From Trash to Tool

Harnessing the Power of Organic Waste for Sustainable Development in Indonesia

Allena Arnold

She/They

Acknowledgements

I would like to express my heartfelt gratitude to the unwavering support and guidance I received throughout my master’s program from my classmates, friends, and family. Their support has been invaluable, and without their presence, these past years would not have been as incredible as they have been. While my journey across Europe in search of skill development may not have been the romantic adventure one might imagine, it is their unconditional love and encouragement that has propelled me to reach this milestone of submitting my master's thesis. I am deeply indebted to them for their friendship during challenging times and for their continuous celebration of our achievements.

I would like to extend a special acknowledgment to Professor Roland Scholz, whose profound insights and guidance have exceeded my expectations. Your expertise and support have played a pivotal role in shaping this research paper. I am sincerely grateful for your willingness to push me beyond my boundaries and help me grow as a researcher. Thank you for graciously tolerating my organized chaos throughout this process.

I am also immensely grateful to my advisor, Professor Maciej Pietrzykowski, who has been a pillar of support throughout this journey. Your invaluable feedback and constructive criticism have significantly contributed to the quality of this work. I appreciate your dedication and commitment to my academic growth.

To all those who have contributed to the completion of this master's thesis, I express my sincerest appreciation. Your encouragement and support have been indispensable, and I am deeply grateful for your role in this endeavor.

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Glossary

MSW: Municipal Solid Waste
MSWM: Municipal Solid Waste management
MOWM: Municipal Organic Waste Management
SW: Solid Waste
OW: Organic Waste
OWM: Organic Waste Management
MOW: Municipal Organic Waste
FW: Food Waste
AD: Anaerobic Digestion
CE: Circular Economy
GHG: Green House Gas
SEA: Southeast Asia
3R: Reduce, Reuse, Recycle
ULB: Urban Local Bodies
TPS3R: 3R Waste Management Facilities
TPST: Integrated Waste Management Facilities
TPS: Temporary Collection Points
NDC: Nationally Determined Contribution
APBD: Local Municipality Budgets
BSU: Waste Bank Units
BSI: Central Waste Bank Unit
P.P.P.: Private-Public Partnerships
TPSA: Secondary Collection to Final Disposal Site
WTE: Waste-to-Energy
MBT: Mechanical Biological Treatment
IPPU: Industrial Processes and Product-use
AFOLU: Agriculture, Forest, and other land use
RDF: Refuse Derived Fuel
RBF: Results-based Financing
IRRC: Integrated Resource Recovery Center
EPR: Extended Producer Responsibility
LCA: Life cycle assessments
RCEP: Regional Comprehensive Economic Partnership
RPJM: National Medium-term Development Plan
SGC: Surabaya Green and Clean
LFG: Landfill Gas Recovery
BAU: Business-as-Usual
CER: Certified Emission Reduction Credits
TPA: Final Disposal centre
APAC: Asia-Pacific
NGO: Non-Governmental Organizations
CO2: Carbon Dioxide
CO2eq: Carbon Dioxide Equivalent

Abstract

Municipal Solid Waste Management (MSWM) is a global issue; this study looks at the case of Indonesia, where rapid urbanization and economic development continue to affect rises in waste generation and Green House Gas (GHG) emissions. The improper management of organic waste (OW) generates significant GHG emissions, mainly methane, when digested incorrectly in landfills. Indonesia must accelerate efforts to manage its Municipal Organic Waste (MOW) systems to alleviate the growing stressors of inadequate waste management processes. This Master's Thesis aims to deepen an understanding and construct a discussion around the constraints and potential options for Municipal Solid Waste (MSW) systems in Indonesia, particularly sustainable technologies for organic waste management (OWM), contributing to a circular economy (CE).

This study analyzes the situation in Indonesia, while attempting to discover and examine the potential of sustainable waste management systems. Concepts delivered hope to contribute to further research, helping to develop recommendations for mitigating climate change in Indonesia through organic waste. The study hopes to contribute to motivating further research towards strategy development for sustainable Municipal Organic Waste Management (MOWM) in Indonesia, likely highlighting the potential benefits of composting and Integrated Resource Recovery Centers (IRRCs) initiatives from utilizing municipal organic waste in a recycling and recovery manner. Additionally, best practices from other countries offer a model for OWM to be investigated, identifying any potential adaptations for Indonesia. Based on a literature review, a case study and awareness of global best practices, this paper hopes to develop a well-rounded view of the current systems dealing with organic waste management. Utilizing secondary data collection methods such as google scholar, ScienceDirect, The World Bank, organizations, and government reports, as well as AI tools like connect papers to help derive related papers.

Introduction

Background of the Study

Municipal Solid Waste (MSW) poses formidable challenges that reverberate across all facets of society. The relentless complications associated with waste management demand our attention and beckon us towards ample opportunities, driving innovation and systemic transformation in pursuit of sustainable development. According to the World Bank (2018), the world generates 2.01 billion tons of MSW yearly, with a daily amount ranging from 0.11 to 4.54 kg per person. Disturbingly, this figure is projected to grow by 70% by 2050 (Statista, 2023b), further pushing the environment's planetary boundaries. Waste mismanagement impacts municipalities, regions, and globally, affecting soil and groundwater pollution, air pollution, marine littering, and further global warming. The mismanagement of waste results in a magnitude of issues, encompassing human health concerns and imposing ecological stress, with waste contributing a colossal 1,580 billion tons of Carbon Dioxide equivalent (CO_2eq), and 3.2% of global Carbon Dioxide (CO_2) emissions annually (ASEF, 2021). As the world population reached an unprecedented number of 8 billion on November 15th, 2022 (United Nations, 2022a), there is an urgent call to action for waste management solutions capable of accommodating escalating consumption patterns, heightened energy demands, and a promising labor market.

The Sustainable Development Goals (SDGs) contain 17 areas for development (United Nations, n.d.-c), seven of which can be associated with waste management. These include SDG 3: Good health and well-being, SDG 6: Clean water and sanitation, SDG 7: Affordable and clean energy, SDG 11: Sustainable cities and communities, SDG 12: Responsible consumption and production, SDG 13: Climate action and SDG 14: Life below water, see Figure 1 (United Nations, n.d.-c). Through the enhancement of waste management practices, the potential to unlock a ripple effect of positive outcomes within these 7 SDGs becomes possible. Additionally, adopting more circular strategies can enable savings of 1.7 billion tons of CO_2 annually (H. B. Sharma et al., 2021).

Figure 1

Sustainable Development Goals Concerning Municipal Solid Waste Management. Source: (United Nations, n.d.-c)

A country's social, economic, and environmental conditions profoundly influence the MSW composition, where the generation rate is intricately linked to countries' income levels and GDPs (Khandelwal, Dhar, et al., 2019). Most developed nations produce substantial amounts of paper and packaging waste, whereas developing nations generate a more organic waste (Shekdar, 2009). In Southeast Asian (SEA) countries, organic waste comprises a significant portion, accounting for approximately 65%-75% of the total waste stream (Kaza et al., 2016); in Indonesia, organic waste constitutes upwards of 60% of total MSW, see Figure (Jain, 2017).

Figure 2

Indonesia's Solid Waste Composition.

Source: (Jain, 2017)

Regrettably, the waste remains disposed of inadequately, with only 37% of waste arriving at landfills and a staggering 33% being openly dumped, with numbers much higher in developing nations (Kaza et al., 2018). Globally, 21% of landfills comprise food waste (Geneva Environment Network, 2016). This dire state of MSW stems from limited infrastructure, financial resources, and stakeholder engagement, particularly in low-income countries like Indonesia, see Figure 3. Moreover, 8% to 10% of annual anthropogenic emissions are a result of waste (H. B. Sharma et al., 2021; UN Environment Programme, 2022).

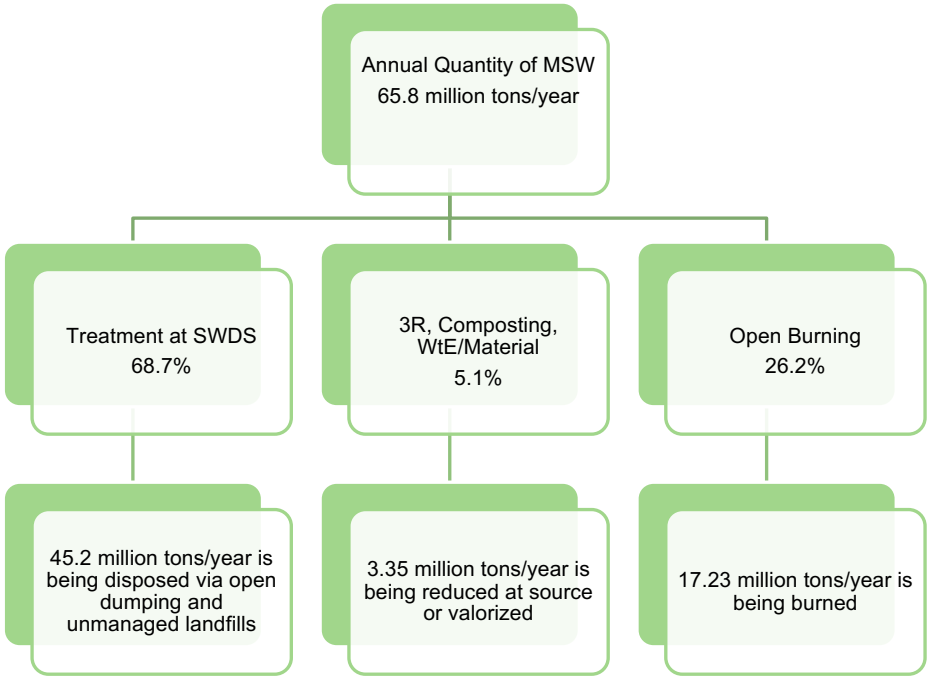

Figure 3

Waste Pathways in Indonesia.

Source: (Anwar et al., 2021; Wang et al., n.d.)

Indonesia ranks high in annual MSW generated, producing 65.8 million tons/year, with organic waste comprising 60% of the composition, see Figure 2 (Jain, 2017; Wang et al., n.d.). With a rapidly expanding economy and a 2.7% urban growth rate, the waste management crisis will only be manageable if it is effectively managed or rechanneled to create value through the recovery and conversion of materials into value-added products and services (Jain, 2017). An approach that embodies recovery, recycling, and value proposition holds the potential to mitigate pollution, improve energy access, unlock economic opportunities, and enrich agricultural lands (Ferronato & Torretta, 2019).

The government of Indonesia strives to reach a waste reduction target of 30% and a waste handling rate of 70% by 2025 (Vidyaningrum, 2020). While the countries' budget is substantial for these aspirations, it falls short at an average of 2.5% compared to the standards of 4% to 9% required for sustainable and effective services (Vidyaningrum, 2020); the current allocation remains inadequate and lacks provisions for recovery costs. This heavy reliance on local budgets without data to determine best practices further hampers progress (Vidyaningrum, 2020).

Problem Definition

The problem at hand revolves around the challenges and adverse consequences associated with the mismanagement of OW in Indonesia. The cost of global food waste alone surpasses the country of Indonesia's annual GDP, further experiencing losses from food waste disposal, equivalent to 4%-5% of its GDP (C40 Cities Climate Leadership Group & C40 Knowledge Hub, 2023; The Ministry of National Development Planning/Bappenas & Waste4Change, 2021). With reduction targets of 2.45% regarding climate change impact on national GDP by 2050, showcases the efforts made by Indonesia as the country strives to build resilience in terms of social, economic, and environmental health (Farahdiba et al., 2023). Food loss and waste also contribute 7.29% of Indonesia's GHGs (The Ministry of National Development Planning/Bappenas & Waste4Change, 2021). These 23-48 million tons of food waste (FW) disposed of annually between 2000-2019 amount to 115-184 kg per capita per year (The Ministry of National Development Planning/Bappenas & Waste4Change, 2021). It is estimated that without intervention, food waste in Indonesia could reach 344 kg/capita/year by 2045 (Farahdiba et al., 2023). It has been identified that food loss in developing nations is mainly due to inefficiencies and inadequacies of infrastructure throughout the value chain, such as storage, transportation, and technology (Scholz et al., 2014). This is displayed given the waste management operations not receiving adequate attention and funding share of government budgets, sitting at an average of 0.7% of regional budgets in Indonesia (SYSTEMIQ et al., 2021).

Improper separation and disposal of organic waste results in the substantial generation of GHG emissions, groundwater contamination, leachate, and soil health deterioration posing significant challenges for Indonesia's MOWM systems (Ferronato & Torretta, 2019; Putra et al., n.d.; Sholichin, 2012). Over the past two decades, Indonesia's methane emissions have doubled, a trend that is likely partially attributed to the inadequate management of the country's 194,002 tons of waste produced daily (Anwar et al., 2021; ASEF, 2021). Methane, a potent driver of climate change that is 84 times more potent than carbon dioxide on a 20-year scale, is released during anaerobic digestion (AD), primarily occurring in landfills, making it a main contributor to rising GHG emissions from the solid waste sector (Composting

to Avoid Methane Production – Western Australia | Agriculture and Food, n.d.; Methane Emissions, 2022). When organic waste undergoes decomposition in landfills, higher amounts of methane are produced (Ramprasad et al., 2022). The environmental impact is not limited to GHG emissions but also encompasses landscape degradation and contaminated groundwater and soil, exacerbating detrimental health and environmental effects, which pose an increasingly significant concern for Indonesia (Indonesia, Soil Pollution Control | Enviliance ASIA, n.d.).

Although Indonesia currently has pilot projects in the waste sector, such as an IRRCs and buyback programs, these initiatives lack the necessary financial and regulatory support at multiple levels (Hettiarachchi et al., 2018; UNESCAP & Waste Concern, 2017). These existing projects need regulatory adjustments, including soil and fertilizer schemes, to enable domestic compost to compete and generate profits (Hettiarachchi et al., 2018). The need for committed financial support from a multi-level stakeholder framework and increased awareness and education regarding organic waste are crucial for progress (Storey et al., 2013). Indonesia faces many hardships, including the need for significant financial or institutional frameworks for developing circular waste management operations in the country (Jain, 2017).

The main challenges faced in Indonesia include the need for more financing, infrastructure, and stakeholder engagement, which continue to hinder the progress and adoption of sustainable waste management practices, see Figure 4 below.

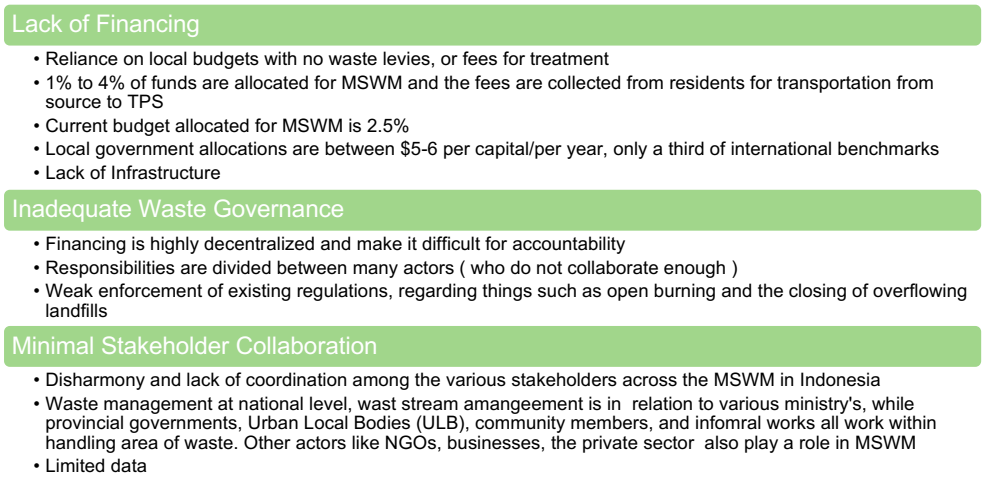

Figure 4

Main Challenges of Indonesia MSWM.

Sources: (Arya et al., 2022; Dhokhikah & Trihadiningrum, 2012; Gómez-Sanabria et al., 2022; Ramboll et al., n.d.; SYSTEMIQ et al., 2021; UNEP-LEAP, n.d.)

The combination of Indonesia's large population and inadequate waste management systems stimulates the research aim of this thesis, seeking to understand the impact of organic waste management on the world's third-largest GHG emitter, Indonesia (Leitmann, 2008). This study will explore the importance of how proper management of organic waste could shift this situation. The need for sustainable waste management practices is evident when considering the detrimental impacts of improper organic waste management across all facets of society. Methane emissions from the waste sector have doubled over the last two decades, see Table 1, with waste contributing to 6.52% of GHG emissions, see Figure 5 (Anwar et al., 2021).

