastes should be separated to reduce the proportions of energy required to eliminate moisture content and consolidate the solid (bio char) output. Panwar et al. 2019 stipulated that the moisture content of biochar feedstock should be < 8% since feedstock with lower moisture content required less energy to convert into biochar (Bridgewater, 2004; Mohan et al. 2006).

Arkham et al. (2016) postulates that the characterization of solid waste is one the most effective steps of solid waste management. It enables the managing authorities to assess the quality, quantity of solid waste generated and evaluate its suitability for various waste treatment processes like composting, biogas, refuse-derived fuel, and landfilling.

Municipal Solid Waste (MSW) is generated by households, commercial and industrial sectors because of the concentration of population and activities in urban areas. However, the potential presence of heavy metals (Zn, Mn, and Cu) in MSW may pose a challenge in its utilization as biochar feedstock (Agblevor, 2007). This point is buttressed by Chen D. et al. (2014) who highlights that products obtained from MSW pyrolysis are likely to be riddled with contamination problems.

Some authors (Hale et al. 2012; Spokas et al. 2011b) have used quantitative and qualitative methods to determine potential organic pollutants in biochar produced from woody feedstock. Also, Hale et al. (2012) showed that biochar may contain substantial amounts of potentially toxic compounds including Polycyclic Aromatic Hydrocarbons (PAH), poly-chlorinated dibenzo-p-dioxins and dibenzofurans, polychlorinated biphenyls, and heavy metals. He counters this by proposing that emission control devices are to be equipped at pyrolysis facilities, and measures for improving the quality of the gas, liquid and char products should be developed to make MSW pyrolysis a more environmentally beneficial process.

While certain heavy metals such as Zn, Mn and Cu, may pose threat to human health, these metals are also important micronutrients needed by crops for proper functioning, therefore feedstock and biochar containing these metals may not necessarily pose a threat to the environment (Yeboah et al. 2022). It is therefore necessary to take into heavy account the pyrolysis temperature of the biochar before their application to the soil. For example, biochar pyrolyzed under temperatures below 300°C are known to be acidic. Under these conditions, most of these elements may not be in available forms when applied to soils.

The other issue worthy of noting is that the application of high pH biochar which has the potential of raising soil pH, also has the potential of precipitating these metals from solution, thereby the application of biochar from MSW may not necessarily affect soils adversely.

Numerous studies have been performed in laboratories to determine pyrolysis behaviours and product properties individual MSW fractions such as paper, plastics, fabric, lignocellulosic materials, and putrescibles (Di Blasi, 1996; Wu et al. 2002, 2003; Wu et al. 2005; Zhang et al. 2008; Zheng et al. 2009; Luo et al. 2010a; Ates. et al. 2013; Miskolczi et al. 2013), Refuse-Derived Fuel (RDF) pellets (Cozzani et al. 1995; Garcia et al. 1995; Lin et al. 1999; Buah et al. 2007; Dou et al. 2007; Grammelis et al. 2009; Bosmans et al. 2013) and real MSW (Islam and Beg, 2004; Islam et al. 2005; He et al. 2010; Luo et al. 2010b; Zhao et al. 2011; Ates et al. 2013; Miskolczi et al. 2013). The interactions between the different individual fractions and the pyrolysis products have also been explored (Williams and Williams, 1997; Williams and Williams, 1999b; Sørum et al. 2001; Grieco and Baldi, 2012; Ding et al. 2013), but not as extensively. Previous studies indicated that the important parameters affecting MSW pyrolysis included temperature, heating rate (HR), residence time in the reaction zone and materials' size.

2.6 Potential for Biochar to Enhance Municipal Waste Management

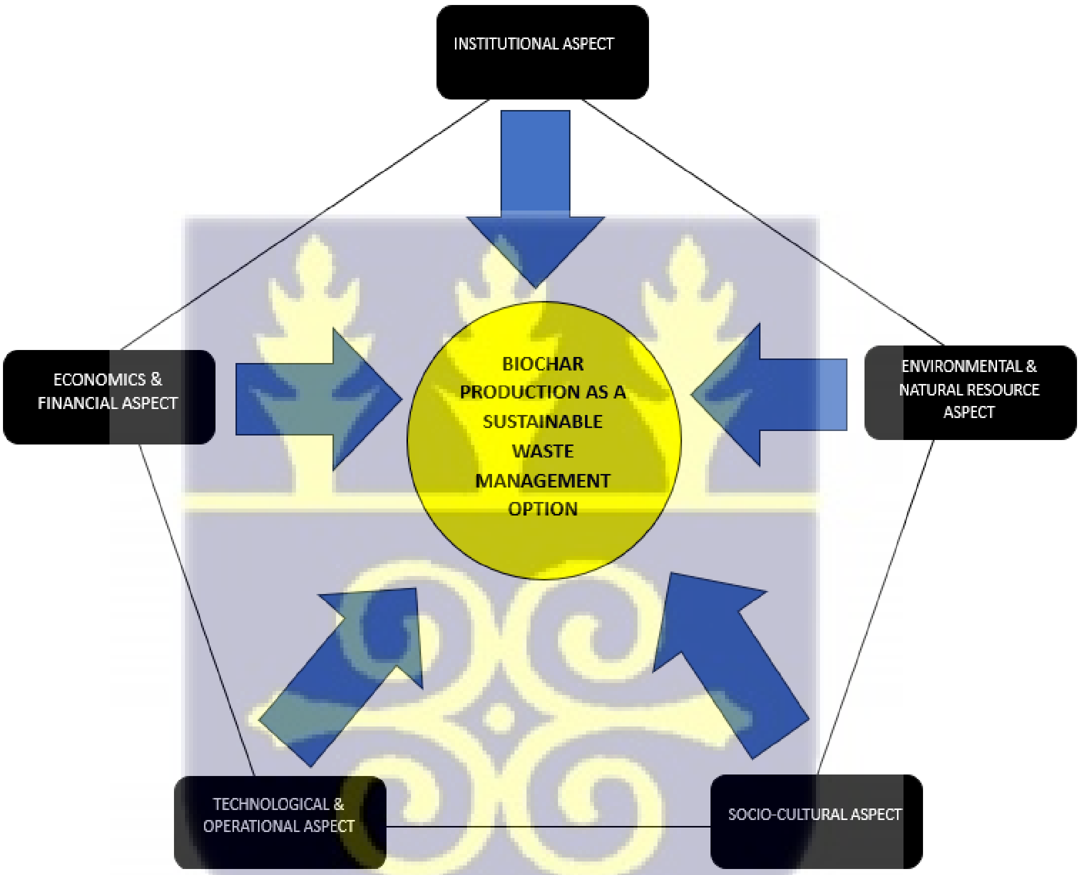
Municipal Solid Waste (MSW) pyrolysis is seen as a cutting-edge alternative for treating MSW, yielding various chemicals and fuels (Schaefer, 1975; Malkow, 2004). This method offers a cleaner energy solution compared to traditional MSW incineration, as it produces lower levels of nitrogen oxides (NOx) and sulfur oxides (SO_2). This is due to the controlled, inert atmosphere during pyrolysis and the ability to clean the syngas before combustion. Additionally, pyrolysis not only reduces gas emissions but also produces higher-quality solid residues compared to conventional MSW treatment methods (Saffarzadeh et al. 2006).

Emerging research on deriving biochar from MSW is generally limited to countries including the USA, Australia, South America, China, and parts of Europe (Gwenzi et al. 2015) with several studies conducted in Ghana having shown great promise in Waste-to-Energy (WtE) production (Duku et al. 2011a; Ofori-Boateng, 2013; Mohammed et al. 2013; Kemausuor et al, 2014; Ulrike et al. 2014; Gyamfi et al. 2015; Danquah et al. 2018; Akolgo et al. 2018; Acheampong et al. 2018), as well as recent studies conducted in developed countries (Gomaa et al. 2020) yet Ghana is has still not realized the biochar potential in coordinated waste management projects (Yeboah et al. 2022).

The primary objective is to evaluate the viability of producing biochar as a sustainable method for managing Municipal Solid Waste.

2.7 Conceptual Framework

The Figure shows the conceptual framework underpinning the study of biochar production as a sustainable waste management option.



Adopted from Firmansyah et al. 2021

Figure 1: Conceptual Framework

The framework has its etymology rooted in the pillars of sustainable sanitation. It focuses on the environmental, economic, technological, socio-cultural and institutional pillars that would underpin the application of biochar production as a sustainable waste management option. It serves as the framework to delineate and network the various pillars of sustainable sanitation and their influence on biochar for waste management. The framework aimed to illustrate the possible linkages and relationships between the mentioned factors and how they collectively influence the consideration of biochar production as a sustainable waste management option.

CHAPTER THREE

3.0 METHODOLOGY

3.1 Profile of the Study Area

This study was undertaken in selected municipalities in the Greater Accra Region which included the Ga East Municipality Ledzokuku Municipality, and La Nkwantanang- Madina Municipality. The profile of these include background, geographical location, economic activities, and waste management practices are presented here. Also presented are the political and administrative features, social, and cultural setup as well as demographic information.

3.2 Greater Accra Region of Ghana

3.2.1 Location and Size

The Greater Accra Region of Ghana was known in 1960 as the Accra Capital District, was geographically and legally part of the Eastern Region and was administered separately by the minister responsible for local government. On 23 July 1982, Greater Accra was created by the Greater Accra Region Law (PNDCL 26) as a legally separate region and including the Ada local council area.

The region houses the Capital city of Accra, is one of the 16 administrative regions in Ghana and is in the south-central part of the country. It shares borders with the Central Region to the west, Volta Region to the east, Eastern Region to the north, and the Gulf of Guinea to the south. It is one of the smallest of the 16 regions, occupying an area of 3,245 square kilometres or 1.4% of the total land area of Ghana.

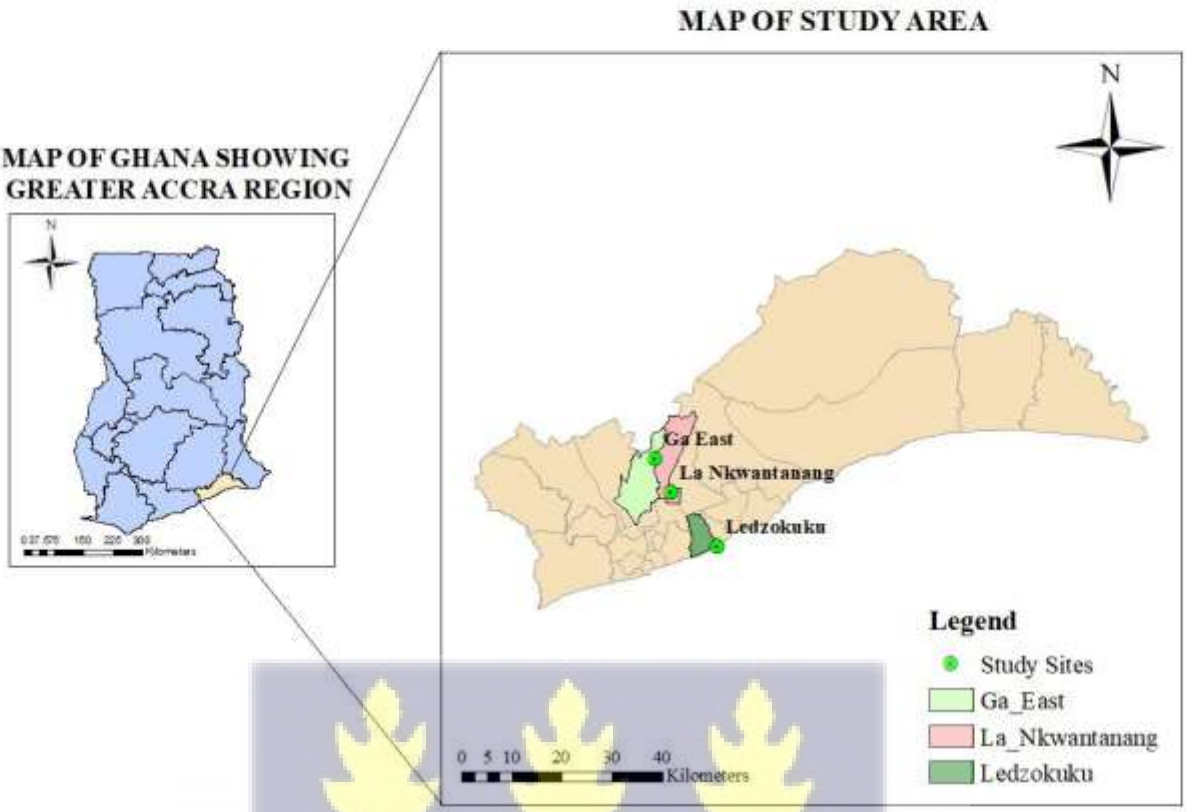


Figure 2: A Map of Greater Accra Region Showing Selected Municipalities considered for the Study

3.3 Selected Municipalities for the Study

Three municipalities in the Greater Accra Region were selected. These municipalities were considered due to the prevalent nature of waste management issues plaguing them. These include the La Nkwantanang, Ga East Municipality, and Ledzokuku Municipalities.

3.3.1 La Nkwantanang Municipality - Madina

The La Nkwantanang-Madina Municipality (LaNMMA) is one of the 29 Metropolitan, Municipal and District Assemblies in the Greater Accra Region and was carved out of the Ga East Municipality in June 2012. The La Nkwantanang -Madina Municipality is located at the northern part of the Greater Accra Region, it covers a total land surface area of 70.887 square kilometers. It is bordered on the West by the Ga East Municipal Assembly, on the East by the Adentan Municipal Assembly, the South by Accra Metropolitan Area and the North by the Akwapim South District.

3.3.1.1 Economic Activities and Source of Livelihood

According to the La Nkwantanang Composite Budget (2024), the main economic activity in the Municipality is trading with Madina market being the main centre for commerce in the Municipality with the market attracting traders across the region. The market is one of the biggest markets in Greater Accra Region and in Accra, ranks only second behind the combined Makola and Agbogbloshie markets. The Market covers an estimated 87,000 m^2 with open markets, stall, shops, parking and other facilities.

Some residents engage in agricultural activities including crop farming, livestock and poultry production, and agro-processing. Major crops cultivated include maize, cassava, chilli pepper, tomatoes, garden eggs, among others. There are fruit farms that cultivate mangoes, pineapples, and watermelon. Livestock cultivation is spread out across the municipality with concentration at Teiman, Ayimensa, Pantang, and Oyarifa. These farms rear cattle, goats, sheep, pigs, and poultry. There are also feed processing factories that produce poultry and pig feed located at Oyarifa and Amrahia. The main ones include Amas Farms and Vida Farms at Oyarifa. A few agro-processing establishments exist in the municipality including Nkulenu Industries located in Madina which process vegetables and fruits on large scale. Gari processing is predominant at Teiman. According to the Municipality's Composite Budget

(2024), alternative livelihoods activities include mushroom, snail production, grass cutter and rabbit rearing.

According to the La Nkwantanang Composite Budget (2024), construction and real estate is one of the key sectors. Real Estates developers have invested heavily in the Municipality over the past few years, building housing units in places such as Pantang, Danfa, Adoteiman, Teiman, Oyarifa, etc. Also, there is a service sector which is dominated by banking, hospitality, personal care and beauty, telecommunications, graphic design, professional services among others. There are 18 commercial banks, 4 rural banks and 10 micro-finance institutions. With respect to Telecommunication and Postal Services, the Municipality has 1 operational Post Office in Madina. With regards to the media landscape, the Municipality is host to 2 TV stations and 2 Radio stations.

The Municipality is linked by road to other parts of Accra and the rest of the country. Commercial transportation by vehicles, taxis and other transport vehicles provide employment for drivers and mechanics. There are several business associations in the Municipality, which include market women's associations, drivers' associations, farmer groups, dressmakers and beauticians' associations.

3.3.1.2 Waste Management

According to the La Nkwantanang Composite Budget (2024), the Municipality generates approximately 125.938 metric tonnes of waste daily comprised of household and industrial waste. The bulk of waste is generated in the Central Business District and market areas.

The Municipality's Composite Budget (2024) states that the Municipality has been divided into 9 zones which are administered by 9 Waste Management Contractors for the management of wastes. Private Waste Collection Companies collect 81% of waste generated in the municipality. Out of the 36,241 households, 26,435, representing 73% of the households are registered with an accredited waste contractor for door-to-door waste collection with a total of 205,528 metric tonnes of waste being generated daily.

3.3.2 Ledzokuku Municipality

According to the Ledzokuku Municipal Assembly Composite Budget (2024), the Municipal Assembly was formed on November 1, 2017, under Legislative Instrument (LI 2319). It is bordered to the south by the Gulf of Guinea, to the east by Krowor Municipal Assembly, to the north by Adentan and Ayawaso West Municipal Assemblies, and to the west by La Dade-Kotopon Municipal Assembly. Teshie serves as the capital of the municipality. The Municipal Assembly includes two zonal councils: Tsuibleoo and Lascala Zonal Councils.

To further deepen decentralization in the country, new Municipals were created in the nation and Ledzokuku Municipal Assembly was among the new Municipals. Currently the total number of electoral areas in LeKMA is 12, namely, Tsuibleoo Central, Akromadeokpo West, Nii Ashietey Akomfra, Akromadeokpo, Tsuibleoo South, Akosekor, Sutsurunor, Teshie-Nungua North, Teshie-Nungua South, Agblezaa, Tsuibleoo North and Aborle electoral areas (Ledzokuku Composite Budget, (2024)).

3.3.2.1 Economic Activities and Source of Livelihood

The Municipality has an area of 35.6sq km and population density of 6,102/km^2. The geographical position of the municipality has attracted both foreign and local investors that have established companies, industries, financial institutions, real estates like Airport Hills and shopping malls such as Accra Mall and International Mall. These institutions contribute a lot to the Assembly's Internally Generated Funds as well as provide employment for most of the inhabitants (Ledzokuku Composite Budget, (2024)).

The Municipality's Composite Budget (2024) stated that the major agricultural activities in the Municipality are crop farming, livestock and poultry production, fishing and other alternative sources of livelihood like grasscutter, rabbit and mushroom production as well as agro processing. Due to inadequate arable lands, the nature of farming in the Municipality is mostly backyard, vertical farming and small scale because the average land area per farmer is about 0.5 acre.

3.3.2.2 Waste Management in Ledzokuku Municipality

The Assembly has collaborated with three Waste Management contractors to manage door-to-door collection of all the 200 tonnes of waste generated per day (Ledzokuku Composite Budget, (2024)).

According to Population and Housing Census (2010), The two most prevalent methods for disposing of solid waste (refuse) are dumping it in a container (49.8%) and having waste collected from households (27.4%). Other disposal methods include burning (12.0%), using public dumps (7.5%), and burying it (0.5%). Additionally, 1.1% of households dispose of solid waste indiscriminately.

In the Ledzokuku Municipality, the main method of liquid waste disposal is throwing it into a gutter (33.6%). Other methods include disposing of it in the compound (22.0%), directing it through a drainage system into a gutter (16.5%), throwing it onto the street or any outdoor area (16.3%), and using a drainage system to empty it into a pit or soakaway (4.1%). It is important to note that only 6.3% of housing units are connected to a central sewage system (PHC, 2010).

3.3.3 Ga East Municipality

According to the Ga East Municipal Assembly Composite Budget (2024), the Municipality is situated in the northern part of the Greater Accra Region and is one of the 29 metropolitan, municipal and district assemblies within the Greater Accra Region, covering an area of about 97 square kilometers.

The capital of the municipality is Abokobi and is bordered by the Ga West Municipality to the west, La-Nkwantanang Municipality to the east, Ayawaso West Municipal Assembly to the south, and Akwapim South District to the north. The municipality is divided into two administrative areas: the Abokobi Zonal Council and the Dome Zonal Council. Some of the notable towns in the urban areas include, Abokobi, Agbogba, Haatso, Papao, Westlands, Dome, Taifa, Kwabenya, Ashongman, Ablor-Adjei and Dome Pillar 2. Some peri-urban areas are Boi, Sesemi, Adenkrebi, Kponkpo, Adjako and part of Teiman.

3.3.3.1 Economic Activities and Source of Livelihood

According to the Ga East Municipal Assembly's Composite Budget (2024), 1.14% of the economically active population are engaged in agriculture in the district with the rural population depending on agriculture as their primary source of livelihood with 95% of rural dwellers being small holders. Major agricultural activities include crop production, poultry and livestock production. Livestock reared include sheep, goat and dairy cattle while pigs and other micro livestock like grasscutter and rabbits are also reared.

The Ghana Poultry Project (GPP) has promoted livestock production in the municipality resulting in the formation of vibrant Famer Groups and Associations. The Groups, which are into livestock, are Poultry, Grasscutter and Sheep groups. However, the accessibility to arable farmlands has been a great challenge due to rapid urbanization of the district (Ga East Municipal Assembly Composite Budget, 2024).

To improve food security within the municipality, the Department of Agriculture in collaboration with the West Africa Agriculture Productivity Programme (WAAPP) has made efforts to encourage farmers to produce crops in greenhouses. The success of this will reduce the effect of the harsh weather conditions, pests and diseases on crop development and thus increase crop production. Crops such as tomatoes and cucumber have been cultivated successfully within plastic houses.

Alternative livelihoods production has also been encouraged especially among the youth. This ranges bee keeping, snail farming, mushroom, grasscutter and rabbit rearing. The idea is to supplement people’s basic income and improve the living conditions of people living within the municipality.

3.3.3.2 Waste Management in Ga East Municipality

The Ga East Municipality faces issues with its waste generation. Rapid urbanization and the increased influx of people in the municipality has resulted in huge amounts of solid waste being generated. It is estimated that about 77,745 tons of waste is generated per annum, out of which 75% is collected (Ga East Municipal Assembly Composite Budget, 2024). This leaves a substantial bottleneck that creates several inconveniences including health hazards to people living in the Municipality.

According to the Ga East Municipal Assembly Composite Budget (2024), there are 23 waste collection companies in the Municipality assigned areas to collect waste on a door-to-door basis at a fee paid to the companies. However, the absence of a properly engineered final disposal site has been a major setback since the closure of the Pantang Landfill site 4 years ago.

There is still the indiscriminate disposal of solid waste in the municipality. People dump rubbish into gutters and during rainfall and into nearby bushes. There is the influx of tricycle waste collection dotted all over the municipality. The practice of these riders is fueling the sanitation menace.

3.4 Justification of Study Areas

The selection of La Nkwantanang-Madina, Ledzokuku, and Ga East Municipalities as study areas highlighted by shared key commonalities. These include rapid urbanization, high population densities, and mounting challenges in Municipal Solid Waste (MSW) management. All three municipalities are part of the Greater Accra Region—Ghana's most urbanized region and experience significant commercial, residential, and industrial activities that contribute to increasing volumes of solid waste generation.

A key similarity across the three municipalities is the high volume of daily waste generated:

La Nkwantanang-Madina produces approximately 125.938 metric tonnes of waste daily, Ledzokuku generates 200 tonnes per day, and Ga East generates 77,745 tonnes annually (approx. 213 tonnes daily).

All three areas reported significant strain on existing waste management systems. Each municipality relies heavily on private contractors for door-to-door waste collection, yet face challenges with indiscriminate disposal, lack of proper final disposal sites, and low levels of waste segregation or recycling. For example, In LaNMMA, although 73% of households are registered with waste contractors, informal dumping still occurs. In Ledzokuku, residents still engage in open dumping, burning, and indiscriminate disposal, with only 6.3% of housing units connected to central sewage systems. Ga East suffers from illegal dumping in gutters and bushes, exacerbated by the closure of the Pantang landfill and a rise in unregulated tricycle waste collectors.

Moreover, all three municipalities exhibit common socio-economic patterns such as high dependence on trade, agriculture, and services, alongside growing real estate and infrastructure development—factors that contribute to increased waste generation without a corresponding robust waste management strategy or increase in waste handling capacity.

These shared characteristics and challenges made the three municipalities ideal areas for the study.

3.5 Sample Size Determination

A total of 280 respondents, comprising heads of households, were selected for the research study. These households were in select communities identified as experiencing significant challenges related to waste management. The selection of these areas was based on observable indicators such as inadequate waste collection services, frequent accumulation of uncollected waste, limited access to formal disposal facilities, and reported environmental and health concerns associated with poor waste handling practices.

The sample size was sub-divided nearly equally amongst the three communities to minimize any significant influence one community's respondents' responses would have on the results and analysis. Another reason this was done was to allow the researcher to be able to cross-reference and analyse the varying responses from each of the communities and how each community's response was comparable or varied from the other. This was used to ensure balanced representation and comparability across subgroups in a study population. It helped reduce sampling bias and improves the precision of overall estimates by controlling variability within subgroups.