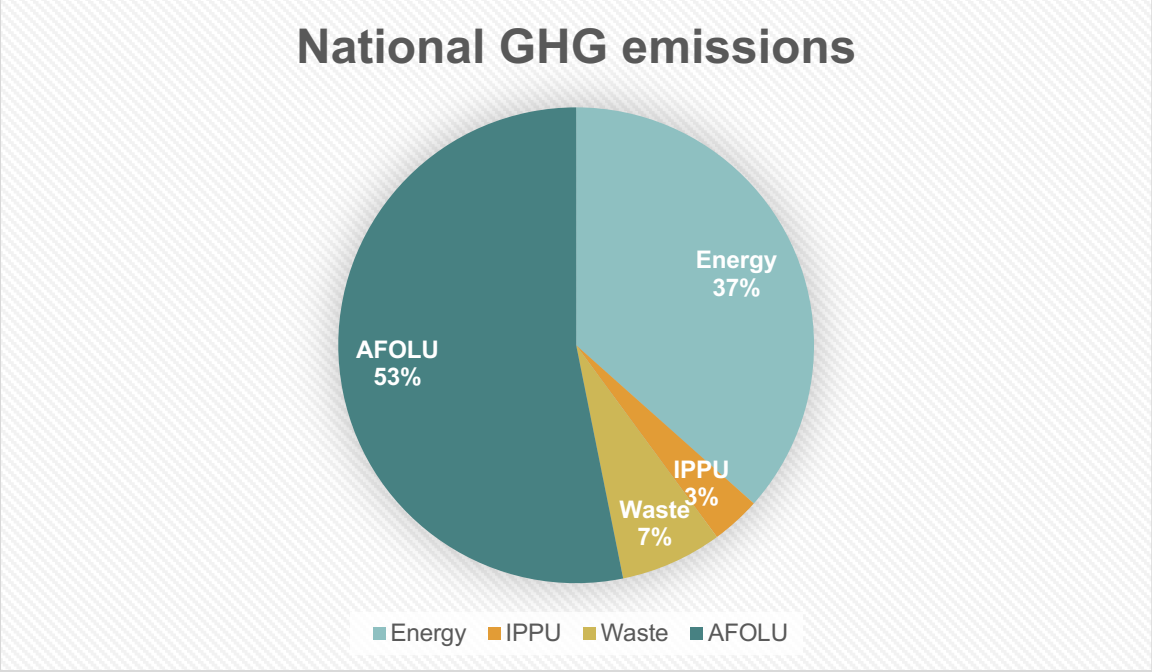

Figure 5

National GHG Emission Composition 2019.

Source : (Anwar et al., 2021)

Sector	Year	CO2	CH4	N2O	Total
Energy	2000	284,503	29,728	3,378	317,609
	2019	615,262	16,464	4,726	636,453
Industrial Processes and Product-use (IPPU)	2000	42,401	98	149	42,648
	2019	57,252	91	784	58,128
Agriculture, Forest, and other land use (AFOLU)	2000	534,525	41,445	40,928	616,898
	2019	917,623	54,934	57,597	1,029,843
Waste	2000	2,216	57,431	2,544	62,191
	2019	3,026	113,702	3,606	120,333
Total CO2-eq	2000	863,645	128,702	46,998	1,039,345
	2019	1,593,163	185,191	66,713	1,845,067

Table 1

Indonesia's GHG emissions according to the sector.

Source: (Anwar et al., 2021)

Indonesia strives to fulfil its climate goals and pursue sustainable development through its National Determined Contribution (NDC), which includes unconditional targets of 29% and conditional targets of up to 41% GHG emission reductions from the business-as-usual (BAU) levels, see Figure 6. The nation must assess and act in accordance to combat major GHG contributors, including waste.

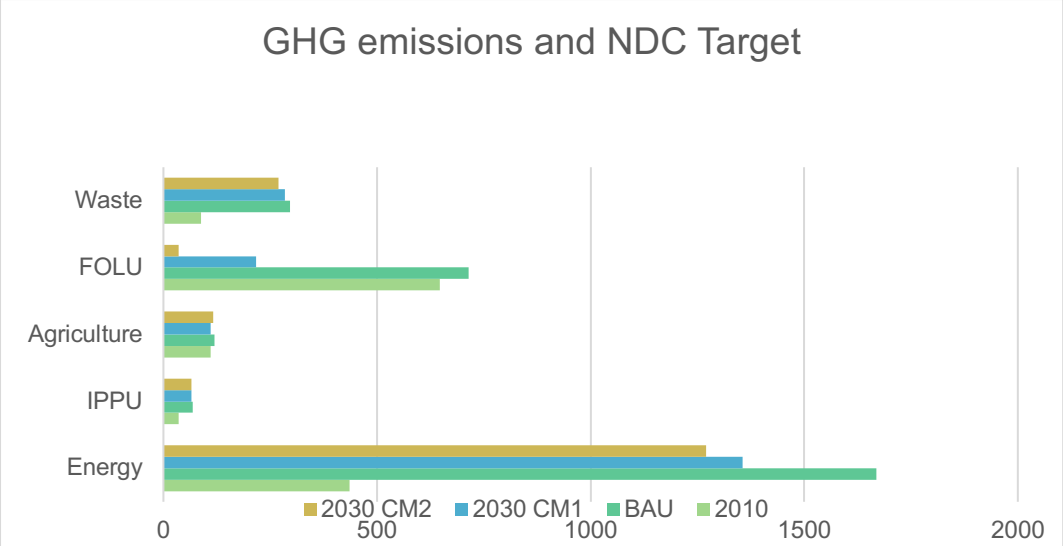

Figure 6

Indonesia National GHG emissions levels for BAU, CM1, and CM2 in accordance with the NDC target.

Source: (Anwar et al., 2021)

Research Objective

The focus of this study is to examine municipal organic waste management in Indonesia and develop an understanding of the constraints and the potential sustainable practices that could help mitigate ecological, social, and economic distress. By exploring the potential valorization options for organic waste, appropriate management technologies, and the current state of MSWM in Indonesia, this study will provide insights into policies, technologies, and stakeholder involvement ongoing in the OW sector in the country while also having a clear view of what constraints are. By examining the various areas in the MSWM process, see Figure 7, this study aims to contribute to efforts towards resource efficiency and strengthening a CE, where waste transformed into a valuable resource, supports sustainable development.

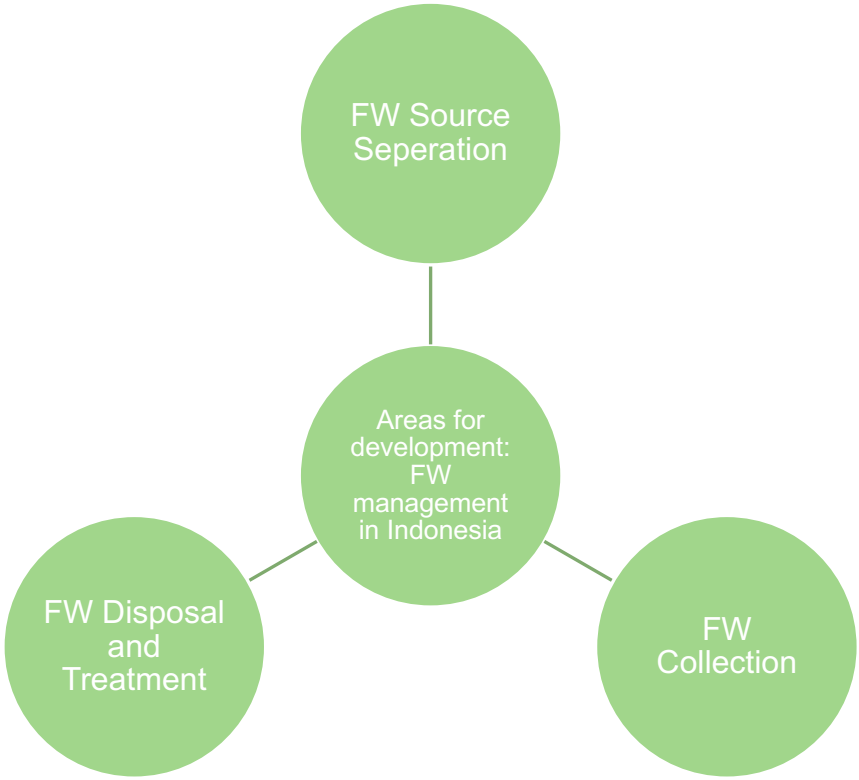

Figure 7

Focus areas for FWM in Indonesia.

The research will pursue the following objectives:

1. Describe and provide insight into current waste management techniques and the state of OW in Indonesia, drawing on global examples to enhance understanding of potential avenues for success and understand challenges.
2. Develop an understanding of the state of OWM in Indonesia.

Therefore, this research aims to address the following research question:

- How can municipal waste management systems leverage the potential of organic waste to contribute to sustainable development in Indonesia?

In particular, the study will examine the following aspects:

- What are some best practices from other countries that have successfully implemented sustainable models for organic waste management?
    - How might these practices be adapted to the Indonesian context?

- What are the potential economic, social, and environmental benefits of integrating organic waste materials into a more sustainable model in Indonesia?
- Does Indonesia have the current infrastructure to support sustainable organic waste management practices?

In order to achieve the desired research objectives and formulate a clearer understanding of the problem at hand, a qualitative analysis will be conducted and further an individual case study on Indonesia. Following this, global best practices are examined as a means to understand potential avenues for Indonesia's challenges and opportunities as it pertains to organic waste management. This study will use all secondary data sources to develop knowledge in this field.

The subsequent section will describe the state-of-the-art knowledge, including an overview of waste streams, potential technologies, and a detailed analysis of the Indonesian context.

1 State-of-the-Art Knowledge

1.1 Municipal Solid Waste Management

In major cities worldwide, solid waste is projected to rise from 2.01 billion tons to 3.4 billion tons annually by 2050 (Kaza et al., 2018). This anticipated increase necessitates implementing appropriate and sustainable waste management techniques under the sustainable development goals. As the global population is estimated to reach nearly 10 billion by 2050 (Nations, n.d.), there will be a surge in

natural resource consumption, pollution, biodiversity loss, and threats to human well-being. Given the predicted urbanization, population growth, rapid industrialization, and economic development, methane emissions alone are estimated to rise by 71% above 2015 levels, contributing to 13% of total anthropogenic methane emissions by 2050 (Ghisellini et al., 2016; Gómez-Sanabria et al., 2022; Khandelwal, Thalla, et al., 2019; Yukalang et al., 2017).

Municipal solid waste management has emerged as a global concern, impacting various aspects of society, from human health to economic prosperity (Almazán-Casali et al., 2019; Ferronato & Torretta, 2019; Sondh et al., 2022). Inadequate waste management systems lead to diseases, pollution, economic hardship, and environmental degradation, acting as significant drivers of health risks, environmental harm, and economic adversity (Almazán-Casali et al., 2019; Ferronato & Torretta, 2019; Gómez-Sanabria et al., 2022; Yadav & Karmakar, 2020).

Most global material use and GHG emissions stem from G20 countries (OECD, 2021), underscoring the importance of resource efficiency and waste management as key pathways toward sustainable development. Nevertheless, the varying income levels of these nations continue to act as a hurdle, challenging potential waste management techniques' effective implementation. With rapid urbanization and burgeoning population growth in SEA, it becomes indispensable to address the waste management crisis holistically, striving for sustainable development across all fronts. To acknowledge there is no one size fts al, and solutions in the global north may not suffice for the global south. If no improvements are made in the solid waste sector, it is estimated that approximately 2.38 billion tons of CO2 equivalent emissions will be produced by 2050 (Kaza et al., 2018).

To gain a better understanding of the term "Solid Waste" (SW), the definition is provided as "any garbage or refuse, sludge from a wastewater treatment plant, water supply treatment plant, or air pollution control facility and other discarded material, resulting from industrial, commercial, mining, and agricultural operations, and from community activities." (US EPA, n.d.-b). It is important to note that any activities carried out by humans and industries generate residue typically discarded as waste, if not needed for immediate secondary use. SW can be categorized based on its

source, composition, related hazards, and potential valorized products. The following are the various categories of SW:

1. Municipal solid waste (MSW): This category includes waste generated from households, commercial institutions, and other establishments within a given municipality. MSW comprises both inorganic and organic waste streams. This study primarily focuses on household FW, which constitutes most cities' main portion of OW streams (C40 Cities Climate Leadership Group & C40 Knowledge Hub, 2019a; Sondh et al., 2022; Woon et al., 2021). Other waste streams, such as hazardous, electronic, and organic waste, can also result from the MSW system (Gholampour Arbastan & Gitipour, 2022; Vinti et al., 2021).

2. Industrial Solid Waste: This includes waste generated by industrial operations and manufacturing processes, such as hazardous (e.g., chemicals) and non-hazardous waste (e.g., scrap materials) and electronic waste resulting from outdated technologies or stimulated by rapid innovation. (Fiksel & Lal, 2018; Ghisellini et al., 2016).

3. Construction and Demolition Waste: This category comprises waste from construction, renovation, demolition, and development operations. It includes building materials, packaging waste, hazardous materials, electronic waste, and landscaping waste, such as demolished pieces of land (EPA, n.d.; UNESCAP, n.d.). Materials such as concrete, plastic, wood, bricks, and other construction equipment fall under this category (European Commission, n.d.). This waste stream also has the potential for source reduction and improved recovery technologies to mitigate adverse effects (Spoerri et al., 2009).

The management process for these waste categories must be aligned with their respective streams and specific country or municipality. Solid waste management involves the collection, transportation, treatment (in some cases), and final disposal of the waste (Almazán-Casali et al., 2019; Erfani et al., 2018; Tsai, Bui, Tseng, Lim et al., 2020; Vitorino de Souza Melaré et al., 2017; Wätzel et al., 2015; Yadav & Karmakar, 2020). The management approach should consider the waste

composition, local regulations, culture, geography, and available processing technologies.

An essential aspect of the MSWM process is stakeholder engagement. These stakeholders can include local governments, waste management companies (typically private), recycling and composting facilities (both public and private), non-governmental organizations (NGOs), community leaders such as community-based organizations (CBO), waste generators, and the informal sector such as scavengers (Cohen-Shacham et al., 2019; Community Based Participatory Waste Management (IDBNG0003), n.d.; Dhokhikah et al., 2015; Ferronato, 2021; Ghisellini et al., 2016; Ilić & Nikolić, 2016; Mccawley, n.d.; WIEGO, n.d.). Stakeholders are responsible for waste generation and accountable for its disposal methods, hence the importance of collaboration amongst actors.

The typical process of MSWM unfolds as follows:

1. Collection: MSW can be collected for households, commercial establishments and community institutions through various methods. Examples include door-to-door collection, community bins, curbside or alley pickup, designated dumping sites, and backyards (Yadav & Karmakar, 2020). The frequency and format of collection depend on the composition of the waste, existing infrastructure, and associated fees (Hondo et al., 2020; Ilić & Nikolić, 2016; Khair et al., 2019; Storey et al., 2013; The World Bank, 2018; Yadav & Karmakar, 2020).

2. Transportation: Collected waste is then transported to temporary holding spaces, treatment facilities, or directly to its final disposal method (Ferronato & Torretta, 2019; Hondo et al., 2020; Sondh et al., 2022; Yadav & Karmakar, 2020). This stage can involve various intermediaries, including scavengers using motorbikes and hand-pulled carts, as well as larger private entities utilizing large vehicles, depending on the geography, financing, and infrastructure (Kaza et al., 2016; Widyarsana et al., 2020).

3. Treatment: Treatment may only sometimes be necessary or required, depending on the disposal option and the prevailing waste management practices in a given country (Bing et al., 2015; Fei et al., 2018; Govind Kharat et al., 2019). The MSW can undergo treatment based on its composition, such as composting, AD and mechanical and biological treatment (MBT) options for sorting and separating wastes (Araya, 2018; Fei et al., 2018; Seruga et al., 2020; Wätzel et al., 2015; Woon et al., 2021; Zamri et al., 2021).