The study used this sample size because it was large enough to cover an extensive portion of inhabitants from each of the selected communities. Yamane's formula (Yamane, 1973) was used in determining the sample size because of its applicability in permitting for inferences and conclusions to be drawn to the complete population from which the sample population was drawn.

The formula:

$$n = \frac{N}{1 + N(e)^2}$$

Where:

n= corrected sample size, N = population size, and e = Margin of error (MoE), e = 0.05 based on the research condition.

3.5.1 Sampling Technique employed in the Study

The target population for the study consisted of heads of households within selected communities known for their waste management challenges. Heads of households were specifically chosen to ensure more informed and representative responses, as they are typically responsible for overseeing household decisions, including those related to waste disposal. This selection also allowed for greater variability in responses, as individual household heads may adopt different practices and attitudes despite common community-level behaviors.

The random sampling technique was used. This reason for random sampling was to avoid any bias when selecting households to participate in the research study. The purposive sampling technique was also deployed in the study. This sampling technique is a non-probability sample used based on the study characteristics. It is also known as selective, judgmental, or subjective sampling, which is a form of unlikely sampling in which scientists depend on their own judgement when selecting population members to engage in the research. The use of the purposive sampling is to access select groups with a specific criterion.

According to the Ghana Population and Housing Census (PHC, 2021) the number of households in the selected areas for study (Abokobi, Madina and Teshie) totalled 242,831 households. That is 90,835 for Abokobi, 79,614 for Madina, and 72,382 for Teshie. Inputting this figure into Yamane's formula gives us 400 respondents. About 70% of the respondents would be considered, bringing the final number of respondents to 280 respondents considered for the study.

Although Yamane's formula suggested a sample size of 400 respondents, a target of 280 was selected due to logistical and resource constraints. These constraints included limited funding, time restrictions for data collection, and the availability of the researcher to personally administer questionnaires across multiple communities. Additionally, transportation challenges and the dispersed nature of the selected municipalities made it difficult to access certain areas efficiently. While a larger sample could potentially enhance the statistical reliability of the findings, the reduced sample size was considered adequate to ensure representativeness and support meaningful analysis within the scope and practical limitations of the study.

3.5.2 Data Collection

The household target group for data collection for the study included lower-to-middle-income class households living in select communities within the three chosen municipalities. Selected communities included Madina, Teshie, and Abokobi. These communities are also characterized by mixed land use, inadequate infrastructure, and fragmented development. The combination of these factors has usually linked communities to disjointed waste management practices with some households opting to dispose of waste materials at dump sites, bury or burn their waste. The combination of these further buttressed the justification for these communities' selection for this study.

Printed out questionnaires containing both open and close-ended questions were administered to both key informants situated at relevant institutions and agencies, and respondents (heads of households) considered for the study. This was done to collate responses of all respondents considered for the study. An interview format was used in data collection to provide a suitable and comfortable means for both key informants and household respondents to freely express themselves.

Table 1: Sample Size Distribution according to the Selected Communities

Municipality-Community	Percentage (%)	Corresponding Population
Ga East - Abokobi	34	94
La Nkwantanang - Madina	33	93
Ledzokuku-Krowor- Teshie	33	93
Total	**100**	**280**

3.6 Data Analysis

The study involved both quantitative and qualitative research methods that sought to examine biochar production as a sustainable means of managing Municipal Solid Waste. The study sought to examine respondent's attitudes, knowledge predispositions, and their willingness to accept biochar production for waste management. As such, qualitative data was studied under the focus thematic areas, quoting respondents where necessary.

The quantitative data was processed, checked for consistency and totality, and then inputted into data analysis tools; Microsoft Excel and Statistical Package for Social Sciences (SPSS). Descriptive statistics including bar charts and frequency distribution tables was used to analyse response of respondents. Qualitative data from open-ended questions from questionnaires was analysed under the thematic areas by representing information provided in the form of quotes written verbatim.

The phenomenological analytical model was further examined in the study with the focus of examining the applicability of biochar production as a sustainable means to manage Municipal Solid Waste. The research sought bridge public perception and interpret their individually unique insights. This was achieved through in-depth interviews and reflective analysis with respondents.

CHAPTER FOUR

4.0 RESULTS

This chapter presents the findings for the study. Quantitative data analysis in the form of frequency tables with their adjoining interpretations, alongside qualitative data were used. The data presented was collected from key institutions responsible for waste management and environmental protection within the region, as well as the study areas of Abokobi, Madina and Teshie.

4.1 Demographic Characteristics of Respondents

This research focused on information from key informants heading purposively selected institutions of relevance to the study, as well as Heads of households within the study communities with waste management issues were also interviewed. Respondents provided their age, occupation, marital status, income range, and waste management behaviours were to provide necessary context for the research data analysis. The researcher implemented this approach to provide a generalized overview of the households considered for the study.

Abokobi recorded 34% of the sample size, representing ninety-four respondents, whilst 66% representing ninety-three respondents each for Madina and Teshie. It is critical to note that these communities account for three of the main communities with waste management challenges.

Table 1: Age of Respondents

AGE OF RESPONDENTS		
Age Group	Number of Respondents	Percentage of out 100%
21-40	118	42.1%
41-59	104	37.1%
60 and Above	58	20.7%

Table 2: Education Level of Respondents

LEVEL OF EDUCATION		
Educational Level	Number of Respondents	Percentage out of 100%
BASIC SCHOOL	53	18.9%
HIGH SCHOOL	99	35.4%
DIPLOMA/HND	56	20.0%
UNIVERSITY DEGREE	39	13.9%
NO FORMAL EDUCATION	33	11.8%

Table 3: Employment Status of Respondents

EMPLOYMENT STATUS		
Employment Status	Number of Respondents	Percentage out of 100%
EMPLOYED	274	97.9%
UNEMPLOYED	6	2.1

Table 4: Occupation of Respondents

OCCUPATION TYPE		
Occupation	Number of Respondents	Percentage out of 100%
ARTISAN	44	15.7%
PUBLIC/CIVIL SERVANT	61	21.8%
TRADER	93	33.2%
FARMER	32	11.4%
SELF-EMPLOYED	43	15.4%
OTHER	7	2.5%

Table 5: Marital Status of Respondents

MARITAL STATUS		
Status	Number of Respondents	Percentage out of 100%
MARRIED	111	39.6%
WIDOWED	25	8.9%
SINGLE	100	35.7%
DIVORCED	44	15.7%

Table 6: Number of Children of Respondents

NUMBER OF CHILDREN BY RESPONDENTS		
Number of children	Number of Respondents	Percentage out of 100%
NONE	107	38.2%
ONE	55	19.6%
TWO	61	21.8%
THREE	33	11.8%
ABOVE THREE	24	8.6%

Table 7: Religion of Respondents

RELIGION		
Religion	Number of Respondents	Percentage out of 100%
CHRISTIANITY	205	73.2%
ISLAM	65	23.2%
TRADITIONAL	8	2.9%
OTHER	2	0.7%

Tables 1-7 show the distribution of background characteristics of the two hundred and eighty respondents under various criteria such as age, occupation, marital status, employment status, religion, among others.

Findings from Table 1 indicate that most respondents were within the working class; that is between the ages of 21 and 59 years of age (79.2%). With the 21–49-year group contributing 42.1% whilst the 41–59 year-group contributed 37.1%. Findings show similarities among the three communities, recording 73 respondents within the working age group, Madina recording 71 respondents, and Teshie recording 78 respondents. This shows that all three communities from the respective communities have high populations of respondents in the working class.

In terms of employment status, 97.9% of respondents being employed, while 2.1% were not engaged in any form of employment. Employment had 33.2% into a trade, 21.8% as public servants, 15.7% were employed as artisans, 15.4% engaged in self-employed menial jobs and 11.4% engaging in farming activities.

Table 4 showed the distribution under the major occupation types, with trading recording 25, 36, and 32, for Abokobi, Madina and Teshie respectively. Other occupations like public/civil servants recorded 21.8% and artisans recorded 15.7% of occupations of respondents.

With regards to marital status, of the 280 respondents involved in the study, 39.6% were married, 15.7% were single, 8.9% widowed and 15.7% divorced from their spouses. The distribution went on to show that 38.2% of households had no children, 19.6% having one child, 21.8% having two children and 20.4% of households had three children or more.

From Table 2, respondents' level of education showed High School education recorded 35.4% with 99 respondents attaining high school education, 20.0% (56) of respondents acquiring a Diploma certificate, and 18.9% accounting for 53 respondents attained basic school education.

It can be deduced from the data on the ages of the respondents that the majority were within the active working class (79.2%), 97.9% of the 280 respondents were gainfully employed, and 88.2% of respondents had received some form of education throughout their lives.

4.2.1 Household Waste Management Behavioural Patterns

Household respondents were engaged on their waste management practices during field engagements by the researcher. The reason for enquiring on this was to understand waste management and disposal behavioural practices of respondents and how it could influence any policy developments that would involve converting MSW into a resource.

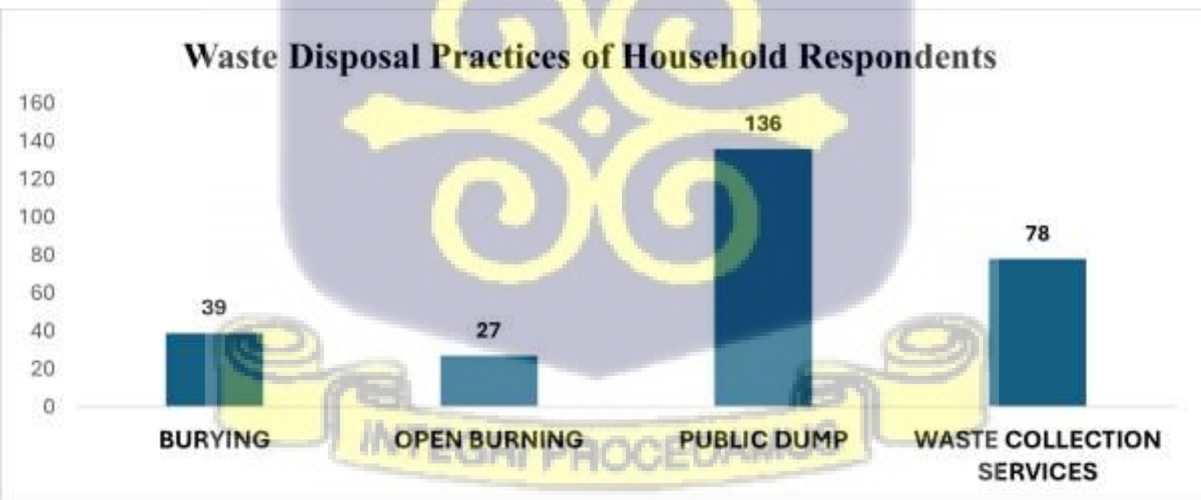


Figure 3: Distribution of Waste Disposal Practices of Households

Figure 3 shows that the most popular waste disposal practice was resorting to public dump indicated by 136 of all respondents. This was followed by waste collection services which recorded 78 respondents.

Even though respondents lived in rapidly urbanizing area, the researcher recorded open burning and burning as waste management options that were practiced by respondents. Burying and Open burning accounted for 39 and 27 respondents respectively. This showed the evident inadequacy of current waste management services that were provided in these communities.

Another waste management practice considered during the field research was the segregation of waste. This was seen as relevant because this criterion would help determine the need for community sensitization and the fortification of waste management services to provide the needed infrastructure to collect separated wastes.

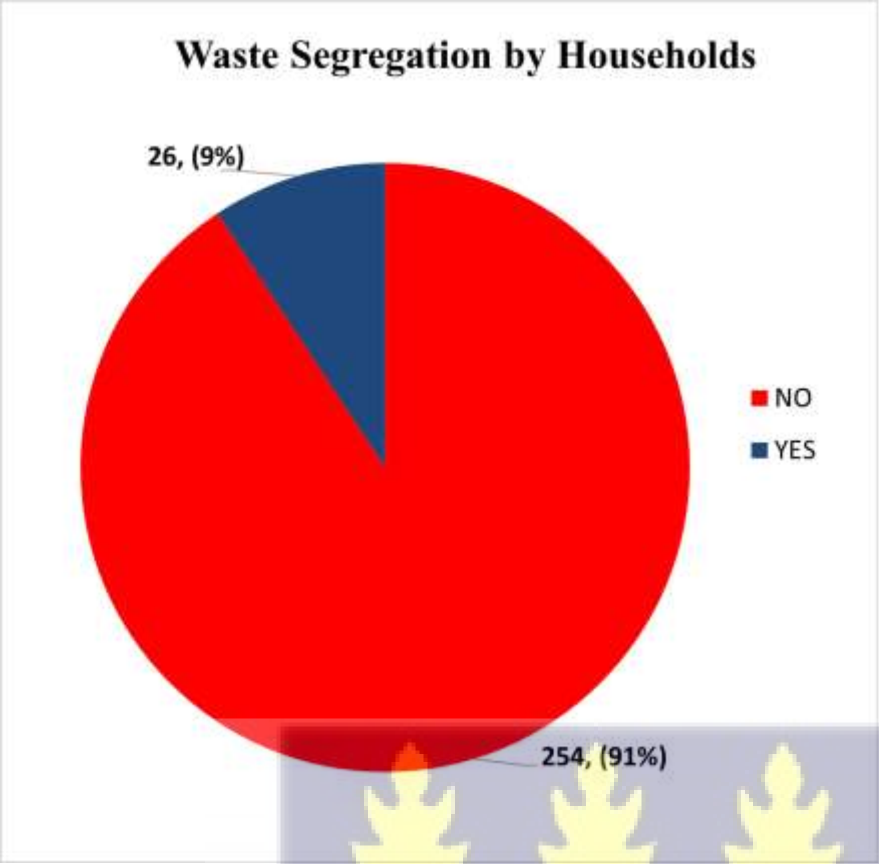


Figure 4: Percentage of Respondents that Practiced Waste Segregation

Figure 4 shows that 91% of respondents did not partake in waste segregation for several reasons. Some which included the fact that "they did not see the need to do it" said one respondent. Another respondent admitted "I used to separate my waste, but the waste collectors come and pile all the wastes together so what is the point?"

Only 9% translating to 26 respondents admitted to still separating their wastes with one respondent stating that they supply their wastes as feed for farm animals whilst another says plastic collectors come around and take their plastic wastes periodically.

4.3 Environmental Issues Related to Biochar Production

This sub-section sought to satisfy the research question, "What are the environmental issues related to biochar. It also looked to determine biochar awareness among key informants.

Data showed that amongst key informants, 8 out of 9 were aware of biochar with only 1 respondent not aware of biochar. This is shown in Figure 5.

Responses from the key institutions were recorded and considered for the section. Certain keywords were recorded and highlighted while engaging key informants. These are illustrated in Figure 6.

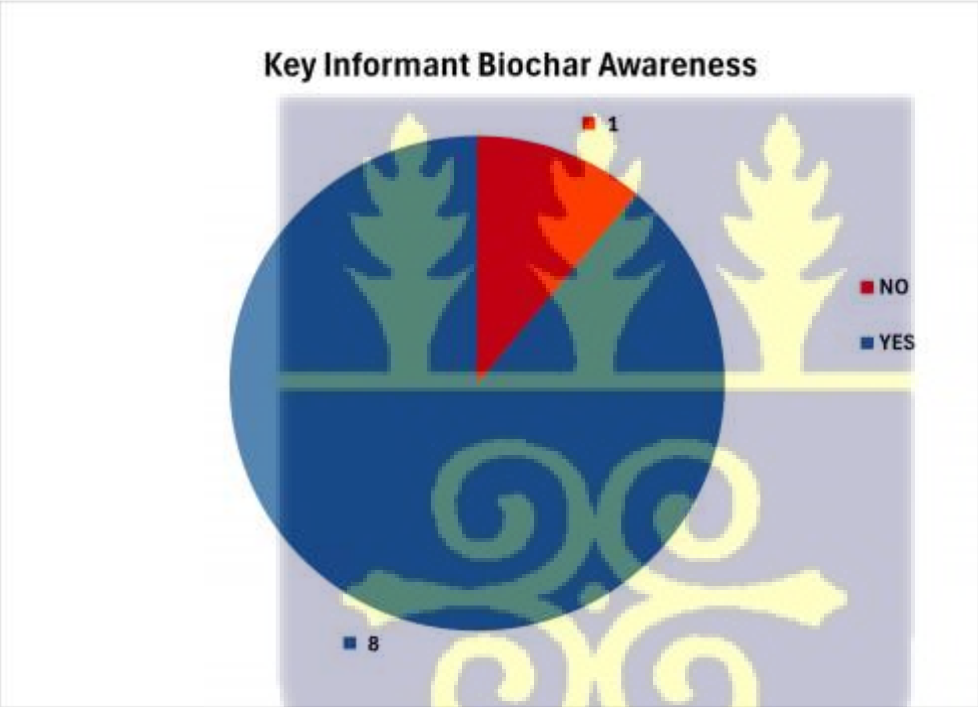


Figure 5: Awareness of Biochar among Key Informants

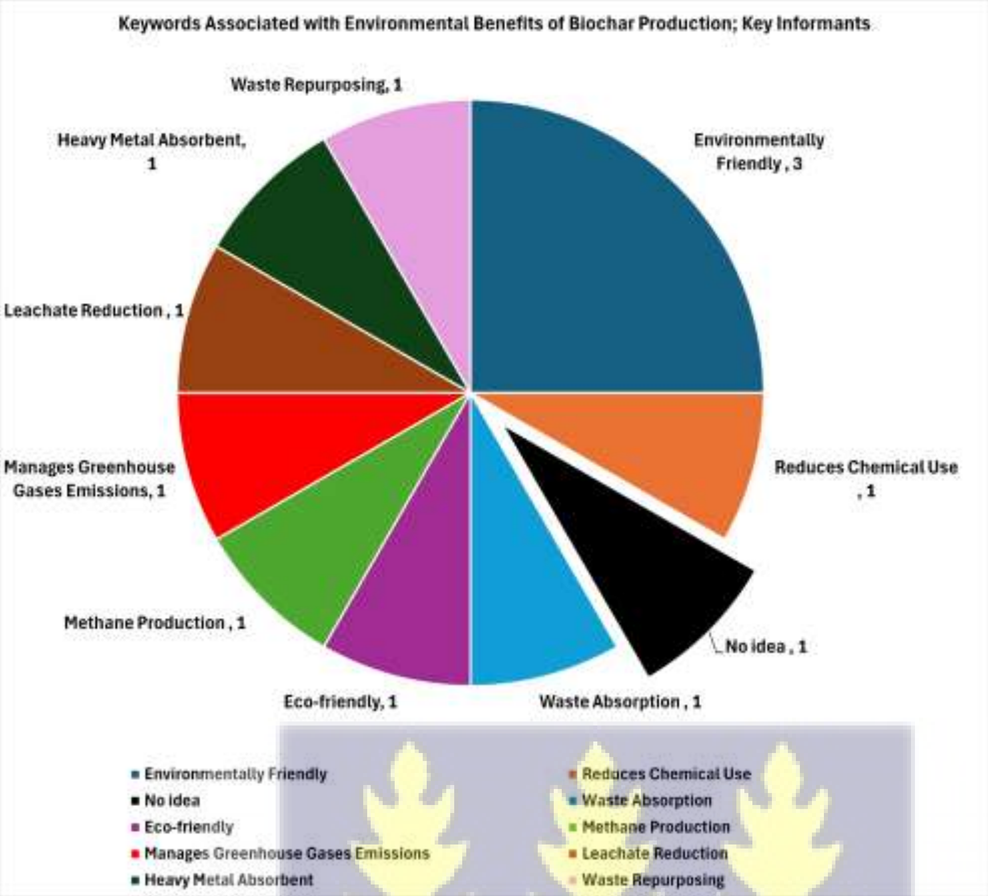


Figure 6: Environmental Benefits of Biochar Production according to Key Informants

Amongst the key informants, 8 informants admitted to being aware of biochar with 3 informants associating the technology as beneficial to the environment. One respondent associated its environmental benefits with waste absorption, while one other respondent associated biochar with reduction in the use of chemicals in managing wastes. A respondent admitted to having no idea how the innovation could benefit the environment whilst 1 respondent mentioned that it provided an opportunity for the repurposing of waste to be reused instead of the "business-as-usual approach" of collecting, aggregating and dumping of waste at landfill and dump sites.

An informant admitted that biochar allowed for the management of greenhouse gases, reduced leachate seeping into the soil and fluvial bodies, and encouraged methane production. A respondent alluded to its benefits with regards to soil restoration and revitalization and soil enhancement.

Based on the responses collected it was evident that the consensus of informants was aware of the potential benefits that were to be reaped from using biochar production as a sustainable MSW management intervention.

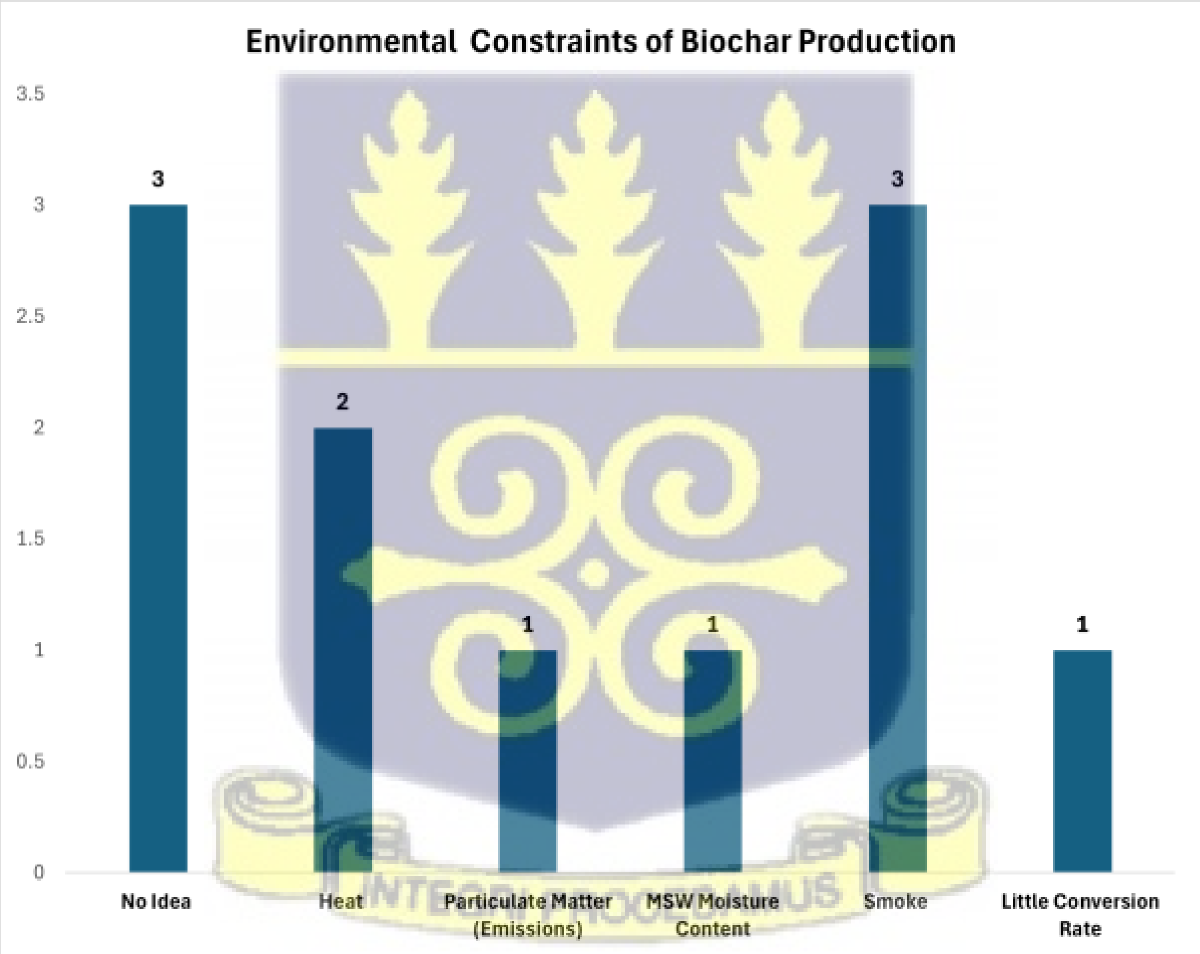


Figure 7: Environmental Constraints of Biochar Production According to Key Informants

Eight informants expressed wary of some of the environmental constraints that posed a stumbling block for biochar production. A respondent expressed concern about the emissions in the form of particulate matter that would possibly be ejected into the environment, whilst another respondent spoke about the rather high moisture content.