4. Disposal: MSW reaches its end of life through disposal methods such as landfills and incineration (Assamoi & Lawryshyn, 2012; C40 Cities Climate Leadership Group & C40 Knowledge Hub, 2019a; Emalya et al., 2020; Govind Kharat et al., 2019; Jain, 2017; Kaza et al., 2018; Meidiana & Gamse, 2011; Rabl et al., 2008; Sondh et al., 2022). There are various means of waste disposal, some being more ecologically sound while others lead to environmental degradation and other social inequalities.

Figure 8 presents an example of waste management focusing on the Island of Bali in Indonesia found in a study conducted by Widyarsana et al. (2020). This flow chart illustrates the abovementioned collection, transportation, and disposal mechanisms, offering a basis for further analysis of waste management practices in Indonesia, the country of focus for this research.

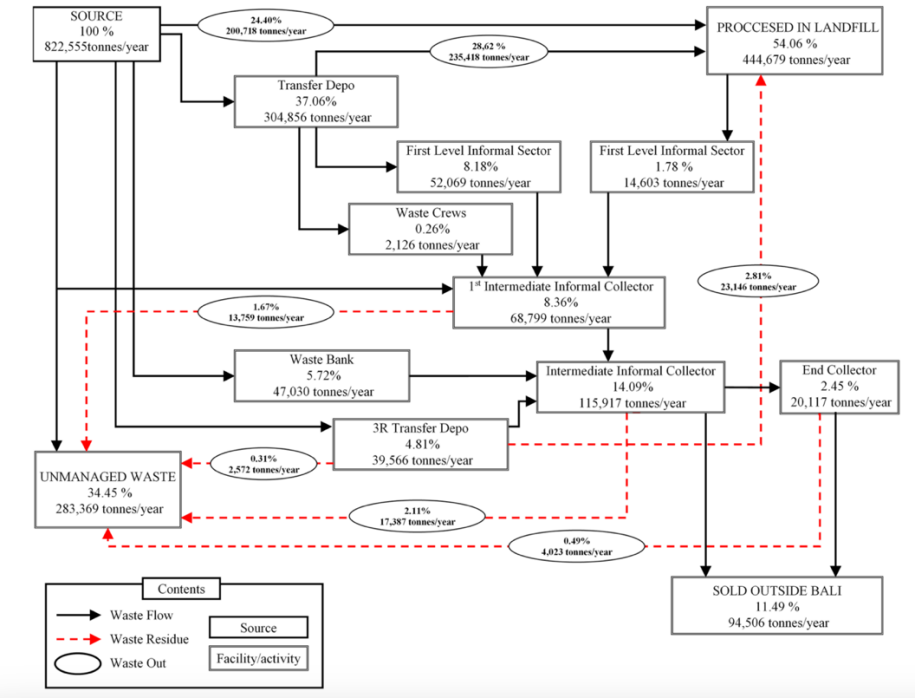

Figure 8

Example from Bali waste management processing.

Source: (Widyarsana et al., 2020)

Another stage that proves integral to successful MSWM systems in achieving sustainable development is the monitoring and controlling of information from the waste management processes. This stage helps ensure enforcement and compliance with laws and regulations for safe waste disposal (Babu et al., 2021; Gómez-Sanabria et al., 2022; UNESCAP, n.d.; United Nations, n.d.-a). Proper monitoring and data collection enables the identification of areas for improvement and promotes sustainable practices in waste management (Cha et al., 2017; Dehghani et al., 2018; Kaza et al., 2018; Niska & Serkkola, 2018). Including site inspections, air and water quality monitoring, and waste composition analyzes. However, many developing nations lack adequate data and information, further challenging decision-making for MSWM systems.

The choice of methods for each stage of the MSWM process is highly dependent on the country. Several factors include geography, economic standing, societal awareness and acceptance, environmental degradation, and government actions. Additionally, cultural factors within a country can influence the implementation of

waste management, such as challenging social norms and preferences, including storage and treatment methods (Joshi & Visvanathan, 2019).

1.2 Organic Waste

As mentioned, MSW comprises various waste categories, including inorganic and organic. Organic waste constitutes a significant proportion of the waste composition in many countries, particularly in developing regions, accounting for around 40% - 70% of total waste produced (Abubakar et al., 2022; Alamgir et al., 2014; C40 Cities Climate Leadership Group & C40 Knowledge Hub, 2019a; Dharmendra, 2022; Jain, 2017; Kaza et al., 2018; Khandelwal, Thalla, et al., 2019; Sondh et al., 2022). Globally, approximately 17% of food production, equivalent to 93 million metric tons, goes to waste for many reasons, such as size, storage, transport, and over-purchasing (United Nations, n.d.-b). Storage and transportation remain a major challenge in the global south, with inadequate refrigeration and infrastructure further contributing to food losses and waste. This significant portion of waste often ends up in dumpsites, creating environmental and health risks (Abubakar et al., 2022; Bruggers et al., 2021; EPA, n.d.; Gholampour Arbastan & Gitipour, 2022; Hamka et al., 2020; Huffman et al., 2022; Kaza et al., 2016, 2018; Sasaki et al., 2014; Themelis & Ulloa, 2007; US EPA, n.d.-a; Vinti et al., 2021; Yang et al., 2018). Unconsumed FW contributes to approximately 8-10% of anthropogenic GHG emissions annually (UN Environment Programme, 2022).

Managing and alleviating the pressure of organic waste has become a pressing concern to combat climate change and realize economic, social, and environmental benefits. For example, reducing FW can create an annual economic opportunity of $155-405 billion by 2030 (US EPA, n.d.-b), and the valorization of FW could unlock more than $700 billion as estimated by the Ellen MacArthur Foundation (Ellen MacArthur Foundation, n.d.). The utilization of organic matter for sustainable development is not a new concept, as described in the book “Farmers of Forty Centuries” by King (2002), which presents examples of organic matter valorization in Asia.

Organic waste is any organic compound derived from various sources, such as food and yard scraps, agricultural waste, and sewage sludge. OW includes items like uneaten food, coffee grounds, grass clippings, leaves, manure, crop residue, and sludge from wastewater treatment. The main contributor to the OW stream is household food waste, often accounting for nearly 90% of organic waste generated in major cities (Almazán-Casali et al., 2019; Arya et al., 2022; Attiq et al., 2021; C40 Cities Climate Leadership Group & C40 Knowledge Hub, 2019a; Li et al., 2023; Schanes et al., 2018). The amount of FW produced tends to positively correlate with higher GDP nations, where it often accounts for the most significant waste stream from households compared to low-income nations (Mak et al., 2020). Various strategies and initiatives can be implemented within homes to address the potentially harmful effects of inappropriate food waste disposal.

Furthermore, FW can be categorized as avoidable or unavoidable. Strategies like cradle-to-grave approaches can be introduced earlier to reduce avoidable waste (Tantrige et al., 2022). At the same time, improved recovery methods can be employed for unavoidable waste after separation and disposal in the home. Without adequate separation of organic waste, valuable resources are lost, and increased pollutants, such as high concentrations of heavy metals, can contaminate the environment and negatively impact soil health (Joshi & Visvanathan, 2019).

Separation is essential in the management process, whether this begins in the home or is implemented later in the system. When striving for circularity and recycling organic waste, the separation, collection, and treatment processes go hand in hand to ensure economic and sustainable development (Lang et al., 2010; Scholz et al., 2014). In contrast, unavoidable waste can undergo appropriate management and recycling practices (Mak et al., 2020).

The organic fraction of waste can undergo biodegradation processes naturally or assisted, wherein microorganisms break it down into simple compounds like carbon dioxide and methane; these two gases are significant contributors to GHG emissions (CLU-IN | Technologies > Remediation, n.d.; Craig Coker, 2014; I. Sharma & Sharma, 2020). Biodegradation can occur with or without oxygen in aerobic or anaerobic digestion processes, respectively (Craig Coker, 2014; Khandelwal, Dhar,

et al., 2019; I. Sharma & Sharma, 2020). It is vital to consider the soil contamination that may result from inadequate waste management from this decomposition under unregulated conditions (Rani et al., 2022). Organic matter is essential in controlling phosphorous recovery and availability, as they are positively correlated and help store and transfer phosphorous after initial organic matter use (Chakraborty & Prasad, 2019; Scholz et al., 2014). Furthermore, the mismanagement or uncontrolled disposal of organic waste in landfills generates leachate and can contribute to groundwater contamination and other environmental concerns (Sholichin, 2012).

Managing OW presents the potential for energy recovery, compost production, and feedstock utilization (C40 Cities Climate Leadership Group & C40 Knowledge Hub, 2019a; Leong et al., 2021; Pace et al., 2018; Rajkumar & Kurinjimalar, 2022). Recovery refers to deriving value from the waste and converting it into valuable materials or value-added products, while recycling involves reprocessing waste for its original or alternative purposes, excluding energy recovery (ecomondo, 2022; What Is the Difference between Recovery and Recycling?, n.d.). Organic waste is considered a leading resource in developing the circular bioeconomy, wherein the recovery and management of this waste stream are integral for sustainable development (Santagata et al., 2020). The circular bioeconomy involves recovering and converting biological resources into value-added products such as food, feedstock, and bioenergy (Mak et al., 2020). Bioenergy has the potential to generate economic, social, and environmental benefits, including job creation, improved health, and reduced GHG emissions (Gold, 2011). The circular bioeconomy concept represents the potential value proposition of resource efficiency, contributing to GHG emission reduction, decreased nonrenewable energy demand, and further valorization of the organic waste stream (Mak et al., 2020).

Given the various stakeholders involved throughout these human-environment systems, this efficiency must be viewed from a multi-level perspective (Scholz et al., 2014). Waste can be transformed into valuable materials and re-enter the market through a circular economy process (Ddiba, 2022; Ellen MacArthur Foundation, n.d.; Ferronato et al., 2019; Fiksel & Lal, 2018; Kalkanis et al., 2022; OECD, 2021; Zorpas et al., 2021). Improperly managed OW biodegradation in landfills or other

inappropriate disposal methods directly releases methane into the atmosphere and, in 2019, was found to have emitted a CO2eq of 99.4 million metric tons of emissions in the US alone (Epa & Change Division, 2022). Methane is 25 to 28 times more potent than carbon dioxide more potent than CO2 in terms of its global warming potential (GWP), making mitigation and use extremely important when addressing climate change related problems (Ferronato & Torretta, 2019). Furthermore, carbon-rich OW could be recovered into energy, material, chemical and mineral components for future use, such as phosphorous recovery (Santagata et al., 2020; Scholz et al., 2014).

In developed countries like the US, diverting just 25% of FW could reduce GHG emissions by 30% (Epa & Change Division, 2022). In low-income countries, approximately 90% of FW is estimated to be dumped in landfills, imagine what the transformation could look like (Woon et al., 2021). The economic feasibility of OW recovery remains a challenge due to competition from industries, such as fossil fuels, hindering progress despite the known adverse effects of continued waste disposal practices (Santagata et al., 2020). Despite legislation and enforcement efforts, compliance and education regarding proper waste management in this significant area often get overlooked. Diverting OW from landfills and other inadequate waste disposal methods is a major area for improvement and a crucial strategy for sustainable development.

1.3 Technologies for MSWM

Municipal solid waste management technologies vary depending on existing infrastructure, culture, financing, and regulations. Each country, city, and community possesses individualized waste management systems and technologies suited for the specific waste mix and capabilities. Many differences exist between developed and developing nations' waste technology options, from collection practices to final disposal methods, resulting in significant variations (Fatimah et al., 2020; Yadav & Karmakar, 2020). Understanding the context and environment in which waste management technology is implemented is crucial for its success, the well-being of the community, and overall sustainable development. Merely implementing a so-

called suitable technology without assessing its compatibility with the local context, including supporting policies, economic feasibility, and environmental potential, is insufficient (Sudibyo, Majid, et al., 2017). The concept of ‘intermediate technology’ is key to understanding why some technologies may succeed or fail based on cultural relevance (Patnaik & Bhowmick, 2019). Technologies developed for developed nations are unsuitable for third-world countries, resulting in inequalities and ensuing crises (Patnaik & Bhowmick, 2019). Therefore, it is integral to understand the scope of the selected technology within the waste management process and implement it effectively. To benefit from the selected technology, a clear comprehension of its purpose, whether it is intended for recycling or recovery, is essential to the success of its operations.

1.3.1 General Technologies for Municipal Solid Waste

Collection, transportation, treatment and disposal technologies exist within each stage of the MSWM journey. Collection options include door-to-door, bins, community facilities, or open burning and dumping sites (Almazán-Casali et al., 2019; Arya et al., 2022; Fatimah et al., 2020; WIEGO, n.d.; Yadav & Karmakar, 2020). Transportation methods depend highly on the geography and financing options available in the country (Fatimah et al., 2020; UN Habitat, 2010; Yadav & Karmakar, 2020). In communities with narrow streets in developing countries, large trucks are not suitable, so often scavengers and other informal workers will use hand-pulled carts, motorbikes, and bikes to transfer the waste to a temporary facility before secondary collection from typically larger entities like private companies or governments collect and transport it for further treatment and disposal via large trucks (Gertman, n.d.).

As for treatment and disposal, various technologies exist, ranging from simple to complex processes (Fatimah et al., 2020). However, the implementation’s success depends on the technology’s compatibility or appropriateness with its intended environment (Patnaik & Bhowmick, 2019). Some of the technologies used for treatment and disposal include:

Landfilling: Landfilling is the most common method for waste disposal accounting for nearly 37% of global MSW disposal (Sondh et al., 2022). This process involves carefully disposing of waste in designated areas, considering the given characteristics of the land. However, landfills contribute to large portions of air and water pollution, human health hazards, and GHG emissions due to proximity and inadequate management (Bruggers et al., 2021; Emalya et al., 2020; Gholampour Arbastan & Gitipour, 2022; Hamka et al., 2020; Rabl et al., 2008; Themelis & Ulloa, 2007; US EPA, n.d.-a; Waste360, 2018). Landfilling threatens the country's and its citizens' health and sanitation through foul odors, pollution, and the spread of diseases (Joshi & Visvanathan, 2019). Landfilling is also recognized to contribute to contamination levels and leachate impact, disrupting groundwater and soil health (Sholichin, 2012). Despite its harmful effects, landfilling remains one of the leading MSWM technologies worldwide.

Open Burning: Open burning, although banned in many countries, still occurs, especially in developing countries. It involves burning household and agricultural waste in the open and contributes to harmful pollutants (ASEF, 2021; Ferronato & Torretta, 2019; Gómez-Sanabria et al., 2022; Jain, 2017; Kaza et al., 2018; Schübeler, 1996). It was estimated that 16% of global MSW was burned in 2015 (Gómez-Sanabria et al., 2022). Lack of infrastructure and limited education on the complications associated with this practice in many developing nations led to around 5.5% of total MSW disposal in 2018 through open burning and dumping (Almazán-Casali et al., 2019; Sondh et al., 2022; Ziraba et al., 2016). Problems like odors, emissions, and pollution from open dumping contribute to climate change (Suhartini et al., 2022).

Incineration: Incineration accounts for nearly 11.1% of MSW processing (Almazán-Casali et al., 2019; Sondh et al., 2022). Waste undergoing incineration involves burning waste at high temperatures to reduce its volume and potentially process the resulting ash and gases into valorized waste by-products. Compared to open burning, incineration occurs inside designated facilities, which are typically highly controlled and monitored for safety. Incineration is said to reduce waste weight by up to 85% and volume

reduction of up to 96%, although achieving such high rates may be challenging for OW stream due it its high moisture content (Joshi & Visvanathan, 2019; RenoSam & Ramboll, 2018). Incineration is used when waste is found to be challenging to process further and is common in high-income or high-waste countries (Govind Kharat et al., 2019; The World Bank, 2018). Initially introduced to reduce the volume of waste accumulated by countries, incineration faces challenges related to emissions contributing to global warming and the difficulty of mineral recycling (Sondh et al., 2022). Incineration is still challenged for whether it is a sustainable waste treatment/disposal (Assamoi & Lawryshyn, 2012; C40 Cities Climate Leadership Group & C40 Knowledge Hub, 2019b; Rabl et al., 2008). Not only is this a question, but the high initial investment for transforming FW into syngas has been proven to be unfeasible due to the high-water content of food waste (Meng et al., 2015). However, with recent strides in research, researchers are finding ways to utilize bottom fly ash and biochar to contribute to the circular economy of waste (Babu et al., 2021; Fiksel & Lal, 2018; Sondh et al., 2022).