Also 3 respondents alluded to having no idea of the constraints that could impede the production process.

4.4 Analysis of the Socio-Cultural Acceptability of Biochar Use

This section focused on the socio-cultural acceptability of biochar production as a waste management option. It considered two major groups in the study. The first being the public acceptability from the perspective of local communities who produce MSW and key informants manning various institutions of interest regarding waste management and issues relating to waste governance.

The section sought to answer the research question; How does public knowledge and attitudes about biochar production influence their willingness to accept it as a waste management strategy?

4.4.1 Analysis Public Acceptability of Biochar Production.

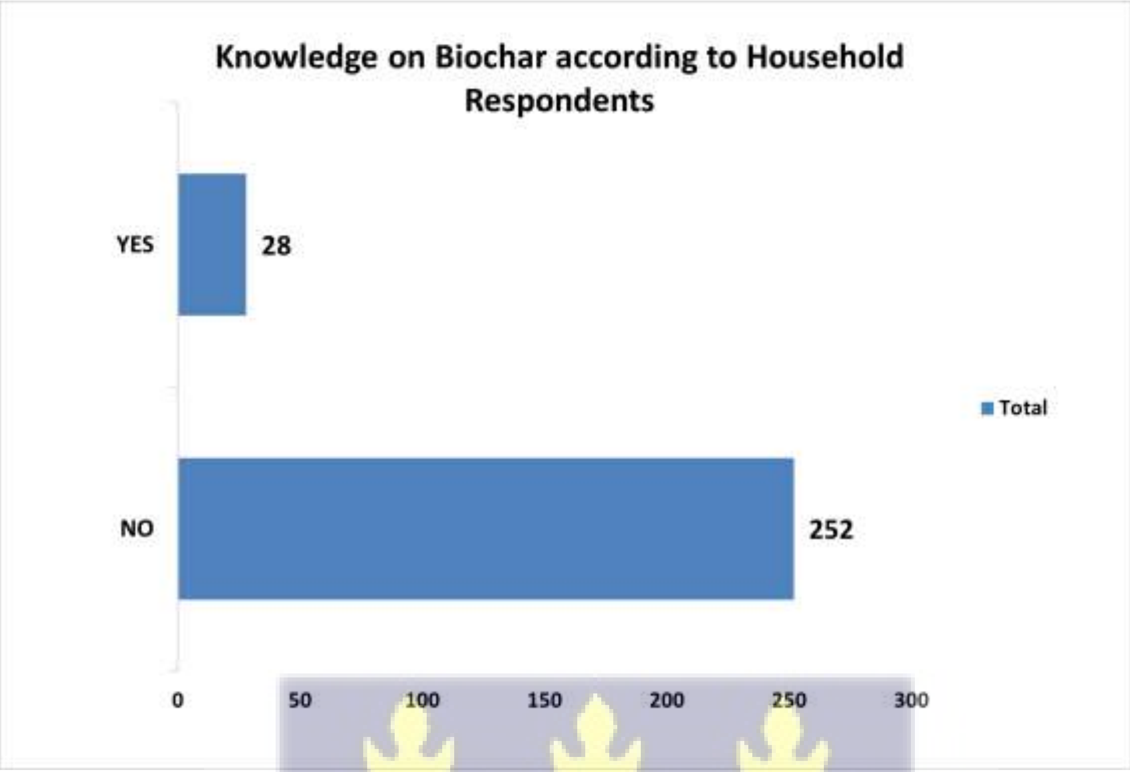


Figure 8: Knowledge on Biochar from Household Respondents

Figure 8 shows that biochar was not a common concept in local communities with most respondents from households either being very unfamiliar, and unfamiliar with the concept. This translated to 252 of all respondents having no knowledge on biochar with 28 of respondents having some idea of the technology.

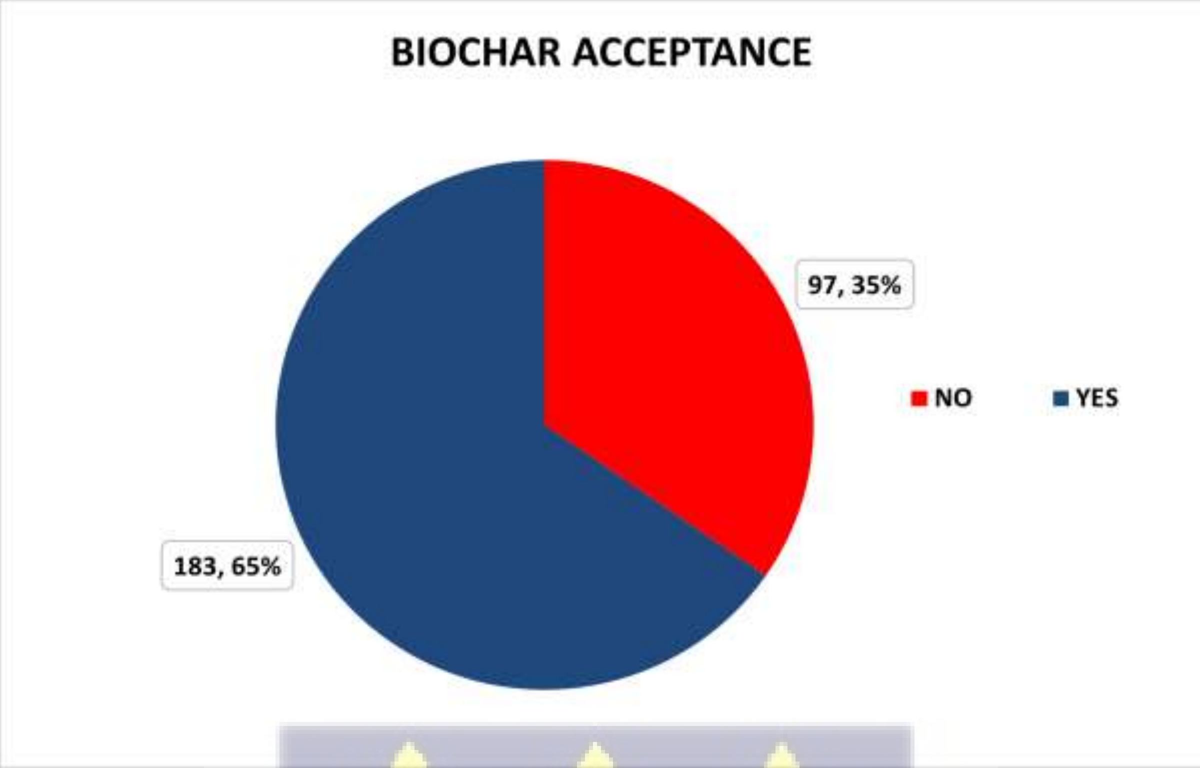


Figure 9: Acceptance of Biochar According to Household Respondents

Data collected showed that even though there was little to no knowledge of the concept by respondents, they were still interested in accepting it. Common responses positively giving the nod to biochar included the unsatisfactory and inconsistent nature of waste collection by waste management services, pungent smell that contributed to air pollution, rodent and pest infestation in and around dump sites and the unsightly nature of overflowing public dump sites. The problem of MSW management had been a topical issue that household respondents believed was causing disrepute in their communities. These portion of households that were willing to accept biochar contributed 65% of all responses collated. Any solution to resolving it would be more than welcome.

However, 35% respondents opposed the use of biochar; raising concerns about converting "garbage" into biochar due to the nature of the materials disposed. Responses from the 35% of respondents varied from respondents satisfied with their current waste management practices, while other respondents showed no interest in the alternative waste management approach.

With regards to the existence of social issues regarding the use of biochar to manage MSW streams the below figure showed that key informants were aware of certain socio-cultural issues associated with biochar.

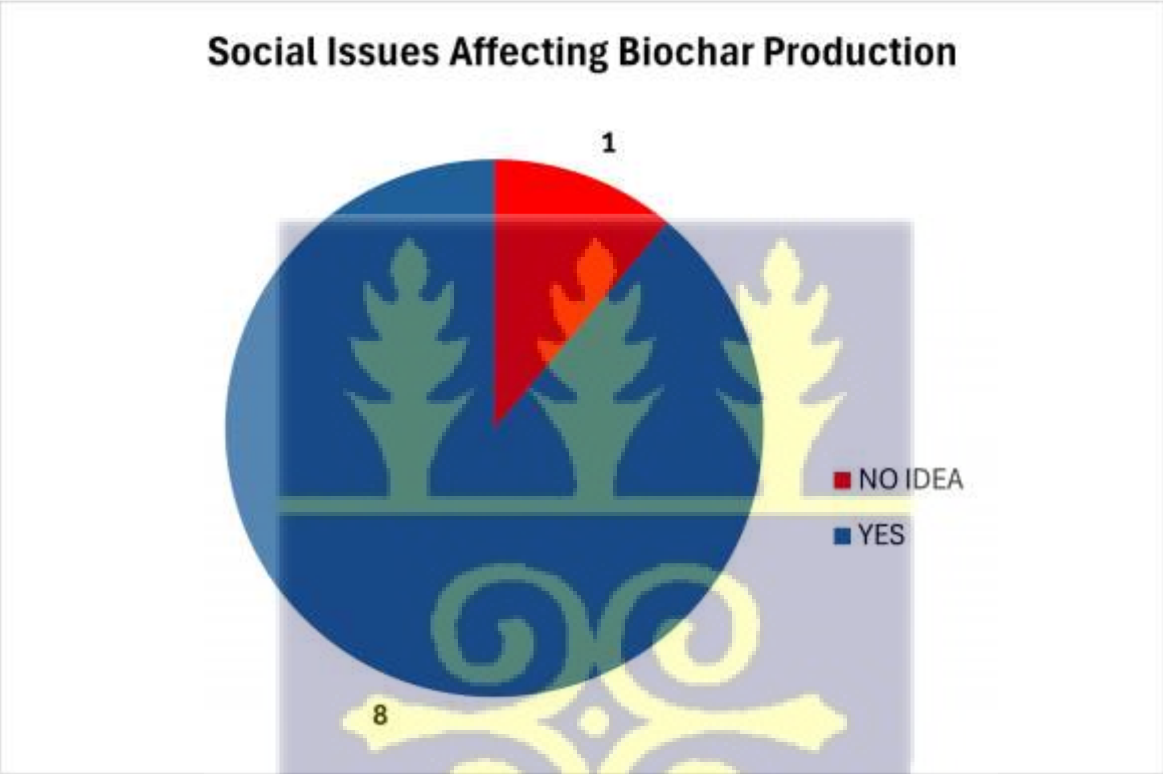


Figure 10: Social Issues that would Positively/Negatively Affect Biochar Production according to Key informants

Figure 10 indicates that one respondent admitting to having no idea of possible social issues that would positively or negatively affect biochar production. One the other hand, 8 respondents commented that they believed there were certain social issues that could positively or negatively affect biochar production in the country.

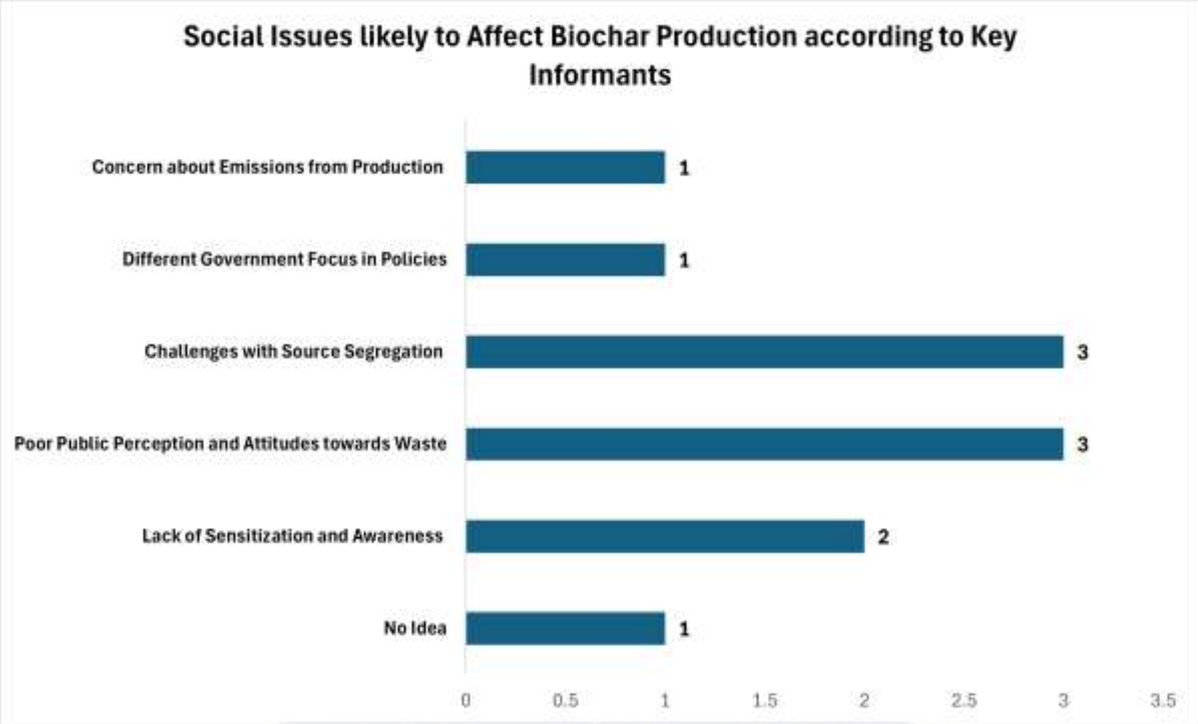


Figure 11: Social Issues likely to Affect Biochar Production according to Key Informants

Figure 11 shows the distribution of social issues likely to affect (positively or negatively) biochar production. Both challenges with source segregation and poor public perception and attitudes recorded the highest number of responses with 3 each. The lack of sensitization and awareness about wastes and biochar production recorded 2 responses whilst different government focus in policies and concerns about emissions and production process both recorded 1 response each. Also 1 respondent said they had no idea of any social issues that would likely affect biochar production.

4.4.2 Biochar as an Acceptable MSW Management Intervention

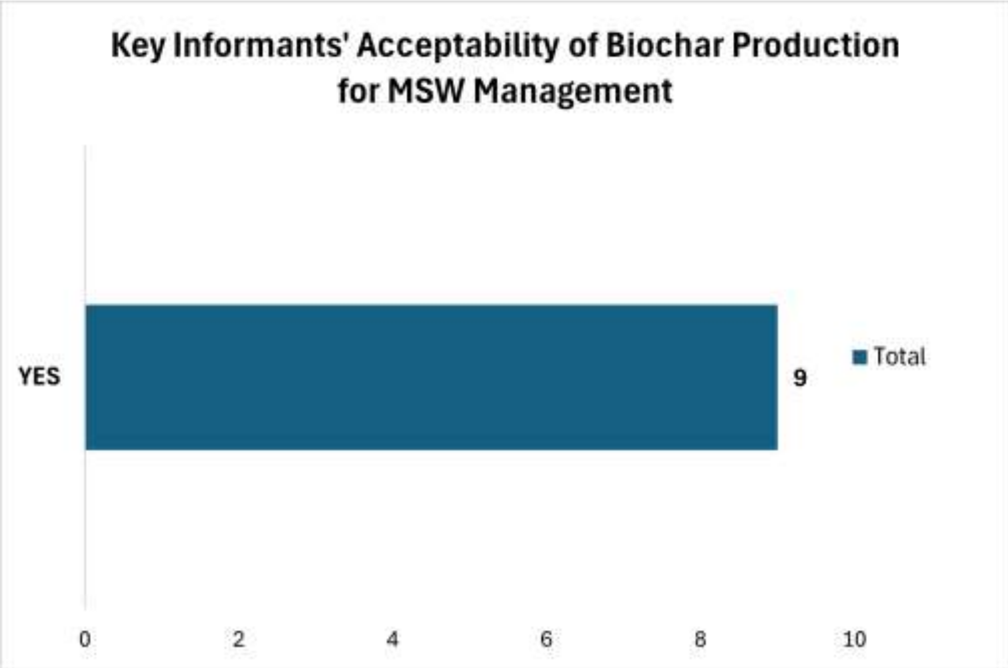


Figure 12: Biochar Production Acceptability for MSW Management

The question of biochar production as a sustainable option for MSW was posed to key informants. All respondents agreed that it should be considered by policy and decision makers as a sustainable waste management option in Ghana.

4.5 Institutional Issues hindering Biochar Production to Manage Municipal Solid Waste

This section focused on the institutional pillar; targeting purposively selecting institutions that could provide any information about possible institutional issues that could hinder biochar production as a sustainable Municipal Solid Waste (MSW) management option. The overarching question that underpins this objective was to understand if there were any policy or frameworks that consider the application of biochar production to manage Municipal Solid Waste volumes?

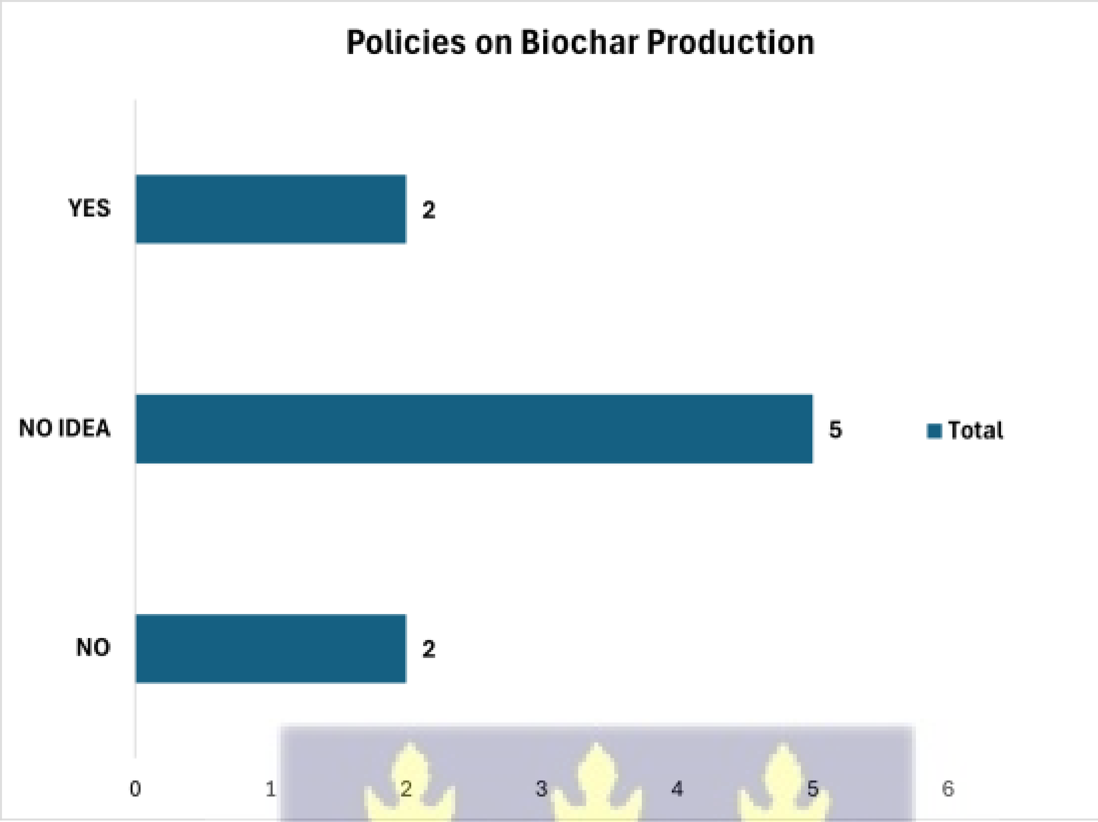


Figure 13: Existence of Policies Governing Biochar Production according to Key Informants

Figure 13 shows that when respondents were asked about the awareness of any policies surrounding biochar for waste management, 5 admitted to not knowing any policies surrounding biochar to manage Municipal Wastes. Two respondents stated “Yes” there is a policy document they know about. However, 2 respondents admitted to having no idea of any policies surrounding biochar production.

4.6 Financial Viability of deploying Biochar Production

This section looked at the financial viability of biochar production as a waste management option and sought to answer the question of potential industries and sectors that would benefit from its production. In pinpointing specific industries, a further case can be drawn to justify its production and thereby linking academia to business which further feeds the larger industry.

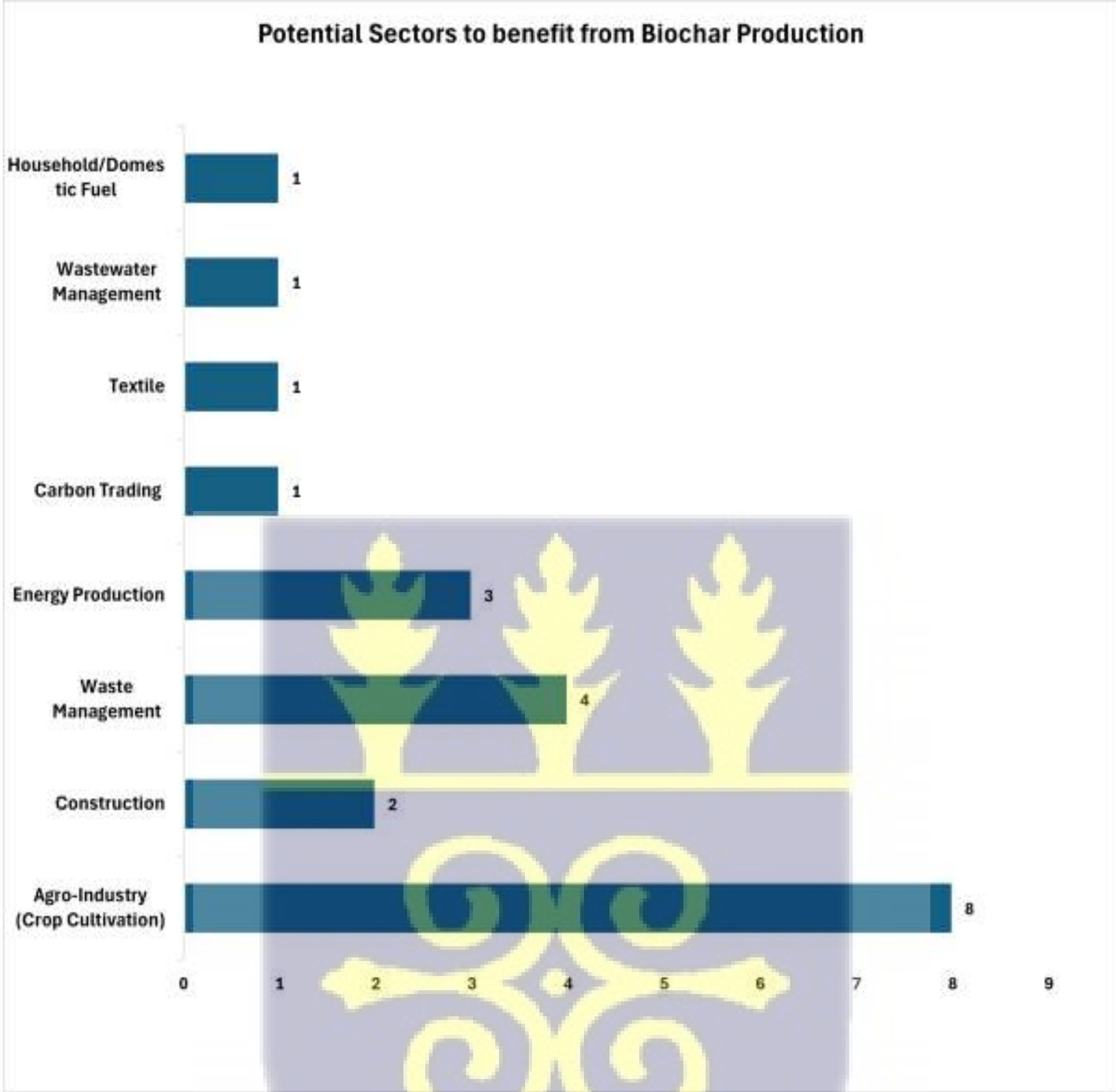


Figure 14: Financial Viability of Biochar Production according to Key Informants

Figure 14 shows the distribution of respondents indicating potential sectors that would benefit from the intervention. Biochar application in agriculture; that is crop cultivation recorded the highest number of responses of 8; with informants believing that biochar production could provide farmers with additional soil additives for soil invigoration and maintenance. In doing so, the demand for inorganic fertilizer could be potentially reduced.

The waste management sector was also mentioned by respondents, recording 4 respondents. With respondents seeing biochar production to effectively manage the bulk of waste volumes generated by our cities and communities Construction and Energy sector recorded responses of 2 and 3 respectively. Other industries worth noting included textile, carbon trading and wastewater management, which recorded 1 response each.