Anaerobic digestion (AD): AD is the process of degrading OW without oxygen, converting organic materials into value products such as biogas and fertilizer (Craig Coker, 2014; I. Sharma & Sharma, 2020; Tomić & Schneider, 2020; W. Xu & Huang, 2022). This technology offers a viable resource for WtE production and helps address increasing energy demands (Ferronato & Torretta, 2019; Sondh et al., 2022). Although AD creates valuable products, producing useful and high-quality products, it requires a significant initial investment (Sondh et al., 2022). AD is a sustainable SWM technology that helps keep waste within the loop by generating valued by-products.

Composting: Composting evolves the natural biodegradation of organic waste into nutrient-rich compost. It is one of the oldest Technologies for managing organic waste (Sarkar et al., 2016). Unlike AD, composting allows the presence of air, preventing the release of methane and promoting a biological process where carbon degrades and stabilizes into soil or fertilizer (Babu et al., 2021; C40 Cities Climate Leadership Group & C40 Knowledge

Hub, 2019a; Dume et al., 2021; Parihar & Sharma, 2021; Yasmin et al., 2022). Composting is a natural and versatile technology that can be implemented on both small and large scales, providing feasible and affordable options for households, communities, and organizations (Babu et al., 2021; Sarkar et al., 2016). Composting comprised 33% of the total MSW treated in 2018 (Sondh et al., 2022) and has been shown to contribute to increased crop production by 15-25% (C40 Cities Climate Leadership Group & C40 Knowledge Hub, 2019a; Sondh et al., 2022).

Recycling: Recycling involves the collection, separation, and processing of paper, plastic, glass, and metal to extend their useful life (Puntillo et al., 2021; UNESCAP & Waste Concern, 2017). It can be done at home for personal reuse, by scavengers for financial gains, or by companies for further circulation. Recycling accounted for 13.5% of the total share of MSW globally in 2018 (H. B. Sharma et al., 2021). Recycling plays a significant role in diverting waste from landfills and conserving natural resources (Ferronato & Torretta, 2019; Puntillo et al., 2021). Promoting recycling can help reduce energy utilization while also preventing methane generation from landfilled waste (Project Drawdown, n.d.). The materials that can be recycled do not easily break and can remain in the environment for lifetimes, emphasizing the importance of initiatives promoting the 3Rs, ‘reduce, reuse, recycle’ (UNESCAP & Waste Concern, 2017).

Waste-to-energy (WtE): WtE technologies convert waste into electricity or heat, helping to address energy demand. It can produce biogas and other valorized by-products (Sadef et al., 2016; Waste Concern, 2018). Biogas is a mix of methane, CO2, and other trace gases made from the decomposition of organic waste. AD also generates this energy source while producing organic digestate that can be used as an organic fertilizer (Suhartini et al., 2022). However, the high moisture content of waste in developing nations may limit the effectiveness of this process (Hettiarachchi et al., 2018). Despite the limitations, waste-to-energy technologies contribute to reducing waste disposed of through inappropriate means while generating renewable energy.

Thermal: Gasification and pyrolysis are potential treatment and disposal methods for MSW. These sound technologies operate sustainably and can derive biofuel and other valuable by-products (Fatimah et al., 2020).

Currently, landfills dispose of 37% of global waste (Kaza et al., 2018), despite the inadequacy of sustainable waste management (Araya, 2018; Schübeler, 1996; Themelis & Ulloa, 2007). Regardless of the well-known negative implications, open dumping and landfilling remain the primary waste disposal method, exacerbating environmental and human health crises (Anwar et al., 2021; Hamka et al., 2020).

By considering these various waste management technologies and selecting the most appropriate ones based on the local context, countries, cities, and communities can enhance waste management practices, promote sustainable development, and achieve environmental goals.

1.3.2 Specific Technologies for Organic Waste

The selection of OWM techniques depends on factors such as infrastructure, culture, financing options, and regulatory frameworks in place. Each country, city, and community have unique waste management technologies tailored to the specific waste composition and requirements. It is crucial to consider not only the waste composition but also the quality of the organic waste, as it greatly influences the outcomes of the treatment processes (Babu et al., 2021; Hettiarachchi et al., 2018; Sondh et al., 2022; Woon et al., 2021). Choosing the appropriate technology is integral to the success of waste management, mainly when the goal is recovery, which involves soil amendment and reducing contamination to extend the life of organic waste and promote clean and safe environments (Scholz & Hansmann, 2007).

Several methods can be employed to process organic waste effectively, including:

- **Composting:** Composting is a natural process that converts organic waste into soil amendment compost (Ayilara et al., 2020). It is widely recognized as a positive for organic waste management, contributing to sustainable

development and longevity of products (Lang et al., 2006). Composting at the household level has shown significant potential in waste reduction and avoiding such waste treatment (Lang et al., 2006). This can be done on a small scale (e.g., backyard composting) or a large scale (e.g., centralized composting facilities). On a larger scale, the process of co-digestion of source-separated organic waste can help achieve high levels of GHG emission reduction, where a study by Yoshida et al. found reductions ranging from 81.5kg Co2 eq/ton for windrow composting to 189kg CO2eq/ ton for co-digestion with sewage sludge (2012). Project Drawdown found that composting can help reduce GHG emissions by more than 50% compared to organic waste decomposition, making it an effective tool for organic waste management and emission reduction (Project Drawdown, n.d.). Composting also assists in soil strengthening and removes the need for chemical fertilizers, improving the capacity and environment for plant growth and has been shown to reduce erosion on slopes from rainwater flow (Storey et al., 2013). By diverting OW from landfills, composting enriches crops, gardens, and agricultural operations, making it an environmentally friendly approach to waste management (Kaza et al., 2016; Waste Concern, 2018).

- **Anaerobic digestion:** AD involves decomposing organic waste without oxygen (W. Xu & Huang, 2022). This treatment method utilizes bacteria to digest organic matter, transforming it into valuable elements and potentially yielding energy and nutrient-rich fertilizers (Singh et al., 2020; W. Xu & Huang, 2022). AD has gained popularity in developing countries due to its cost efficiency and potential for energy recovery (Joshi & Visvanathan, 2019). It has been identified as the preferred method for organic waste management in Asia, according to a study conducted by Joshi & Visvanathan(2019). Not only is this a preferred method, but AD helps to mitigate methane emissions that typically occur at landfills and during the open burning of waste by doing the conversion in a controlled environment (Ariunbaatar, Panico, Esposito, et al., 2014; Ariunbaatar, Panico, Frunzo, et al., 2014). Additionally, this by-product is a great substitute for fossil fuels, reducing waste contribution to emissions (F. Xu et al., 2018).

- **Vermicomposting:** Vermicomposting is an alternative form of composting that involves the addition of earthworms to aid in the decomposition process and produce high-quality compost (Lleó et al., 2013). The presence of earthworms accelerates the composting process and enhances the retention of essential minerals like nitrogen, phosphate, and potassium (Fatimah et al., 2020). Vermicomposting can be practiced in various settings, including large-scale operations, small-scale environments, agricultural operations, and home gardens (Fatimah et al., 2020). It is considered one of the most sustainable methods of organic waste degradation (Lalander et al., 2015; Lleó et al., 2013). A study by Cholilie et al. (2019) provides insight into the success of such composting initiatives in Indonesia.

- **Animal feed:** Food waste can be directly utilized as animal feed, providing a simple and efficient way to convert waste into a nutrient source for animals. This practice has been employed in both large and small-scale farming activities, such as chicken feed production at home or livestock nutrition (Jayathilake et al., 2022; McBride, 2021; Nath et al., 2023).

- **Waste-to-energy (WtE):** WtE technologies can reduce waste volume while utilizing waste as a resource for energy production. Examples include incineration and gasification; however, their feasibility may vary depending on environmental considerations, despite their economic viability (Sudibyo, Majid, et al., 2017). Biogas produced through AD can be upgraded to remove impurities, primarily the carbon dioxide content, and increase methane content, otherwise known as biomethane, which can be inserted into the natural gas grid or utilized as transport fuel (IEA, n.d.; Werkneh, 2022). Biogas contains various levels of methane, with a higher concentration of methane contributing to a greater energy content of the biogas produced, offering a major solution to methane generated from the mismanagement of organic waste (Chandra et al., 2011; Porpatham et al., 2008).

Currently, only 6% of FW is composted, while 4% is treated through methods like AD, incineration, and conversion into feedstock (Woon et al., 2021). The given

characteristics of food waste make it a wonderful feedstock for technologies such as AD (Lin et al., 2013; Meng et al., 2015; Suhartini et al., 2019). The need for pre-treatment is also interesting to explore, as it can alter the composition of the waste in order to be managed in alternative methods. A potential opportunity arrives from dehydration as a pre-treatment for food waste, helping reduce the mass by about 70%, making the waste easier to handle than wet waste, further preventing odors and biological decomposition (Sotiropoulos et al., 2015). Other methods, such as biological treatment through fungi and bacteria, have been explored. Studies have revealed that this fungal pre-treatment can improve glucose production, creating a higher bioethanol result from the treated food waste (Uçkun Kiran & Liu, 2015), as well as leading to increased methane yields prior to undergoing AD treatment (Yin et al., 2016).

These methods offer innovative opportunities and the potential for valorization, but when used scarcely, these benefits may go unfulfilled. Countries can simultaneously address energy scarcity and food insecurity, by implementing OW recovery strategies. Recovery serves as a powerful tool to address significant environmental, economic, and social factors on a global scale (Santagata et al., 2020). Implementing circular economy initiatives and annual savings of 1.7 billion tons of CO_2 is estimated to be possible (H. B. Sharma et al., 2021).

1.4 Municipal Food Waste Valorization

To consider municipal solid waste as mere trash after its initial use limits the potential benefits of continuous utilization and future life cycles. A sustainable waste management system can drive sustainable development and improve various aspects of society and the environment (Lang et al., 2006; Mesjasz-Lech, 2014; H. B. Sharma et al., 2021). The valorization of MOW refers to extracting value from waste through the abovementioned methods, aiming to reduce waste generation, promote resource efficiency, and minimize the environmental impact associated with FW disposal. It is important to note that the ideal way to manage waste is an overall waste reduction strategy. Understanding how much effort goes into producing and managing food waste and loss alone is staggering, with nearly 38% of total energy

consumption devoted to food that never gets consumed (Geneva Environment Network, 2016). Understanding the transformation in consumption patterns from “Buy Today, Eat Today” to the new supermarket centric “Buy one Get One” deals help to grasp this wasteful behavior making strides alongside the rise in urbanization in the Global South (Soma, 2018, 2019). However, as consumption rises, the demand for efficient and sustainably sound techniques is required to treat and dispose of produced waste sufficiently.

In line with the 2030 targets and the imperative need to curb GHG emissions, individuals and countries are embracing a more circular mindset to reduce dependence on landfills and capitalize on the valorization of FW. FW presents numerous avenues for creating value, including the production of organic fertilizer, livestock feed, and renewable energy (Arya et al., 2022; C40, 2019; Parihar & Sharma, 2021; Vinayaka & Kadkol, 2022; W. Xu & Huang, 2022). Currently, inorganic fertilizers contribute nearly 30% of all Nitrous Oxide emissions within the agriculture sector across the Asia-Pacific (APAC) region, and Asia contributes 61% of relevant emissions from synthetic fertilizers, in addition to other GHGs being emitted throughout the supply chain of these fertilizers (Prakash, 2022; Tubiello et al., 2013). Reducing the demand for such fertilizers could offer a potential recycling initiative and reduce emissions. Additionally, harnessing FW generated employment opportunities and fostered economic development (Santagata et al., 2020). While several of these practices are already prevalent in developed nations like the Netherlands, Japan, and Sweden (Fatimah et al., 2020; Sondh et al., 2022; Woon et al., 2021), the valuation of waste necessitates the presence of suitable technologies, an informed citizen, and government support to foster a circular approach to food waste management.

Assigning value to waste beyond its initial use enables the creation of new products and enhances existing operations through substitution. For instance, substituting mineral fertilizer with compost can positively impact palm oil plantation operations (Goh et al., 1999). Synthetic fertilizer has increased GHG emissions by 9.5 times from 1961 to 2019 due to its increased uptake, making Asia have the highest emissions from such fertilizers compared to the world (Prakash, 2022). In Malaysia, biogas production through anaerobic processing strengthens national climate

change governance and alleviates pressures on the waste and energy sectors (Woon et al., 2021). Singapore's anaerobic digestion operations, producing 45,000m3 of biogas and 78MWh/d of electricity, with 98.8% sold to the national grid, exemplify this trend (Tong et al., 2018). Similar trends are observed in Denmark (Khoshnevisan et al., 2020) and Norway (Ahuja et al., 2020), where food waste aids in generating renewable energy and reducing reliance on fossil fuels. WtE conversion represents one facet of FW valorization, while waste-to-material processes yield cementitious and construction materials, as well as soil fertilizers (Fiksel & Lal, 2018; Sondh et al., 2022; Woon et al., 2021). Furthermore, producing wax, bio-oils, and biochar from FW addresses the growing energy demands associated with urbanization (Nanda & Berruti, 2021; Sondh et al., 2022).

Waste valorization is viewed as preserving the environment and natural resources (Sondh et al., 2022). Life cycle assessments (LCA) are proposed to investigate these materials' environmental feasibility and potential application in agriculture, cooking, electricity generation, and vehicle usage (Ferronato & Torretta, 2019; Woon et al., 2021). Within the context of the circular economy, the goal is to retain waste within operations for as long as possible, diverging from the traditional linear model of take-make-waste (Fiksel & Lal, 2018; Khandelwal, Dhar, et al., 2019; Zorpas et al., 2021). By reintegrating FW back into the biosphere or repurposing it for other uses, its life cycle is renewed. This concept holds substantial potential for improving existing MSWM systems worldwide.

Although diverse operations and infrastructures are required, every country has the potential to adopt an "intermediate technology" approach (Patnaik & Bhowmick, 2019). The valorization and recycling of waste contribute positively to the environment and stimulate economic growth in developing economies, combating the hazards associated with improper waste management techniques. The success of these efforts hinges upon the entire waste management pathway, including source separation at the individual level. The management and recovery of organic waste pose multidimensional challenges and opportunities that necessitate transdisciplinary solutions to adequately address, mitigate, and fully capitalize on the potential of organic waste. It becomes crucial to synergize and resolve existing conflicts within national policies to achieve success in OWM (Mak et al., 2020).

1.5 Developing Nations MSWM

In developing countries, the waste composition is predominantly biodegradable, accounting for approximately 65-70% (Kaza et al., 2016). The burden of treatment and disposal of organic waste continues to strain developing nations' sustainable development, where other urgent matters remain a priority to manage while having limited resources to do so; in such cases, developing nations fall short on waste management (Joshi & Visvanathan, 2019). Typically, waste in these countries is rarely separated into categories, with wet waste consisting of food and organic matter and dry waste including recyclables (Gertman, n.d.; Storey et al., 2013). MSWM services consume a substantial portion of municipal budgets in developing countries, with 20-50% allocated for the total expenditure and 80-90% dedicated to waste collection (Hoornweg & Bhada-Tata, 2012). Consequently, waste management becomes the costliest service expenditure for these nations (UN Habitat, 2010). Challenges exist for numerous reasons, a significant struggle being a lack of monitoring and data collection (Jain, 2017), further preventing the potential success of systems.

The success of MSWM systems in developing countries is highly dependent on the existing market conditions, meaning there is no one-size-fits-all solution. Various socioeconomic factors can make implementing MSWM solutions more (Ghisellini et al., 2016; Hettiarachchi et al., 2018; Tsai, Bui, Tseng, & Wu, 2020)8; Tsai, Bui, Tseng, & Wu, 2020). While the world’s reliance on fossil fuels continues to threaten negative impacts on these factors, adding avoidable costs and risks (Lin et al., 2013; Mahmood et al., 2016). Limited financial support, government enforcement, and regulations pose barriers to adopting circular waste management practices in low-income nations compared to developed countries (Arya et al., 2022; Ilić & Nikolić, 2016; tearfund, 2019; Tsai, Bui, Tseng, & Wu, 2020). The marketability of waste recovery operations is often overlooked, and leveraging the transformation of waste products can be more effective than solely implementing regional waste management practices (Lang et al., 2006). Multi-stakeholder engagement becomes crucial to emphasize the importance of these operations. Implementing circular

bioeconomy operations can enhance competitiveness and alleviate poverty (Mak et al., 2020). Understanding basic business principles, such as supply and demand, can also improve developing countries' recycling schemes and market conditions (Lang et al., 2006).

As stated by Lang et al. (2006), the primary purpose of waste management is to find ecologically sound solutions under the current economic barriers that may lead to optimal results. Despite the challenges, appropriate technologies exist for improving MSWM in developing countries. Waste Buy Back Programs, Waste-to-energy, Recycling, Biomass production, and collaboration with the informal sector are some possible solutions (Hettiarachchi et al., 2018; Hondo et al., 2020; tearfund, 2019; UN Habitat, 2010). The challenges that may arise with biomass derive from the varied supply chain, including supply and demand, weather conditions, technology, and regulations (B. Sharma et al., 2013). The supply chain is important and requires much consideration to successfully fulfill demands and ensure environmental sustainability (Gold, 2011; Yue et al., 2014).

High-income nations have implemented comprehensive policies and tools to manage increasing flows of municipal solid waste, such as the EU Waste Framework Directive, the amendment EU Directive 2018/851 7, the EU Landfill Directive 1999/31/EC 8 and the amendment EU Directive 2018/850 9, the EU Directive on packaging and packaging waste 94/62/EC 10 and the amendment EU Directive 2018/852 11, the 3 R's strategy in Japan 12 and the Resource Conservation and Recovery Act 1976 13 in the United States (Ghisellini et al., 2016; Gómez-Sanabria et al., 2022; Naustdalslid, 2014). However, despite the established regulatory frameworks, low-income countries face persistent problems due to limited funds, planning, laws, expertise, and technology availability (Gómez-Sanabria et al., 2022; Schübeler, 1996; The World Bank, 2018). Many developing countries have agreements and regulations such as Law No. 18/2008 and Regulation No. P.76/Menlhk/Setjen/ Kum.1/10/2019 (ADIPURA) in Indonesia (Anwar et al., 2021; CCAC, 2020). Developing countries have established agreements and regulations, but the enforcement and compliance aspects are often lacking, exacerbating MSWM problems alongside urbanization and population growth.

Developing nations have been recommended to adopt reduction plans for ecological footprints and transition to a circular waste model to achieve sustainable development and economic growth. Open dumping and inadequate waste management practices are common in low and middle-income countries, perpetuating inequalities and undermining MSWM systems (CCAC, 2020; Ddiba, 2022; Ferronato & Torretta, 2019; The World Bank, n.d.-b). Composting and biogas generation are suggested as more suitable solutions for MSWM in developing countries (Ferronato & Torretta, 2019; Gómez-Sanabria et al., 2022). The transformation of organic waste has shown promising results for sustainable development and has gained momentum in recent years (Lang et al., 2006). However, scaling up composting faces challenges due to subsidies and other barriers to entry, while AD requires significant capital investment, expert staff, and costly equipment (Arya et al., 2022). The full potential of composting efforts in low-income countries is yet to be realized, with only an average of 1.5% of MSW effectively utilized (Hoornweg & Bhada-Tata, 2012). Implementing a bio-based economy can significantly address critical obstacles like climate change, population growth, resource dependency, and rising consumption levels (Mak et al., 2020). It is estimated that with increased levels of composting worldwide, a substantial reduction in GHG emissions is made possible, helping reduce emissions by 2.1 billion tons by 2050 and offering a significant opportunity to mitigate emissions associated with organic waste (Oakes, 2020).

With rapid urbanization and population growth in developing nations, resource management has become a critical concern, such as in Asia (Hotta, 2010). Legislation and regulations are crucial in successfully implementing MSWM for sustainable development in low-income countries. The regulations applied in the EU may not be directly applicable to developing countries, necessitating case-based solutions and their enforcement. Decentralization and IRRC are recommended for effective SWM in developing nations, with estimates suggesting that 80-90% of APAC waste could be converted into valuable resources (Storey et al., 2013). Transitioning to decentralized waste management techniques, can improve operational efficiency, space utilization, and feed requirements (Joshi & Visvanathan, 2019). Initiatives at the community level focusing on composting and anaerobic digestion technologies are particularly suitable given waste characteristics, energy

footprint, simplicity, resource needs, acceptance, and financial requirements (Joshi & Visvanathan, 2019).

Given the alarming rates of waste generation and inadequate waste management practices in developing countries like Indonesia, it is imperative to prioritize the development of sustainable waste management strategies, especially for organic waste. A surge of OW is inevitable due to the foreseeable increase in population and urbanization. Effective OWM presents opportunities for innovation, job creation, and mitigation of ecological crisis (C40 Cities Climate Leadership Group & C40 Knowledge Hub, 2019a; Ferronato & Torretta, 2019). However, it often receives insufficient attention compared to other sectors requiring heavy investment (Hondo et al., 2020). These challenges still need to be addressed, including budget constraints, social acceptance, poor management, and limited policy and governance support (Joshi & Visvanathan, 2019).

1.6 Waste Management in Indonesia

Indonesia has a surface area of 1,910,931 square kilometres and consists of approximately 18,110 islands and islets and is the world's third-largest emitter of GHG emissions from its waste sector (ASEF, 2021; Consulate General of the Republic of Indonesia in Vancouver, n.d.). The country is vast and unique, with only 6,000 islands inhabited (Consulate General of the Republic of Indonesia in Vancouver, n.d.; Jain, 2017). As the world’s fourth most populous country, with a population growth rate of 1.12%, Indonesia grapples with a population density of 142.57 people per square meter as of 2018 and an expected increase in waste generation (Statista, n.d.-a). Numerous individuals reside in close proximity to landfills, with over 3000 families inhabiting the Bantar Gebang Landfill in Indonesia (Waste360, 2018). This close coexistence inflicts detrimental health effects on citizens (Hamka et al., 2020), generates environmental pollution (Babu et al., 2021), and imposes severe economic pressures (World Bank, 2012). Urbanization is rapidly increasing in Indonesia, with approximately 57% of the population living in urban areas and an annual growth rate of 2.7% (Jain, 2017; The World Bank, 2021). By 2030, over 73% of Indonesians are expected to reside in cities (ASEF, 2021; Asian

Development Bank, 2022; Martinez & Masron, 2020), 2022; Martinez & Masron, 2020). The population of Indonesia has been steadily growing, reaching 273.8 million in 2021, a significant increase from 244 million in 2010 (Data Commons, 2022). The country is experiencing economic growth, with a GDP growth rate of 5.31% projected for 2022 and over half of the GDP is derived from household consumption (Shibata & Damayanti, 2023). In recent years, Indonesia has undergone a structural shift from an agricultural focus to alternative economic sectors (Anwar et al., 2021). However, the COVID-19 pandemic substantially impacted Indonesia's GDP, dropping its growth rate to 2.5% (Asian Development Bank, 2020). This placed immense stress on the country and required finding a solution to encourage growth.

As economic growth, urbanization, and an increasing population are prevalent in Indonesia, waste generation is expected to rise. Major cities are projected to produce approximately 8 million tons of waste daily (ASEF, 2021). Jakarta alone generates more than 10 million tons of waste annually, which is expected to increase, putting further strain on waste management systems (Fatimah et al., 2020). The daily generation of MSW in Indonesia is estimated to be 194,002 tons, with urban centres contributing the majority (ASEF, 2021). Organic waste accounts for a significant portion of Indonesia's MSW composition, around 60% (Jain, 2017). Emissions from food waste alone contribute to 7.29% of Indonesian GHG emissions (Cahyani et al., 2022). The growing amount of food waste in Indonesia could be due to transforming consumption behaviors, a growing income, and limited awareness regarding sustainable waste management practices (FAO, 2013).

Household waste constitutes nearly 40% of the waste disposed of in landfills daily, and a significant portion of this waste is organic, such as 61.35% in Medan City and 49.7% in Jakarta (ASEF, 2021; Khair et al., 2019; Saraswati, 2022). If not disposed of in landfills, households often resort to open burning, accounting for 53% of waste disposal practices (Sabarinah & Djaja, 2017). Illegal dumping and burning remain a prominent disposal method, without any utilization of produced methane; a missed opportunity (Farahdiba et al., 2023; Indonesia, n.d.). Finding appropriate disposal methods helps keep the environment clean and the air less polluted and could be leveraged for alternative value propositions. Waste sorting at the household level is

only practiced by approximately 9% of households, with reasons against doing so mainly being laziness or lack of awareness and education (Sabarinah & Djaja, 2017).

Mismanaged waste is a significant concern in Indonesia's society. Waste in Indonesia follows a typical flow of collection, transportation to temporary collection points (TPS) and then to the waste's final disposal centre (TPA) (Fatimah et al., 2020). Only 50% of waste is collected, primarily by Urban Local Bodies (ULBs), while the remaining waste is handled by waste pickers and scavengers from the informal sector (Jain, 2017). Landfilling is the predominant technology for MSW disposal in Indonesian cities, accounting for 95% of the waste management system in Surabaya (Wibisono et al., 2020). As landfills are rapidly reaching maximum capacity, immense pressure is placed on the environment, human health, and funding, and they will face even more significant challenges with projected population growth (Sabarinah & Djaja, 2017).

In terms of GHG emissions, Indonesia's sources include forest and land conversion (50%), energy (34%), waste (7%), and agriculture (6%) (Anwar et al., 2021; ASEF, 2021). Emissions from the waste sector alone amounted to approximately 127 billion tons of CO2 in 2020 (Badan Pusat Statistik, 2020). Landfilling and burning, the main disposal methods for Indonesia's MSW, contain high organic content, exacerbating GHG emissions and producing numerous pollutants and leachate concentrations. Properly managing this waste stream can reduce GHG emissions in Indonesia significantly. However, composting and recycling efforts in the country are currently unregulated and inadequately implemented, lacking safety measures and proper infrastructure (ASEF, 2021; Sabarinah & Djaja, 2017), which hampers the transition to sustainable development and robust waste management practices.

The Government of Indonesia has committed to lowering GHG emissions through its 2021 Nationally Determined Contribution (NDC) document (ASEF, 2021), setting unconditional and conditional reduction targets of 29% and 41%, respectively, by 2030 (Anwar et al., 2021). Although Indonesia already has a decentralized waste management system, it lacks the benefits that could be derived from it (Fiddin et al., 2018; Storey et al., 2013; Wardhana, 2019; Wätzel et al., 2015).

Despite these lofty goals set by the Indonesian government for sustainable frameworks, the lack of coordination among stakeholders, weak governance structures, and limited infrastructure create obstacles to achieving these objectives. Disturbingly, Indonesia has experienced over 70% of 3R waste management facilities (TPS3R) and 40% of Integrated Waste Management Facilities (TPST) abandoned, or their status remains unknown, with more people resorting to open dumping methods for waste disposal (SYSTEMIQ et al., 2021). Additionally, a mere 1.5% of MSW across SEA undergoes composting technologies (Hoornweg & Bhada-Tata, 2012). Given Indonesia's current operations and history, the attainment of their 30% waste reduction at source and 70% waste handling by 2025 is a challenging goal to achieve because of the anticipated surge in MSW in the years ahead coupled with inadequate infrastructure (SYSTEMIQ et al., 2021).

Indonesia has various existing legislation and regulations related to MSW, but compliance levels among stakeholders could be higher. Waste management policies exist at the national level, under the jurisdiction of the Ministry of Environment, while other actors play specific roles throughout the waste management cycle (Jain, 2017). However, sustainable development challenges persist in Indonesia due to weak public and private sector engagement, resource management issues, and the demands of economic development. Barriers to adopting adequate MSWM technologies include a lack of financial support, social issues, limited political action, inadequate human resources expertise, and a need for data and information on waste management (ASEF, 2021). Without robust support systems, addressing such a complex multi-level challenge to reduce Indonesia's ecological footprint while creating a healthy environment for its citizens can seem insurmountable. A comprehensive assessment is necessary to find more effective because a significant portion of municipal budgets is already allocated to waste management (Hoornweg & Bhada-Tata, 2012).

Zero waste was introduced in Indonesia in 2016, with implementation scheduled to begin in 2020; however, the COVID-19 pandemic has caused complications and interrupted these efforts. Indonesia has adopted the 3R concept of "reduce, reuse, recycle" through programs such as solid waste banks supporting Indonesia Law No. 18/2008 on solid waste management (Khair et al., 2019). Prior to the enactment of

this law 18, “end of the pipe” solutions were used, discarding waste simply as trash and not as a resource, with continual exploitation of fossil fuels as opposed to the potential valorized products like bioenergy (Farahdiba et al., 2023). The lack of infrastructure, marketing and waste valorization has proven to make this law ineffective (Damanhuri et al., 2014; Soma, 2017b). Initiatives like these offer the potential for citizens to benefit financially from participating in the waste management process. However, due to a lack of awareness, inadequate safety measures, and limited government collaboration with communities, the potential rewards of such operations still need to be fully realized (Sabarinah & Djaja, 2017). When properly implemented, initiatives like these are expected to yield significant results, such as the potential diversion of 91.69% of waste generated in Medan City from landfills and its integration into the circular economy (Khair et al., 2019).

Another legislation enacted by the Indonesian government concerning MSW is Waste Management Law No. 18/2008, which tries to ensure enforcement of local governments and stakeholders to dispose of according to laws (Khair et al., 2019). This law contributes a definition of food waste which includes food waste as a result of distribution and consumption, as opposed to agro-industrial insufficiencies, characterized as food losses (Farahdiba et al., 2023). Other legislation enacted by the Indonesian government related to MSW includes:

- Government Regulation No. 81/2012, which addresses economic-oriented household waste management,
- Ministerial Decree of the Environmental Department Act No. 13/2012, which focuses on reducing, reusing, and recycling actions through waste banks,
- Ministerial Decree of the Interior No. 33/2010, which involves the community as waste producers in the waste management system,
- Ministerial Decree of Public Works No. 03/2013, which governs household waste management, and
- Presidential Regulation No. 97/2017 pertains to the national policy and strategy for household waste.

Indonesia requires a comprehensive approach to managing its organic waste. This approach may include more robust enforcement of existing regulations, enhanced stakeholder engagement, increased financing for infrastructure, improved public awareness and education, and overall promotion of sustainable waste management practices. The collaboration between stakeholders is essential for implementing effective and lasting solutions and thus achieving the targets set out in Indonesia's NDC. By adopting more sustainable waste management practices, Indonesia could significantly reduce its GHG emissions, mitigate environmental pollution, and create a healthier and more sustainable future for its citizens.

1.6.1 Challenges / Opportunities of the Municipal Organic Waste Sector in Indonesia

Indonesia exemplifies dedication to circular economy principles through their National Medium-term Development Plan (RPJMN) for 2020-2024, presenting economic and environmental resilience potential. However, barriers to success persist in Indonesia's current practice of MSWM, hindering the implementation of sustainable solutions for managing the existing and anticipated increase in waste. Some of the significant challenges and opportunities in the municipal organic waste sector are:

- **Lack of collaboration and integration of all stakeholders**: Indonesia faces challenges in creating a reliable and efficient MSWM system due to minimal private sector engagement, limited government enforcement, and little social awareness about environmental measures. It is crucial to foster stakeholder collaboration and engagement to develop a comprehensive waste management system.
- **Limited expertise, funding, and technological improvements**: Sustainable technologies such as composting, WtE facilities and landfill gas recovery offer potential solutions for managing the organic waste fraction. However, cities in Indonesia struggle with limited expertise, funding, and technological advancements, making it challenging to leverage appropriate technologies for sustainable development.
- **Limited regulations, enforcement, and compliance**: The lack of robust regulations, enforcement mechanisms, and compliance make it challenging to

ensure sustainable management of MSWM in Indonesia. The country must adapt and establish concrete goals and associated frameworks that all stakeholders can agree upon.

- **Circular mindset**: Introducing a circular mindset among households, the private sector, and governments could be a key driver for energy recovery, improved agricultural operations, and reduced GHG emissions. Emphasizing the circular economy approach can create opportunities for sustainable waste management practices.

1.7 Relevance of Subject

Organic waste management in Indonesia is highly relevant due to its connections with various SDGs (United Nations, n.d.-c). Waste management aligns with at least seven out of the 17 SDGs, see Figure 1. Understanding and improving waste management has the potential to trickle positive effects within 7 of the 17 SDGs is the driving force of this field of research aimed to be understood throughout this thesis.

ASEAN comprises ten Southeast Asian countries, including Indonesia, Malaysia, the Philippines, Singapore, Thailand, Brunei Darussalam, Cambodia, Laos, Myanmar, and Viet Nam, and have a combined population accounting for nearly 8.8% of the world's population (Jain, 2017). As the global population increases, food consumption and, thus, food waste is rising (Suhartini et al., 2022). These countries have in common the lack of engineered landfill sites and rehabilitation programs for dumpsites, further exacerbating the pressures on society, the environment, and the economy (Jain, 2017). Recognizing this urgent need, a UN report on Waste Management in ASEAN countries emphasizes creating attractive business opportunities for proper closures and restoration of dumpsites (Jain, 2017).