4.7 Technological Sustainability and Constraints underpinning Biochar Production

This section sought to determine the technological feasibility of biochar production to manage MSW. It sought to answer the research question; what are the technological constraints in operationalizing biochar production for waste management?

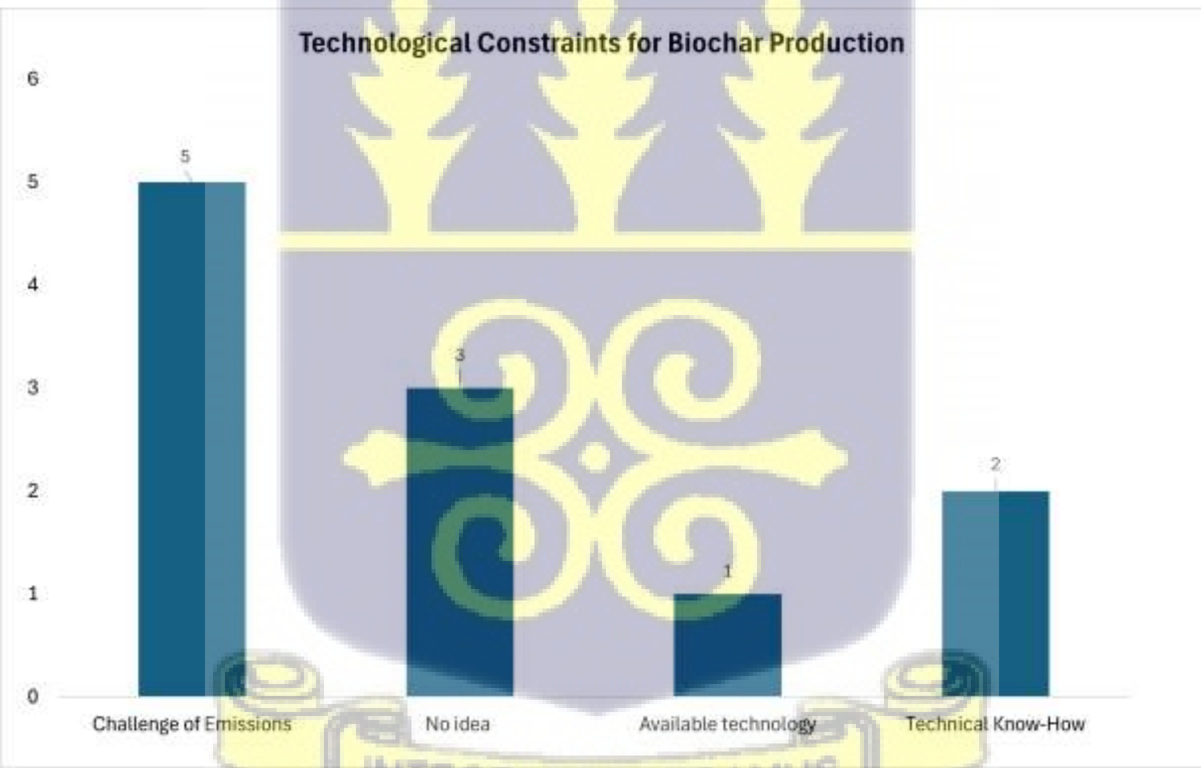


Figure 15: Technological Constraints for Biochar Production according to Key Informants

Engagements with key informants show varying responses regarding the technological feasibility of biochar production. The challenge of emissions recorded 5 responses, the highest tally of responses, whilst 3 respondents admitted they had no idea what sort of technological constraints biochar production would face. One respondent raised the issue of available technology, whilst 2 respondents admitted the issues related to technical-know-how in the production process could impede biochar production.

4.7.1 Alternative Biochar Production Techniques

The question of alternative production techniques and processes was posed to informants.

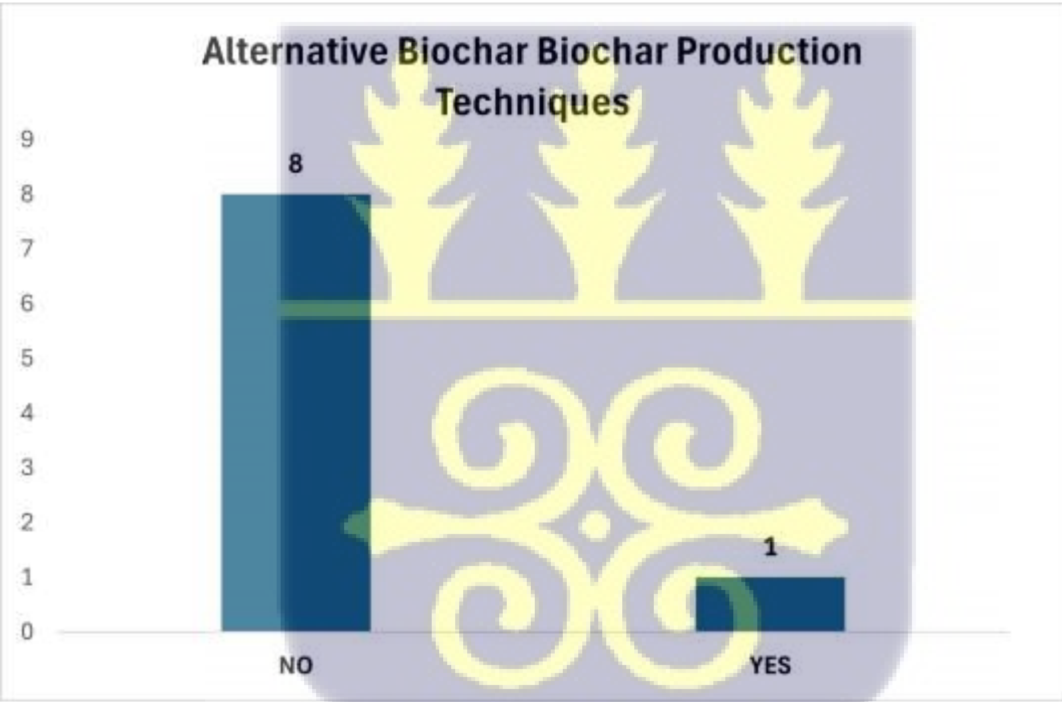


Figure 16: Alternative Biochar Production Techniques according to Key Informants

8 respondents mentioned they had no idea how else biochar could be produced. Whilst 1 respondent mentioned having some knowledge of an alternative. The respondents stated, “there is a smokeless type that if we can use, it would be very helpful”.

CHAPTER FIVE

5.0 DISCUSSION

This chapter covers the discussion of the sustainable feasibility of applying biochar production to manage Municipal Solid Waste. It covers the environmental issues, socio-cultural acceptability, institutional issues hindering biochar production, financial viability and technological constraints and sustainability of biochar production.

5.1 Environmental issues related to Biochar Production

Results (see Chapter 4, Figure 7) showed that there are preconceptions about biochar production in Ghana. The range of concerns varying from heat produced, particulate matter emissions, moisture content and conversion rate were issues that were raised.

Literature reviewed showed that a recommended moisture content for organic component of MSW conversion was recommended to be less than 8% (Panwar et al. 2019). The failure to meet this requirement would require more energy and fuel to convert the organic waste component into biochar, while lower moisture content required less energy to convert into biochar (Bridgewater, 2004; Mohan et al. 2006).

Another issue of concern was the particulate matter emissions. Ghana is known to have mixed MSW. This is very likely to be riddled with contaminants in the form of heavy metals and other phytotoxic and carcinogenic substances which Agblevor (2007) emphasized in their work, who raised concerns about the presence of heavy metals including Zinc and Copper in feedstocks. Hale et al. (2012) countered this by proposing that emission control devices to be equipped to pyrolysis plants. This would allow for measurement reading of the quality of gas, liquid, and solid (char) products. This would make the process more environmentally beneficial.

The low conversion rate was another issue of concern. Available literature (Tripathi et al. 2016) showed that slow pyrolysis yielded about 35% of biochar products. Concerns about output are justified in the sense that huge volumes of MSW would be required to meet the 35% biochar conversion mark. Fast pyrolysis on the other hand is known for the producing biofuels and syngas (Cheah et al. 2016) which were deemed more valuable, and outputs of oils change with temperature.

Smoke raised the highest concern by key informants whilst the heat produced in the production process was another concern by key informants. This was emphatically highlighted by Gwenzi et al. (2015) stating that poorly constructed pyrolysis plants could produce potent Greenhouse Gases (GHG), which could exacerbate the degradation of air quality, contributing to worldwide climatic changes (Laird, 2008). These issues have continuously been pitted against biochar production by environmental activists and sceptics (www.greenfuelwatch.org.uk).

In summary, though biochar production would have associated environmental constraints, major concerns should be placed on regulating the mixed nature of MSW, whilst reducing the concentration of heavy metal and pollutant contamination.

5.2 Socio-cultural acceptability of Biochar use

This section is divided into two parts. It discusses responses from key informants and household respondents.

General responses from key informants showed that biochar production would face several social pushbacks (Chapter 4, Figure 11). Many of which were related to social perception and cultural concern. A poor attitude towards waste being one of them. One respondent stated that “the attitude towards waste by the public is generally poor. For the intervention to reap fruitful results, it’s important that the general perception of wastes be changed”. Ghanaian cultural perception about waste is seen to be very conservative and traditional. The repurposing of waste is seen to be strange and not openly accepted. This trickles down to behaviors exhibited to waste collectors and pickers who are often looked down upon in society.

Another respondent’s result went on to state that that “culturally, our idea of waste has been of something that cannot be used any longer and should be disposed. In all these, the commonality is the generally negative perception about waste. This is seen with how the public are more likely to dispose of waste rather than to re-use, repurpose or recycle their waste materials.

These concerns were seen in responses made by households on the field with some respondents raising concerns about converting “garbage” into biochar due to the nature of the materials disposed, some household respondents were content with their current waste management practices, while some household respondents were simply not interested in considering alternative waste management options. However, even though there was little to no knowledge of the concept by respondents, a good majority of respondents were still interested in accepting it (see Chapter 4, Figure 9). Common responses positively giving the nod to biochar production included the unsatisfactory and inconsistent nature of waste collection by waste management services, pungent smell that contributed to air pollution, rodent and pest infestation in and around dumpsites and the unsightly nature of overflowing public dumps as stated by (McElligot et al. 2011; N. Scarlat et al. 2015) and strong linkages to diseases (Okot-Okumu, 2012) which were prevalent in their communities.

There is a pressing need to make the public aware that these wastes can be used for other purposes". The narrative of waste should just be thrown away is heavily imbibed into the average Ghanaian's psyche. To make strides in this regard, a radical shift is thinking is needed to provide an enabling environment for the use of organic waste components.

Also, with such a strong attachment to the environment the concern about the emissions produced from production with one key informant saying, "Trust me there will be public outcry. The volumes of emissions that would potentially be released into the environment will not go down well with the public". This has been a major scrutiny of biochar in other societies. This argument has been used for extensive lobbying by environmental activists and sceptics opposed to biochar and biofuels (www.greenfuelwatch.org.uk). Strong inclinations to the traditional waste management practice of landfilling would not produce as much public concern because of the remote location of landfill sites not situated in urban areas.

Policy direction from institutions was mentioned to impede the efforts of biochar production. An informant mentioned that the government's direction with regards to MSW management may be geared towards a certain direction focusing on different waste management processes. "Policies only provide guidelines and directions on how the government wants to approach a sector. The direction of government policy has focused on biochemical conversion of waste rather than thermochemical conversion. This is why composting is seen as the preferred option for the conversion of MSW. This is not to undermine biochar production because it is a big business". This is seen in literature with more encouragement given to composting and landfilling (Duku et al. 2011), a biochemical anerobic process rather than a thermochemical process, which according to Gwenzi et al. (2011), more emphasis will continue to be placed on conventional and proven technologies rather than biochar technology.

Challenges with source segregation of wastes from households and poor public perception towards waste were also issues raising the most concern among key informants. With one informant stating "the household behavioural challenges with source segregation that lead to the production of mixed waste is an area that still requires attention to ensure that waste inputs for biochar production do not compromise the quality of the final product. This is due to a lack of data on the practice of source segregation across various settings to inform targeted interventions that improve the practice of sustainable waste management by households. However, efforts are currently ongoing to develop a National Source Segregation Plan which will provide a roadmap to address this challenge". Whilst another informant raised their concern about the lack of sensitization and awareness by both government officials and the public.