Among the ASEAN nations, the per capita MSW is 1.14 kg/capita/day (Jain, 2017). Significantly, organic waste constitutes the highest fraction, accounting for over 50% in all locations except Singapore (Jain, 2017). Indonesia faces the highest annual MSW generation totalling 65.8 million tons, with organic waste comprising 60% (Jain,

2017; Wang et al., n.d.). This alarming trend is exacerbated by Indonesia's rapidly growing economy and a 2.7% urban growth rate, highlighting the urgent need for effective strategies to mitigate the ongoing waste management crisis (Jain, 2017).

Regulating and repurposing organic waste in Indonesia promises substantial benefits, including reduced GHG emissions, improved societal welfare, and economic relief. Progressive approaches to organic waste management systems can serve as a lever for sustainable development, making it vital to comprehend the complexities of implementing circular economy operations in this context. By embracing this challenge, Indonesia can make significant strides in combating climate change and uplifting communities.

While Indonesia has initiated pilot projects and backed initiatives such as IRRC and buyback programs, these endeavours must improve their financial and regulatory support deficiencies across multiple levels. In some instances, digesters no longer operate due to a lack of citizen knowledge, emphasizing the need for education surrounding new waste management solutions (Suhartini et al., 2022). An example of AD projects in Indonesia for FW includes the Malang Regency IRRC, a decentralized community plant that handles up to 90% of FW cost-effectively (Farahdiba et al., 2023). To ensure the success and durability, these projects require regulatory adjustments to soil and fertilizer schemes, enabling domestic compost to compete and generate profit. The reduction in synthetic fertilizers could help reduce levels of nitrogen pollution across Asia (Prakash, 2022). Additionally, committed financial support from all stakeholders and increased awareness and education on organic waste management are essential for the success of these initiatives.

Like many SEA countries, Indonesia faces numerous challenges in its pursuit of sustainability, with weak land and natural resource management being a prevalent issue. Notably, since 1990, Indonesia has witnessed a staggering 313% increase in GHG emissions, further highlighting the urgency of addressing waste management alongside other sectors like energy and agriculture (Jain, 2017; Orim, 2020). Overcoming these hurdles necessitates significant financial and institutional frameworks for developing circular operations and a strong focus on raising awareness and education on organic waste management.

Regarding essential resources for successful sustainable development, Indonesia faces many hardships, with no significant financial or institutional frameworks for developing circular operations in the country regarding waste (Jain, 2017). Lack of awareness and education is of the leading factors in unsuccessful organic waste management (Kaza et al., 2016). Across the developing nations in SEA, many need appropriate regulations and enforcement regarding MSW (Hettiarachchi et al., 2018). It becomes time to reframe the idea of ‘waste’ and nurture a new growth model in which circularity is prevalent (Hondo et al., 2020).

One mode of pollution mitigation, energy access, economic potential, and enriched agricultural lands is the recovery and conversion of organic materials (derived from waste) to create value in energy or compost (Ferronato & Torretta, 2019). An elaborate, multi-level plan to support a nature-based solution of waste to value may provide the stimulation to reach the 2030 sustainable development goals.

The recovery and conversion of organic waste hold immense potential in mitigating pollution, providing energy access, unlocking economic opportunities, and enriching agricultural lands. By leveraging organic materials derived from waste to create value in energy or compost, Indonesia can actualize nature-based solutions that align with its sustainable development goals.

However, the success and durability of compost and biogas technologies rely heavily on multi-level support, which poses a significant challenge due to the lack of comprehensive backing (Kaza et al., 2016; The World Bank, 2017). Overcoming these barriers requires marketing efforts to create awareness and profitability for innovative organic waste processing techniques such as windrows (Lang et al., 2006; Storey et al., 2013). Additionally, addressing the barriers posed by subsidized fertilizers and soils in the market is crucial for domestic compost to generate profit. Education and awareness campaigns can help households adopt better methods to separate and utilize their organic waste, contributing to the sustainability of these processes.

Across ASEAN, waste management insights remain limited, with a particular need for more accurate and up-to-date data in Indonesia. Investing in waste statistics is essential for monitoring the success, failures, opportunities, and challenges in the waste management sector. Assessments and studies encompassing waste generation rate, composition, collection rate, recycling, and energy recovery rates, accompanied by a clear dissemination strategy, can provide valuable insights for managing these complex issues (Jain, 2017). Furthermore, exploring the economic benefits of recycling schemes, including savings, revenues from transformed goods, and grants, is a viable alternative to inadequate disposal (Lang et al., 2006). ASEAN's establishment of "Blueprints" for sustainable development and waste management underscores the need for accurate and consistent statistics.

Developing sustainable organic waste management practices that effectively reduce emissions and address environmental and social challenges is crucial for achieving Indonesia’s sustainable development goals. However, with minimal regulation, financing, and awareness, the prospects of “closing the loop” appear difficult. Furthermore, implementing MSW composting and waste-to-energy initiatives that utilize MOW in a recovery manner holds significant potential for reducing GHG emissions across sectors and advancing sustainable development goals.

In conclusion, managing OW in Indonesia presents challenges and opportunities for sustainable development. By understanding the intricacies of CE operations and implementing innovative solutions, Indonesia can pave the way for significant reductions in GHG emissions, improved societal welfare, and economic relief. However, these endeavours require robust financial and regulatory support, increased awareness and education, and comprehensive waste statistics to monitor progress and inform future strategies. Through substantial efforts to repurpose OW, Indonesia can bring new life into this abundant resource, benefiting households, fuelling homes, nourishing gardens, and empowering communities.

2 Methodology

This section will discuss and justify the research methods for this thesis. A brief description of the structure and methods and a detailed overview of the topic choice will be mentioned. Finally, the presentation of action plans will be examined and defined further.

2.1 Introduction

Studying Municipal food waste is integral to achieving a sustainable and resilient society. Learning how to properly manage and value municipal food waste is relevant to transforming many facets of society, from land use to human health, resource management, and pollution. Focusing on developing countries, specifically Indonesia, with large amounts of household food waste ending up in landfills, contributing to numerous harmful effects on humans and the environment, discovering the options for better management techniques is essential to build thriving cities and communities. Closing the loop through waste valorization is a vital initiative with many avenues for implementation; thus, studying the various ways to achieve sustainable development through MSWM is critical to reaching the UN's 2030 SDGs.

2.2 Research Design

This study aims to examine the state of municipal food waste management in Indonesia to further understand the potential avenues of sustainable development by adjusting this sector. Concepts of Circular Economy are looked at as resources for innovation and inspiration. To achieve the research objective and answer the relevant research questions, the underlying phenomenon for this research exists as follows:

1. The data must be up to date.
2. The collected information must be relevant to municipal solid waste management systems.
3. The data must be analyzed from a unbias perspective and be open to the possibility of multiple proposed solutions.

4. Data should focus on the organic aspect of MSW.

As seen in the previous section, state-of-the-art knowledge has been conducted to support claims of waste's detrimental effects on people, the planet, and profit. This intensive literature review and overview of relevant waste management structures form a knowledge base to better understand Indonesia’s struggles. This case study answers the ‘what,’ ‘how,’ and ‘why’ questions regarding Indonesia's food waste management. This research will be completed using qualitative methods, being inductive and exploratory. The methodology is a single case study and an overview of global best practices.

Further enabling a comparative analysis to highlight the ‘why’ of certain countries' waste management strategies and the potential within the Indonesian context. This methodology is selected to gather details and conduct an intensive analysis of food waste management in Indonesia, thus comparing it against other countries' practices. Through this in-depth analysis, the case study will provide focus and generate clear aims for improving food waste management in Indonesia. The principles, lessons, and practices can lead to transferability using case studies and comparative analysis.

The research will determine if uniformity exists if differences persist and how this affects the environment for action. Given the time constraints and research question, a cross-sectional time horizon has been selected. This will help us understand the current state of food waste management and result in relevant and diverse knowledge, see Figure 9 below.

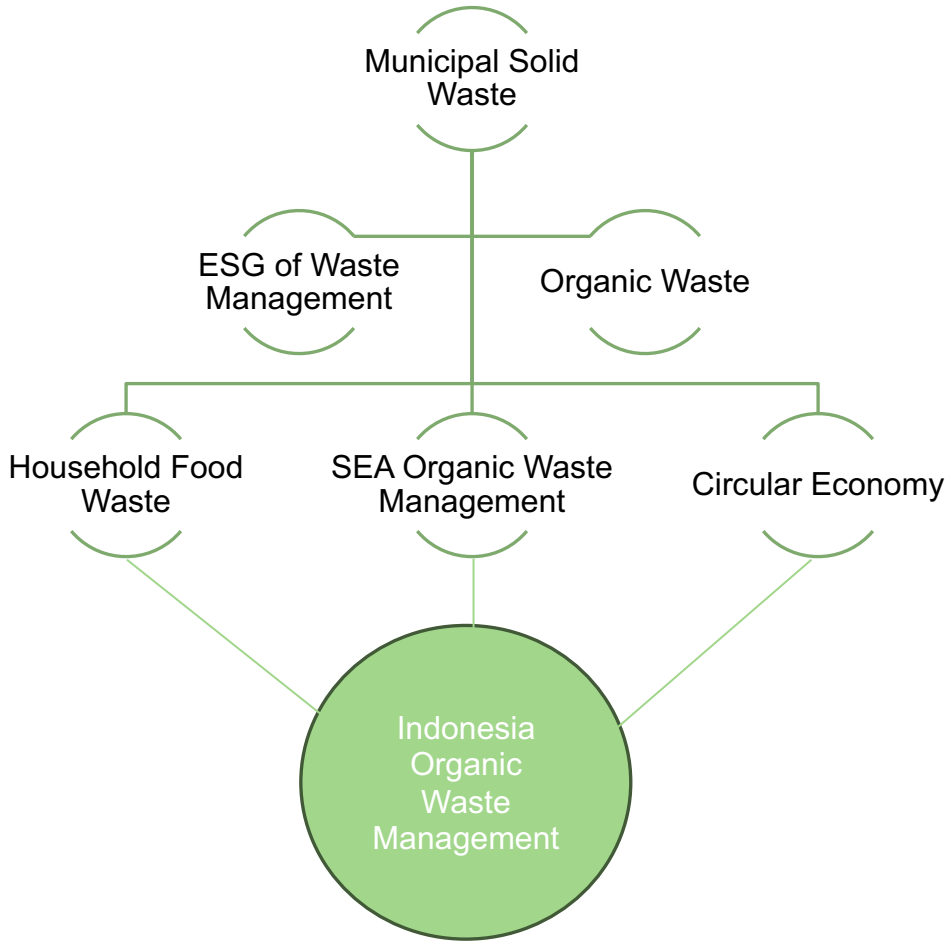

Figure 9

Research Framework.

2.3 Data Collection

This study seeks to expand and bring together numerous research on topics of relevance to the research question. This research is conducted utilizing secondary data sources. The pre-existing data is sourced from reports, case studies, documentation, and articles. Sourced have been collected via google scholar, JSTOR, ResearchGate, The World Bank, and other international bodies' websites. Using multiple sources helps to collaborate knowledge and bring the bigger picture together. An overview of the collection process is described in Table 2. A chain of evidence is further a result of this diverse data collection and case study visualization.

Research Question	Type of Information Needed	Data Source(s)	Access Method

How can municipal waste management systems leverage the potential of organic waste to contribute to sustainable development in Indonesia?	-Existing organic waste management practices in Indonesia -Potential organic waste disposal methods -Capacity for circular economy in Indonesia	Secondary data -Reports -Articles -Organization -Country data -Media	Retrieve online -Review and examine papers and report
What are some best practices from other countries that have successfully implemented circular economy models for organic waste management?	-Global success in organic waste management -Why has it been successful for certain countries -What methods are used	Secondary data -Reports -Articles -Organizations -Media -Case studies	Retrieve online -Review and examine papers and report

Table 2

Types of data and information needed, how it is sourced and further accessed.

2.4 Data Analysis

The data collection from secondary sources will be further analyzed through thematic and discourse analysis methods. This information will be transcribed and processed through themes, then presented and discussed regarding the research objectives. The collected data will be analyzed through qualitative means and is described in Table 3 below;

Data and Information Collected	Method of Analysis
• Existing organic waste management practices in Indonesia • Potential organic waste disposal methods • Capacity for circular economy in Indonesia • Awareness levels	**Qualitative Method & Discourse Analysis** **-**Analysis of literature about existing management practices, disposal techniques, and levels of awareness from citizens
• Global Success in organic waste management • Why has it been successful for certain countries • What methods are used	**Qualitative Method & Thematic Analysis** - Analysis of global best practices, government interventions, citizen engagement, and other factors of success through a literature review

Table 3

Data and information collected and its associated method of analysis.

2.5 Research Limitations

When seeking to answer the research question, “How can municipal waste management systems leverage the potential of organic waste to contribute to sustainable development in Indonesia?”. Through the utilization of secondary data and undergoing qualitative analysis, potential limitations are possible such as:

Data quality & availability: When looking at data from developing countries such as Indonesia, there is a lack of data collection and reporting. The data may be incomplete or outdated, lacking specific insight into the research question. The credibility is also questionable, however, this paper attempts to leverage the available information to the best of its ability.

Generalization of findings: When using qualitative methods, research tends to be specific or generalized to sample sizes, which could provide indirect results and insight into answering the question. The data may not apply to all countries, cities or communities and vary in context.

Lack of control of variables: Since data collected and examined is secondary, there is limited control over certain variables included within data sets. This challenges the accuracy and detail of this specific analysis and does not allow for precise manipulation or measurable aspects.

Potential bias: All data is secondary, hence the innate biases within the original researcher’s data collection methods and reporting style. This requires diligent evaluation of sources to ensure validity.

Lack of real-time data: Secondary data inherently represents time differences in reporting. The data collection examined and utilized in this research is subject to potential time lag difficulties, limiting the immediate impact and relevance of data collected for presenting findings.

To ensure this research combats as many limitations as possible, the research will critically assess the reliability of the data sourced and used. Furthermore, data

accessed will be cross-referenced between one another and examined for similarities or disparities. By acknowledging this, the research hopes to ensure that the information provided is unbiased and sufficient in answering the question.

Now that the research method is explained, the Indonesia case study will be presented and examined in the following section.

3 Case Study: Indonesia

3.1 General Overview

Indonesia is a diverse archipelago nation in Southeast Asia, consisting of approximately 18,307 islands and islets, with only 6,000 known to be inhabited (Consulate General of the Republic of Indonesia in Vancouver, n.d.; WorldData, n.d.-c). It is home to the third-largest tropical rainforest in the world and possesses vast natural resources crucial for long-term sustainable development (The World Bank, 2022). The country is characterized by its rich cultural heritage, with over 300 ethnic groups residing across the many islands (The World Bank, 2022). This diversity brings many food cultures influenced by Malay, Chinese, Arab, and Dutch traditions (Soma, 2017a). Regardless of cuisine culture, rice remains a staple in Indonesia; from cultivation to consumption, there is a rich history and relationship with rice. However, the supply chain of rice is less sustainable than one may believe and contributes a large amount of GHG emissions sitting at 65.19% of total methane emissions in Indonesia between 2015 and 202 (Afiyanti & Sari Handoko, 2019; Naik, 2023).

Urbanization and population growth are rapidly occurring in Indonesia, with eleven cities surpassing one million residents and Jakarta alone having over ten million residents (Martinez & Masron, 2020; *Population of Cities in Indonesia 2023*, 2023). The urbanization rate is around 57% of the population, indicating a continuous trend (Statista, n.d.-a). As the fourth most populous country in the world, Indonesia is facing the challenges of urbanization (Kamal et al., 2022; The World Bank, 2022) while striving for economic growth (Sulaiman & Nangoy, 2023), which will result in a

significant increase in waste generation. Currently, Indonesia is known to be the second-largest food waste producer across the globe, disposing of an estimated 13 million tons per year, urging response from stakeholders to take action to mitigate associated adverse effects with management operations (Farahdiba et al., 2023; Ong et al., 2018; Suhartini et al., 2022). Some factors that contribute to this high level of food waste generation include low environmental knowledge and awareness, purchasing/consumption behavior, and limited adequate infrastructure (Dhokhikah et al., 2015; Kasavan et al., 2019; Mattar et al., 2018; Soma, 2017a). With consumption patterns increasing, solutions to resolve food waste can help increase incomes, and provide adequate nutrition in Indonesia and other developing nations experiencing similar trends (Farahdiba et al., 2023).

Indonesia is estimated to produce over 65.8 million tons of solid waste annually, which averages around 232kg/person (Jain, 2017; Ministry of Environment Denmark, 2022). By 2050, municipal solid waste in Indonesia is projected to reach 83.8 million tons (Anwar et al., 2021). In 2020, 30% of waste generated was FW, proving yet again that the generation of food waste is higher than assumed in most developing nations (Farahdiba et al., 2023). It is estimated that food waste in urban areas will grow by almost 50% between 2005 to 2025, making it essential to comprehend how to transform the potential negative effects this may have on the nation (Adhikari et al., 2006). At the same time, it is estimated that 80% of this FW comes from households, emphasizing the need to understand behaviors of citizens and the services available to support adequate management (Farahdiba et al., 2023). However, approximately 40% of urban residents in Indonesia do not have access to essential waste collection services, and the situation is even worse in rural communities (EPR Indonesia, 2022). Understanding the supply chain in Indonesia is an integral aspect of understanding where transformation may need to occur. A study by Kristanto and Koven (2019) and Soma (2017b) offers insight into the hurdles faced in Indonesia, including separation/segregation of waste and lack of infrastructure for food waste management.

Landfilling is the predominant disposal method for solid waste in Indonesian cities, with a disposal rate of 98% (Sabarinah & Djaja, 2017). Like other developing nations in SEA, Indonesia's waste consists mainly of decomposable organic waste

(Dhokhikah et al., 2015). It was found that around 60%-70% of food waste goes directly to landfills, and the remaining 30%-40% is disposed of in rivers, burned, or composted directly by the community (Kristanto & Koven, 2019). Unfortunately, only 5.1% of all waste undergoes 3R (reduce, reuse, recycle) processes, while 26.2% is openly burned (Anwar et al., 2021). In Indonesian households alone, an estimated 9.3 million tons of food were wasted in 2019, with only 11% undergoing valorization processes such as composting and biogas production (Kementerian PPN/ Bappenas & Embassy of Denmark, 2021). Indonesian biogas units have processed waste with additional elements, such as manure and palm oil effluent, to improve operations (Budihardjo et al., 2021; Farahdiba et al., 2023). A program named BIOMIRU has established 24,769 small-scale biogas reactors across 12 provinces in Indonesia, operating from an individual household level and yet to expand (BIRU, n.d.). Projects like this help push the agenda for environmental protection and establish circularity within the waste management sector.

With such a large composition of organic waste, primarily from households, Indonesia faces numerous challenges in managing and mitigating the stressors of organic waste management systems (Sudibyo, Pradana, et al., 2017). The country's efforts towards sustainable development are hindered by food loss and waste, estimated to reach between 115-184 kg/capita/year between 2000 and 2019 (Waluyo & Kharisma, 2023). Further information regarding the traits of Indonesia can be found in Table 4 below.

	Indonesia
Area	1,913,580 Km2[1]
Provinces	32[2]
Population (Density)	275,773,800[3] 142.57 people per square meter[4]
Urban Population	157191066[5]
GDP (Ranking)	1,186 trillion USD[6]

[1] (WorldData, n.d.-c)
[2] (WorldStatement, n.d.)
[3] (Data Commons, 2022)
[4] (Statista, n.d.-a).
[5] (The World Bank, 2021)
[6](Data Commons, 2022)

	Ranked 16th globally [7]
Avg. Annual Income per person	9872 USD[8]
Median Income	Ranked #101 Globally[9]
Household Composition	44.65% of homes consist of 4-5 members[10]
Urbanization Rate	2.7%[11] 157191066 people living in urban areas[12]
Municipal Waste per person	+65.8 million tons/year[13] 238.60 kg/person[14]
Municipal Waste Composition Organic	60%[15]
Climate	Tropical, high humidity 25- 32°C with heavy rainfall [16]
Agriculture land use	31%[17]
Climate Change	• Top-third of countries facing climate risk (flooding and heat) [18] • Higher temperatures reduce rice crop yield, threats food security[19] • 2.3 metric tons CO2 per capita[20] • Eighth largest global GHG emitter[21]
Poverty Rate	9.78%[22]

Table 4

Overview of Indonesia's Characteristics.

Transitioning to circular waste management models that support the SDGs is not only possible but also essential. The challenges Indonesia faces regarding OW are

[7] (WorldData, n.d.-b)
[8] (Time Doctor, n.d.)
[9] (Wisevoter, n.d.)
[10] (Statista, 2023d)
[11] (Jain, 2017)
[12] (The World Bank, 2021)
[13] (Jain, 2017; Wang et al., n.d.)
[14] (Data Commons, 2022; Jain, 2017; Wang et al., n.d.)
[15] (Jain, 2017)
[16] (ADB, 2021; Britannica, n.d.; WorldData, n.d.-a)
[17] (WorldData, n.d.-c)
[18] (ADB, 2021)
[19] (ADB, 2021)
[20] (The World Bank, n.d.-a)
[21] (Statista, 2023c)
[22] (ADB, 2021)

due to the need for improved government budgets, insufficient technologies, and limited awareness from citizens (Ministry of Environment and Food of Denmark et al., 2018). Examining Indonesia's organic waste management within an economic, social, and environmental framework to effectively address these challenges can help build a holistic picture. Understanding the stages of MSWM in the Indonesian context is also necessary for a comprehensive analysis. Figure 10 provides an overview of the organic waste management process in Indonesia.

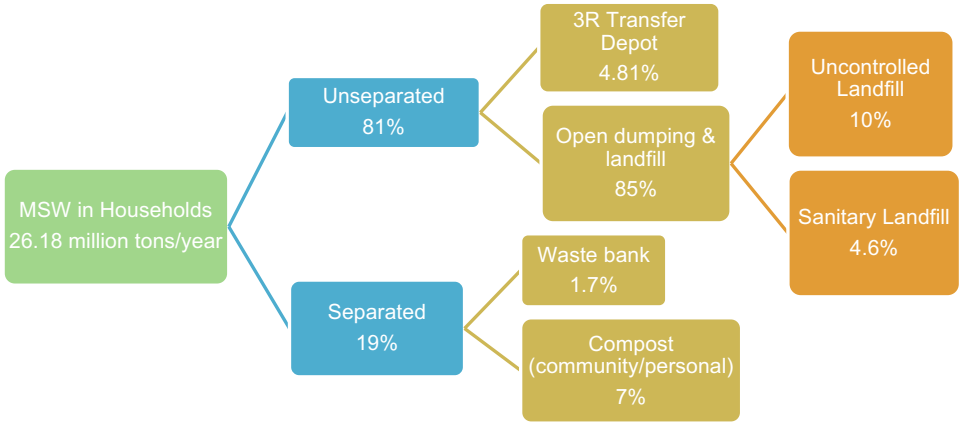

Figure 10

Process flow of MSWM in Indonesia.

Source: (ASEF, 2021; Khansa Hafsah & Maria Sri Asih, 2021; Marine Plastics Pollution Indonesia, n.d.; Ramboll et al., n.d.; Widyarsana et al., 2020)

3.2 Economic Outlook: Analyzing the Viability of Organic Waste Management in Indonesia

Indonesia’s ongoing economic recovery and revitalization process focuses on building resilience and sustainability; however, many threats within governance pose challenges to achieving these goals (Mccawley, 2006). Governance tensions arise from the market-oriented society versus the governance enacted over politics, regulations, military, and economic activities (Bland, 2020; Mccawley, 2006). Despite decentralization opportunities, top-down regulatory frameworks prevail, see Table 5,

hindering nationwide implementation (Wardhana, 2019). However, as a member of G20, Indonesia remains committed to achieving sustainable development.

The COVID-19 pandemic caused a decline in Indonesia's GDP in 2020 (OECD Economic Surveys: Indonesia 2021, 2021). Nonetheless, GDP is projected to reach 1.243 trillion USD by the end of 2023 (Trading Economics, 2022; World Bank, n.d.). Manufacturing constitutes the most considerable portion of Indonesia's GDP at 19.25%, followed by agriculture, forestry, and fishing at 13.28% (Statista, n.d.-b). Water, sewage, waste management, and remediation activities accounted for 0.07% of GDP in 2021 (Statista, n.d.-b). Indonesia’s heavy reliance on resource extraction threatens sustainable development (United Nations, 2021). However, the country recognizes the potential of the circular economy to drive GDP growth and create jobs, particularly benefiting women by 2030 (The Government Encourages a Circular Economy to Achieve Indonesia's Nationally Determined Contribution, 2021). The question of how remains.

Research has shown that fiscal decentralization in Indonesia has varying impacts on regional GDP per capita, with cash transfers and natural resources revenue sharing leading to adverse effects (Fiddin et al., 2018). The tax policy strains regional income, leading to income disparities despite capital spending (Fiddin et al., 2018). Infrastructure expenditure plays a significant role in regional economies. It can contribute to higher tax revenue, while positive effects on regional GDP and local economic growth arise from specific revenue-sharing and capital expenditure policies (Fiddin et al., 2018). The reliance on extractive resource operations exacerbates health and environmental issues, emphasizing the need for alternative management strategies and renewable energy sources. These mining activities can also create leachate leaks like landfill mismanagement, resulting in erosion and biodiversity loss, further harming Indonesia and the world (Anggriawan, 2022).

Waste management in Indonesia relies on local municipality budgets (APBD), where the financing of municipal solid waste management falls under the responsibility of each municipality and less than 40% of the operational costs of waste management in Indonesia are covered (Schübeler, 1996; Vidyaningrum, 2020). The allocation for waste management activities in Indonesia is only 2.5% on average, falling short of

the standard requirements of 5% or more needed to provide satisfactory service (The World Bank, 2019). Insufficient economic and government support for waste management can increase costs in other sectors, such as health, environmental remediation, and missed economic opportunities (The World Bank, 2019). Countries with sustainable and effective waste management typically allocate 4% to 9% of their municipal budgets for waste management (Vidyaningrum, 2020). Indonesia has legal and regulatory frameworks for hazardous waste but lacks coordination with other departments and agencies, creating an insufficient regulatory capacity and lack of infrastructure.

Waste fees collected from citizens are relatively low and vary significantly across Indonesian cities, typically covering collection and transportation but not the actual treatment of waste, resulting in low treatment levels in Indonesia (ASEF, 2021). In Yogyakarta, disposal costs are around 200 million IDR per month for 25 thousand tons of waste, while the city's budget is annually 20 billion IDR (Fatimah et al., 2020). Under these circumstances, citizens are charged between 200,000 to Million IDR per family (Fatimah et al., 2020). This fee is used to transport waste from individuals to TPS sites. To generate additional financing, enforcing tourist waste taxes and implementing extended producer responsibility (EPR) systems have been suggested (ASEF, 2021). Implementing an integrated waste management system can bring cost savings and reduce improper disposal (Engel et al., 2016; Peng et al., 2023; Rashid & Shahzad, 2021; Woon et al., 2021)

McKinsey (2016) found that the economic cost of uncollected waste improperly disposed of through burning and open dumping is $375/ton, while implementing an integrated waste management system costs only $50-$100/ton (Engel et al., 2016). Waste-to-energy and compost production from waste valorization activities can also contribute to cost savings (Peng et al., 2023; Rashid & Shahzad, 2021; Woon et al., 2021a). Certain crops possess more importance than others, such as rice being a staple in Indonesia. Rice crop yield is sensitive to climate changes, such as temperature changes, where an increase of 1°C is estimated to reduce production by 10% to 25%, further limiting the productivity of Indonesia’s agricultural sector by 10% (ADB, 2021). Indonesia spends over $2.3 billion annually on fertilizer subsidies, and its citizens pay more for rice than other ASEAN countries (Indonesia Expat, 2017;

Kementerian PPN/ Bappenas & Embassy of Denmark, 2021). There was a push for more WtE development across Indonesia in 2016, helping to convert FW and other MSW into sustainable energy by-products, with thermal waste capacity reaching 3160,90 tons/year in 2022 (Farahdiba et al., 2023). However, there remains a lack of IRRC facilities or WtE operations and difficulties with selling local compost and fertilizers, making this a missed economic opportunity for Indonesia.

Although participation in programs such as the Regional Comprehensive Economic Partnership (RCEP), financing remains challenging for sustainable development in Indonesia (Basri & Riefky, 2023; RCEP Agreement Enters into Force for Indonesia - ASEAN Main Portal, 2023). The RCEP aims to enhance regional economic integration and offers increased trade and investment opportunities with other member countries, potentially alleviating financial pressures and promoting sustainable development through partnership within the APAC region (RCEP Agreement Enters into Force for Indonesia - ASEAN Main Portal, 2023). The Solid Waste Management Act No.18/2008 and other international collaborations, such as with the World Bank, help support adequate waste management systems. However, insufficient financial aid and lack of enforcement hinder infrastructure and technological advancements (The World Bank, 2019; Wang et al., n.d.). It is possible that the allocation of these financial gains is divided incorrectly or not towards the correct technological advancements, hence the existing challenges with MSWM in Indonesia (Jain, 2017). Distribution of support measures relies on the individual municipalities due to the decentralized nature of governance; this is an area to consider regarding the division. The lack of data does not support significant decisions such as budget allocations for organic waste management, further hindering progress for sustainable development.

Government Regulation No. 81/2012[23]	- The law primarily focuses on managing household waste and household-like waste, emphasizing waste reduction, recycling, and reuse (3Rs) for individuals. - It provides a policy framework and implementation strategy for the Solid Waste Management Act (No.

[23] (Waste 4 Change, 2018)

	18/2008), explicitly addressing domestic waste management and its equivalents. - While also imposing responsibilities on producers to limit and recycle their production waste. This includes measures like using easily degradable packaging and establishing recycling programs.
Ministerial decree of Department Act No. 13/2012[24]	- Promotion of 3R; reduce, reuse, and recycle actions by establishing waste banks. - Defines the Waste Bank and outlines its requirements, mechanism, and implementation as the central government tool to increase household and similar waste recycling.
Ministerial decree of the Interior No. 33/2010[25]	-The involvement of the community as waste producers in the waste management system -Discussions garbage guidelines and instructions
National Waste Management Policy and Strategy (Presidential Regulation) No.97/2017[26]	- Otherwise known as JAKSTRANAS, is the Indonesian National Strategy Policy on Managing Domestic Waste and Domestic Waste Equivalents. - Establishes a roadmap towards achieving a Clean-from-Waste Indonesia by 2025. - The law sets targets, including a 30% reduction in waste and a 70% proper waste handling rate by 2025. These targets aim to decrease waste generation, limit plastic bag usage, increase waste treatment methods, reduce landfilling, and reduce marine plastic pollution by 70% by 2025.

[24] (Wang et al., n.d.)
[25] (Fatimah et al., 2020)
[26] (Wang et al., n.d.; Waste 4 Change, 2018)

The Regional Government Act 23/2014 (Article 282)[27]	-States that the execution of government affairs within the jurisdiction of local governments is financed through the local government budget (APBD) and at its own expense.
Solid Waste Management Act No. 18/ 2008[28]	- Focuses on MSWM and the objective of eliminating open dump waste disposal by 2013. - Provisions aimed at discouraging using non-recyclable and environmentally unfriendly production materials. - The law also acknowledges the lack of a definition for food waste while recognizing that current waste management practices do not align with environmentally friendly mechanisms, leading to adverse effects on public health and the environment.
MoEF decree No. P.75/2019[29]	- Guidelines for producers to implement Extended Producer Responsibility (EPR) and reduce waste from their goods, packaging, and services - Emphasizes three key components: promoting sustainable design practices to minimize waste generation, facilitating the return of post-consumer products and packaging for reuse, and establishing systems to collect and recycle post-consumer products and packaging. -It also highlights the importance of managing food waste sustainably, particularly the proper management of food packaging to avoid negative environmental impacts.

Table 5

Current Regulations in Indonesia for Waste Management.

[27] (Vidyaningrum, 2020)
[28] (Wang et al., n.d.; Waste 4 Change, 2018)
[29] (Wang et al., n.d.)

Organic waste management in Indonesia faces significant challenges due to the large quantities generated, lack of financial support, unskilled workers, and inadequate infrastructure (Zamri et al., 2021). Limited access to foreign capital markets and financial leverage also pose challenges to technological development in waste management (Kearney, 2022). The lack of data on municipal solid waste management operations hinders implementation efforts. Despite available regulations and financing, Indonesia's sustainable economic development is currently affected, and continued waste mismanagement may further negatively impact the economy. ASEF's report (2021) highlights that regardless of government regulations, Indonesian residents still struggle with proper waste separation at the source, leading to increased pressure on temporary storage sites and creating opportunities for informal sector workers.