Nevertheless, key informants showed positive posture of integrating biochar production into the national waste management policy framework with one respondent stating that "… in the transition to a zero-waste society through increased practice of circularity, biochar production offers a resource recovery option and supports the implementation of a materials-in-transition concept, which is advanced by the National Solid Waste Management Strategy" which was also recommended by Gwenzi et al. (2015) for consideration.

5.3 Institutional Issues hindering Biochar Production

Another consideration that was made for biochar production was the existence of policies surrounding its technology. The mixture of responses showed uncertainty about any clear framework surrounding biochar production. One respondent stated that "there is a policy on waste management that has biochar captured within it. It is not a standalone policy of only biochar but of the whole umbrella of waste management. It was a recent addition to a policy document at the Ministry of Environment, Science, Technology and Innovation (MESTI) and Environmental Protection Agency (EPA)"

On the other hand, one other respondent countered this in their response saying that "In Ghana, the National Solid Waste Management Strategy recognizes that waste recovery, re-use and recycling is a strategic approach that can progressively transition the country to a zero-waste society. While there isn't a specific policy on biochar production, the Strategy allows for innovative resource recovery solutions in the waste management value chain including biochar production and recommends increased coordination and collaboration between Government and the private sector to enable this circular economy focused waste management options".

Gwenzi et al. (2011) stressed the lack of supportive policy framework for its production and subsequent adoption. Karekezi and Kithyoma (2003) again stressed that experience in Sub-Saharan Africa (SSA) and the integration of innovative technology is reliant on legal frameworks which are in turn driven by benefits to be derived from the technology which strongly applies for Ghana. Unlike in developed countries where large scale pyrolysis plants are already in operation.

The admission of the lack of policy surrounding the technology came with rebuttals with pipeline developments of policy that was hinged on ng solutions to other underlying issues associated with waste management in the country. As seen in the submission by one key respondent who stated that "...efforts are currently ongoing to develop a National Source Segregation Plan which will provide a roadmap to address this challenge".

5.4 Financial Viability

The financial viability of biochar production (See Chapter 4, Figure 14) showed an understanding of potential sector that could benefit by informants. Responses from informants were usually likened to charcoal and its myriad of uses as seen in literature (Karaosmanoglu et al. 2000; Demirbas, 2004a; Harris, 2019). Respondents also associated the production process and applications to charcoal. As is the case by Vest (2003) and Mwampamba et al. (2012), who discussed the conversion of waste produced in agricultural setting into charcoal briquettes used for domestic cooking.

Informants targeted specific industries and sectors that were in line to benefit from the technology. These clear roadmaps could provide linkages between academia and business, further establishing and expanding industries for national and economic growth and development. This in turn will have a trickling effect on employment as stated by one respondent; “the issue of youth unemployment remains an issue; this can open avenues to create employment for the youth in our communities. Be it from waste collection to segregation, biochar production could create employment opportunities”. A similar submission was raised by one respondent saying “this can link academia to business and then to industry, this is something that has been lacking in our country. By identifying sectors where biochar can be of use, we can solve our waste management once and for all and supply biochar which will feed industries”. In Ghana, where unemployment is a significant challenge, biochar production has the potential to create widespread job opportunities and offer benefits across multiple sectors. This could contribute to economic growth while addressing overarching environmental and waste management issues.

5.5 Technological Constraints and Sustainability

This section discusses the technological feasibility and sustainability of biochar production.

Informants shared their thoughts surrounding the technology with issues such as conversion rate being mentioned. Reviewed literature (Triparthi et al. 2016) indicated a conversion rate of 35% in producing biochar using slow pyrolysis. With even lower conversion rates of 30% without oxygen (Amalina et al. 2022).

Concerns about emissions and particulate matter was the major challenge raised by respondents. Greenhouse Gas emissions from land use conversions and waste aggregation and transportation may offset biochar's potential benefits. Poorly constructed pyrolytic plants could also emit potent Greenhouse Gases which will degrade air quality, and contribute to global warming (Laird, 2018).

Also, the lack of technical-know-how poses an uphill task for biochar production raised by respondents. Available literature (Gwenzi et al. 2011) proposed that local technical capacity building and basic research on biochar and its associated processes were required to demonstrate its impact on food security, employment, energy provision and environmental quality. This knowledge gap calls for urgent research and knowledge transfer on biochar to be conducted.

Basic production has not been established for biochar production possibly due to research on biochar application in Africa remains at the basic stage (Torres, 2011). This would therefore trickle down to alternative production processes that would fortify a case for the technology. Notwithstanding, information gathered from one respondent showed promise of a modified pyrolysis process. The user stated, "there is a smokeless type that if we use, would be very helpful". This would eliminate concerns about particulate matter and emissions that were initially associated with the biochar production process.

CHAPTER SIX

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Based on the findings of the study, the following conclusions are drawn:

- The issue of waste and its poor management has created opportunity for the consideration of more sustainable options, apparently due to the traditional and conservative understanding of waste. Biochar production came with obvious scepticism, associated with the organic waste component feedstock and production processes. Nevertheless, a solution to the spillage of waste in their communities and water bodies remains a primary concern for communities.

- A basic understanding of biochar likened to charcoal provides a map of potential sectors to benefit from the technology, with direct paths leading the waste management, soil amelioration and restoration, and energy production being at the forefront of sectors that could benefit. Unlike other waste management initiatives that target a single industry, the multi-dimensional nature of biochar production could provide benefits to many sectors.

- An in-depth understanding of the technological and technical requirements of a biochar production system is needed to allow for better management of the disadvantages of biochar production. This would propel efforts for further modification of the process and improved efficiency in feedstock conversion.

- The direction of policy framework and waste management guidelines are indicative of the course of action governmental institutions and agencies have resorted to in their attempt to manage wastes volumes; with a clear priority given to biochemical and anaerobic waste processing techniques, as compared to the thermochemical option offered by biochar production.

6.2 Recommendations

The following recommendations are made from the study:

- A National Organic Waste Management Policy like the National Plastic Waste Management Policy, with input from agencies like Ministry of Environment, Science, Technology and Innovation (MESTI), Environmental Protection Agency (EPA), and the Ministry of Sanitation and Water Resources would provide a coordinated approach to managing organic waste in the country, a collaborative policy framework to offer a comprehensive masterplan for effective organic waste management.

- The government needs to identify key industries and sectors that could benefit from biochar production to overcome financial challenges to attract investment for biochar and its co-products.

- Increased government investment in the waste management sector is essential for efficient waste separation, to provide resources for opportunities for waste processing, and to reduce landfill disposal.

- Municipal Assemblies and Waste Collection Services should enforce regulations on source segregation, while integrating the informal waste collection sector into the formal waste management system to improve coverage and proper disposal in underserved communities.

- State agencies like the Environmental Protection Agency (EPA) should conduct a Lifecycle Assessment (LCA) to compare current waste management practices with biochar production to highlight the long-term benefits and potential uses of organic waste for biochar production, to promote a shift from a cradle-to-grave to a more sustainable cradle-to-cradle approach.

- Knowledge exchange with international biochar industries can lay the foundation for establishing local biochar production hubs in the country through transfer of technical expertise and skills in biochar production, to reduce environmental challenges while refining biochar production efficiency.

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APPENDICES

Appendix 1; Key Informants' Interview Guide

INTERVIEW GUIDE FOR KEY INFORMANTS

I am a Sustainability Science student at the University of Ghana, in the Institute for Environment and Sanitation Studies (IESS). I am undertaking a research study as part of my final year thesis. The study seeks to analyse the use of biochar as a sustainable waste management option in the Greater Accra Region.

I would be very grateful if you could objectively respond to the following questions to enable me to complete this study. We assure you that the information provided would be strictly confidential and would be used only for the purpose of the study. Thank you for your understanding.

Date of interview……………………..

Institution………………..

1) Have you heard about Biochar? A. Yes B No
2) How familiar are you with Biochar on a scale of 1-5 with 1 being Very Unfamiliar and 5 Being Very Familiar
3) Are you aware biochar can be extracted from MSW? A. Yes B. No
4) Has biochar production been considered to manage MSW streams?

   A. Yes B. No
5) If NO, Why not...
6) If YES, are there any environmental benefits for using biochar production to manage wastes?...
7) If YES, are there any advantages of using biochar to manage MSW compared to practices currently deployed?..

8) Would you consider biochar production an acceptable method for managing MSW?

A. Yes B. No

9) If YES/NO, why?...

10) Are there any societal hindrances that would impede biochar production as a waste management option?...

11) Are there any policies surrounding biochar production from Municipal Solid Wastes?

12) If YES, which..

13) If NO, why not?...

14) What are some challenges that have impeded the formulation of policy surrounding sustainable waste management technologies; specifically, biochar production from MSW?..

15) How potentially financially viable would you consider biochar production? On a scale from 0-5 And compared to other waste management approaches...

....

16) Are there any economic benefits biochar can offer?...

17) Are there any potential sectors/ industries (value chains) that would profit from of biochar?...

18) Are there any financial constraints impeding biochar production?...

19) Are there any issues associated with the processes and technologies related to biochar production that you're aware of?...

20) Are there any alternative biochar production technologies which are being considered?

A. Yes B. No

21) If YES, have they been tried?

22) Do you believe biochar production should be considered for the future management of MSW streams? A. Yes B. No

Appendix 2: RESEARCH QUESTIONNAIRE

This questionnaire aims to analyse responses by heads of households on their knowledge and awareness, and acceptability of biochar production as a sustainable waste management option. This waste sustainable waste management option would be used to manage the organic component of Municipal Solid Waste that are usually collected, aggregated and dumped at landfill sites and dump sites. The information provided is strictly for academic purposes and will be used as such. Your cooperation will be highly appreciated. You are ensured of confidentiality of any information provided. Thank you for understanding and participating in the survey.

BACKGROUND DATA OF RESPONDENT

A. DEMOGRAPHIC CHARACTERISTICS

1. Town of Respondent……………
2. Age of respondents A) less than 20 B) 21 to 40 C) 41 to 50 D) 51 and above
3. Marital status 2. Marital status of respondent

   (A) married (B) widowed (C) single (D)divorced
4. Highest educational level attained

   (A) Basic school (B) Senior Secondary/High School (C) Diploma/HND

   (D) University Degree (E) No formal education
5. Occupation of respondent

   A) Employed

   B) Unemployed

6) Type of occupation if employed

A) Artisan

B) Public/ Civil Servant

C) Trader

D) Farmer

Others (specify)

7) Number of children

A) None

B) One

C) Two

D) Three

E) Above three

8) What is your religion

A) Christianity

B) Muslim

C) Traditional

D) Others, specify…

9) Do you practice waste segregation

A) Yes B) No

IF NO, Why………………………………………………..

11) What is your monthly income?...

HOUSEHOLD

B. WASTE DISPOSAL PRACTICES

10) Do you use any form of domestic waste for domestic purposes?

A) Yes

B) No

11) How do you dispose of your wastes?

A) Burying

B) Public Dump

C) Waste collection Services

D) Burning

11B) If Other, specify…………………………….

13. How would you rate your current waste management practice?

A) Bad

B) Average

C) Good

D) Very Good

14. How would you rate your satisfaction with your waste disposal choice?

A) Very Bad

B) Bad

C) Neutral

D) Good

E) Very Good

15. How much is spent on this waste management monthly

A) Below 50ghc

B) 100ghc to 150ghc

C) 150ghc to 200ghc

D) Above 200ghc

16 Are you open to trying an alternative waste management option?

A) Yes B) No

17 If No, Any reasons?..................................

18 Have you tried any other waste management options?

A) Yes

B) No

19 If Yes, which form was used? ....

11) PERCEPTION OF BIOCHAR

20 Have you heard about “biochar”? A) Yes B) No

21 How familiar are you with Biochar

A) Very Unfamiliar

B) Unfamiliar

C) Somewhat familiar

D) Familiar

E) Very familiar

22 IF YES, Are you aware we can obtain biochar from organic wastes? A) Yes B) No

23 Are you aware MSW biochar can be used to manage wastes? A) Yes B) No

24 Will you be willing to adopt biochar to manage your MSW wastes?

A) Yes B) No

25 How likely are you to adopt biochar for your domestic waste management needs?

A) Very Unlikely

B) Unlikely

C) Neutral

D) Likely

E) Very Likely

26 If YES, why?.................................

27 If NO, WHY?

Any reasons?..................

28 What factors do you look at when considering your waste management options?

A) Cost B) Availability C) Comfort D) Satisfaction