In summary, economic recovery in Indonesia faces regulatory complications, and fiscal decentralization significantly impacts GDP levels. From an economic perspective, implementing integrated waste management systems can alleviate pressures across sectors and yield cost savings. Financing remains a significant obstacle to development, but through continued government measures and international collaborations, Indonesia can expect to catch a break when beginning new techniques. In the next section, we will explore the role of informal sector workers in waste management.

3.2 Social Dynamics: Analyzing Social Factors in Organic Waste Management

As one of the world's largest producers of organic waste, Indonesia faces significant challenges in waste management due to weak policy frameworks, minimal infrastructure, and scarce public awareness. Examining Indonesia's organic waste management through a social lens offers valuable insight into the complexities, obstacles, and opportunities encountered by various social actors. Food waste can further be understood as highly dependent on age, household composition, education, and income levels, thus understanding whom the primary actors are involved in waste management in the home is important (Almazán-Casali et al., 2019; Sabarinah & Djaja, 2017; Szabó-Bódi et al., 2018).

While there have been some recent improvements, Indonesia continues to grapple with high levels of inequality (Oxfam International, n.d.) Gender disparity is particularly pronounced, with women constituting only 50.3% of the workforce compared to 84.4% of men (Hoque, 2015). Women's representation in parliament is also alarmingly low, with only approximately 21% of seats occupied by women (Country Fact Sheet | UN Women Data Hub, n.d.). Moreover, women predominantly engaged in the informal sector, comprising nearly twice as many workers as men (Unemployment & Employment in Indonesia | Indonesia Investments, n.d.). Unfortunately, women in this sector face disproportionate challenges relating to poor sanitation. The COVID-19 pandemic has further accentuated these inequalities, underscoring the urgent need to address persistent poverty and inequalities in Indonesia while striving to improve the country's low Gini index rating (World Economics, n.d.).

Indonesia has introduced various policies and regulations to address waste management issues and the environmental strains caused by inadequate systems (Wang et al., n.d.). The government aims to reduce waste by 30% and manage 70% of waste by 2025 (SYSTEMIQ, 2021). The National Medium-Term Development Plan (RPJMN) 2015-2019 prioritize inclusive and sustainable growth, environmental quality improvement, disaster mitigation, and climate change mitigation (National Medium Term Development Plan 2020-2024 (RPJMN 2020-2024) - Climate Change Laws of the World, 2015). This plan promotes the importance of green city development and focuses on strengthening institutions and public capacity for improved waste management. It establishes goals for reducing greenhouse gas emissions and enhancing community resilience, with each municipality expected to set targets aligned with the national agenda (Anwar et al., 2021; National Medium Term Development Plan 2020-2024 (RPJMN 2020-2024) - Climate Change Laws of the World, 2015). However, Indonesia has yet to achieve its desired objectives, prompting the addition of a new phase to the RPJMN 2020-2024 that places the green economy at the core of its development (Nugraha, 2021; Suparyati, 2022).

Limited infrastructure hampers effective organic waste management in Indonesia. Initiatives such as waste banks, or "bank sampah" in Indonesian (Salim, 2013), can help reduce the amount of organic waste sent to landfills by promoting household

waste recycling and providing economic benefits to residents. However, the impact of these initiatives has been limited due to factors such as the exclusion of organic waste from certain programs and insufficient financial support (ASEF, 2021; Samsu Alam & Lukman Irwan, n.d.), leading to closures and suboptimal outcomes (Khair et al., 2019). Currently, a central waste bank unit (BSI) and 30 waste bank units (BSU) have been formed with the goal of education and economic valuation of waste (Community Based Participatory Waste Management (IDBNG0003), n.d.). However, not all these units operate effectively due to a lack of trust and participation from the community (Community Based Participatory Waste Management (IDBNG0003), n.d.). Although alternative methods such as anaerobic digestion and composting have shown promise in managing organic waste, their implementation remains limited (Jain, 2017).

Household waste accounts for 36% of total waste in Indonesia, with organic waste comprising over 60% in regions like Medan City (Khair et al., 2019; Khansa Hafsah & Maria Sri Asih, 2021). Regrettably, 53% of households resort to burning their waste as a means of disposal (Sabarinah & Djaja, 2017). Additionally, waste separation practices are inadequate, as evidenced by a 2014 study revealing that only 18.84% of household respondents engaged in waste separation, while the majority, 81.16%, did not (Khansa Hafsah & Maria Sri Asih, 2021). Another study by Susilo et al. (2021) highlighted that 62% of respondents were unaware of the dangers posed by food waste, with a mere 20% being aware but not taking appropriate action. This lack of awareness and education impedes successful source separation and waste management procedures.

Furthermore, the challenges in waste management are further compounded by low education rates. Compared to other countries in the OECD, only 19% of individuals aged between 25 and 34 possess tertiary qualifications, representing a significant disparity (OCED, 2022). Strengthening educational efforts can play a pivotal role in cultivating an advanced workforce and fostering improved waste management practices (Employment and Skills Strategies in Indonesia, 2020; Skills Development: Indonesia Continues to Improve Skills Development through Industry - Vocational Education and Training (Partnership, 2018; Kalambura, 2015; Nambiar et al., 2019). Educational reforms are closely intertwined with labor market reforms, aiming to

transform how formal and informal actors operate within the waste management sector (Davies & Lafortezza, 2019). Hamka H. et al. (2020) noted that while the mismanagement of waste in Indonesia provides a livelihood for scavengers and waste pickers, this situation is unsafe and unsustainable.

The informal sector, accounting for 65% of employment in SEA (UN Habitat, 2020), plays a crucial role in waste management within Indonesia. For instance, in Bandung, at least one in a thousand people work within the informal waste management sector, predominately comprising marginalized groups that face additional risks due to unhygienic practices (Sembiring & Nitivattananon, 2010). These informal collectors, known as "Pemulung" (Sasaki et al., 2014), make substantial contributions to the country's waste management economy and recovery of waste (World Economic Forum, 2021). They actively support waste reduction efforts and waste valorization through waste segregation efforts at TPSs (Dhokhikah & Trihadiningrum, 2012; Sembiring & Nitivattananon, 2010), thus serving as an integral aspect of the MSWM system. While municipalities handle collection, transportation, and final disposal, the informal sector primarily focuses on recycling and waste revitalization.

The flexibility offered by informal work in waste management attracts individuals, including those with limited hard skills, as they can earn income from waste (Sasaki et al., 2014). However, many informal workers lack education, especially elementary school dropouts aged 15 and above (Sasaki et al., 2014). A study by Sabarinah (2017) found that low-income and low-education individuals were likelier to partake in recycling and waste separation at home due to the associated incentives. Additionally, it was reported that 80% of workers in this sector had less than a primary school education (Sembiring & Nitivattananon, 2010). However, the distinction between the informal and formal sectors lies in registration and regulations rather than the individuals, groups, or businesses involved (Sembiring & Nitivattananon, 2010). Despite their significant efforts to maintain cleanliness in Indonesia through labor-intensive, unsafe, and low-income labor, the government has yet to recognize them as legal actors in waste management (Sembiring & Nitivattananon, 2010).

Rather than limiting individuals' education and income to enforce source separation in households, the focus should be on educating and providing hard skills to individuals while simultaneously innovating waste management technologies. Adopting CE principles within Indonesia's food and beverage sector, for instance, is estimated to generate over USD 26.3 billion by 2030 and create 2.4 million jobs between 2021 and 2030 (Kementerian PPN/ Bappenas & Embassy of Denmark, 2021). Stronger implementation of CE practices in households could result in annual savings of USD 177 per household and contribute to emission reductions (Kementerian PPN/ Bappenas & Embassy of Denmark, 2021).

While Indonesia has aspirations for plastic waste management, there is currently no direct focus on food waste management, and the challenges associated with its mismanagement are not acknowledged (SYSTEMIQ, 2021). Figure 11 illustrates the journey of MSWM in Indonesia, starting from households and moving toward final disposal or recovery. Efforts to improve waste management practices have been primarily initiated at the community, ULBs, private-public partnerships (P.P.P.), and business levels across Indonesia. Generally, the community carries out the primary collection through user fees. In contrast, secondary collection, and transportation to TPSAs are the municipality's responsibility, funded through municipal budgets (Vidyaningrum, 2020).

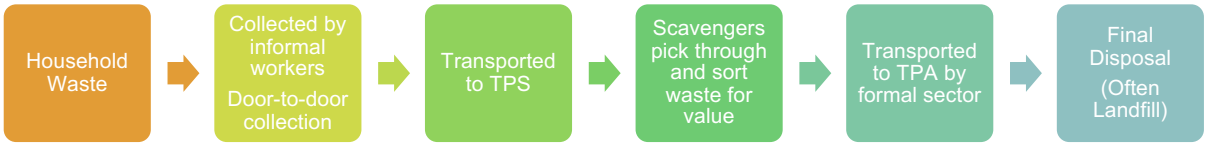

Figure 11

Journey of MSWM in Indonesia.

Despite commitments, numerous governance challenges arise when implementing and maintaining 3R waste management facilities and TPST, with 70% and 40% being abandoned or having an unknown status (SYSTEMIQ, 2021). Local authorities in Indonesia often opt for open dumping operations due to their ease of disposal

(Sudibyo, Majid, et al., 2017). When circular operations fail for waste management, there is increased pressure on landfills and open dumping, leading to the devaluation of organic waste and exacerbating greenhouse gas emissions. Consequently, numerous disadvantages arise in terms of health, safety, and the environment, including the spread of diseases, odors, and water contamination (C40 Cities Climate Leadership Group & C40 Knowledge Hub, 2019a; Ferronato & Torretta, 2019; Hondo et al., 2020; Khan et al., 2022; Sudibyo, Majid, et al., 2017).

Recognizing the need for alternative waste management approaches, private businesses and community initiatives have taken steps to address the issue. Some businesses and NGOs have supported these initiatives, striving to improve informal workers' livelihoods and MSWM operations (Indonesia – Indonesian Waste Platform | International Waste Platform, n.d.; The SeaCleaners | In Indonesia, Our Fight against Waste Starts on Land!, n.d.; SYSTEMIQ, 2021; Tanjung, 2020). Organizations such as Kebun Kumara and Garda Pangan and waste management apps like Octopus, are notable examples. Kebun Kumara focuses on educating individuals on environmental efforts through gardening, composting, and eco-brick building (Kebun Kumara, n.d.). Garda Pangan, on the other hand, aims to minimize food waste and alleviate hunger in Indonesia (Garda Pangan, n.d.). Octopus, an app, helps producers track and collect their post-use products, fostering a circular economy and supporting businesses in their EPR strategy (Octopus Indonesia, n.d.).

Community-based participation also plays a significant role in waste management in Indonesia. Many BSUs have been established but often face challenges such as lack of community participation, difficulty selling recyclables, inadequate technology, and limited capital (Community Based Participatory Waste Management (IDBNG0003), n.d.). The 2021-2024 Action Plan for Community-Based Participatory Waste Management (IDBNG0003) aims to educate the public about the potential value of waste through proper management practices. By empowering communities and promoting the 3R mindset, this commitment aims to create clean environments, achieve government waste targets, and increase income for marginalized individuals, thus reducing poverty (Community-Based Participatory Waste Management (IDBNG0003), n.d.). The Surabaya Green and Clean (SGC) initiative is an example of citizen engagement and improved waste management, where citizens

are involved through environmental education and competitions related to waste handling, leading to increased awareness and action from the community (Yodha et al., 2018).

Waste management is a collective responsibility involving citizens, governments, and businesses. Five roles have been highlighted for governments when adopting a circular mindset to tackle food waste; this includes a clear vision at all levels, stakeholder engagement, economic incentives, urban management collaboration, and regulations (Suhartini et al., 2022). All actors must actively participate in implementing waste management technologies and strategies. There is minimal synergy among stakeholders in the waste management sector in Indonesia (Waluyo & Kharisma, 2023). Given Indonesia's decentralized nature, effective engagement among numerous stakeholders is crucial for successfully implementing future waste management strategies.

The following section will explore how waste mismanagement in Indonesia impacts the environment and the potential mitigation efforts.

3.4 Sustainability Scan: Environmental Factors of Organic Waste Management in Indonesia

Unfortunately, only 40% of total MSW is properly managed, while the remainder ends up in landfills, rivers, and oceans, causing environmental pollution and health hazards (Sulistyowati & Astuti, 2019; SYSTEMIQ, 2021). Notably, 70% of waste going to landfills in Indonesia is organic waste (Shahab, 2021), as it decomposes and releases methane, a potent greenhouse gas (Kementerian PPN/ Bappenas & Embassy of Denmark, 2021). Being a humid country, the produced food waste rots much faster, which forces individuals to expect rapid turnover and disposal of waste services (Soma, 2017b). This contributes to the explanation of citizens opting for rapid disposal methods like dumping and open burning to remove foul odors and pests since most lower-income households do not have the space to conduct alternative practices or lack the financial capability to do so (Soma, 2017b).

With Indonesia being the third-largest generator of greenhouse gases globally, following China and the USA (ASEF, 2021; Consulate General of the Republic of Indonesia in Vancouver, n.d.), their food loss and waste account for 7.29% of Indonesia's greenhouse gas emissions (Cahyani et al., 2022). The mismanagement of organic waste contributes to MSW, which is the third-largest source of human-caused methane emissions, making it crucial to address this issue in Indonesia (Bruggers et al., 2021; EESI, 2017; Ferronato & Torretta, 2019; Huffman et al., 2022; US EPA, n.d.-a).

Contaminated soils in Indonesia are a complex issue, exacerbated by poor waste management practices and heavy reliance on synthetic fertilizers. Synthetic fertilizers persist in the high rates of soil nutrient depletion in soils, sitting at 45% (Kaza et al., 2016). Indonesia favours chemical fertilizers, supported through their substantial subsidies (Hettiarachchi et al., 2018; Kaza et al., 2016; Storey et al., 2013; tearfund, 2019). Current policies do not incentive local farmers to produce compost to support clean farming practices, making it difficult for individuals to make their compost marketable and thus opt for low-priced chemical fertilizers. The compost produced from MSW was found to be poorly received in the eyes of the public despite its ability to divert waste from landfills and support clean agricultural practices (Kaza et al., 2016). Additionally, the reliance on oil and gas extraction presents sustainability challenges and contributes to high volumes of contaminated soil (Indonesia: A Sustainable Solution for Contaminated Soil, n.d.; Rahman et al., 2023).

The production of leachate is also a major concern. Unsustainable waste management techniques contribute significantly to environmental pollution through leachate production (Emalya et al., 2020). Although the government established Act No. 18/2008 to ban landfill leachate and promote proper management, some sites that should have been closed remain open, causing soil and groundwater contamination (Emalya et al., 2020). Managing leachate in Indonesia is particularly challenging due to the heavy rainfall, making it difficult to stabilize the leachate composition (Emalya et al., 2020). The leachate runoff may further require pesticides and fertilizers to compensate for damaged soils resulting from inadequate waste management systems. Surprisingly, Indonesia currently spends around 2.3 billion on

annual subsidized fertilizers (Waluyo & Kharisma, 2023), while funding for improved waste management or organic waste recovery for fertilizers remains inadequate.

Leachate is formed through water seepage from external sources into landfills, containing high concentrations of heavy metals and minerals that further pollute groundwater and the environment and can be attributed to the mismanagement of organic waste (Emalya et al., 2020). Landfills in Indonesia lack the capacity and technologies to mitigate these leachate-related issues, further straining the environment effectively. Existing treatment facilities often need more proper processes due to limited consideration of leachate characteristics (Emalya et al., 2020). Diverting organic waste from landfills through household separation and minimizing the introduction of external liquid streams can help reduce leachate generation and the need for further treatment.

The lack of infrastructure and resources remains a major obstacle to MSWM in Indonesia. Inadequate waste management practices, exemplified by the Bantar Gebang open dump site, also known as "the Mountain," has been the primary disposal site for Jakarta citizens since the 1980s, posing severe health and safety risks to both humans and the environment (Ahluwalia, 2018; Lamb, 2018). Furthermore, over half of Indonesia's landfills operate as open dumpsites, exacerbating the environmental impacts (Yodha et al., 2018). Many landfills were intended to be closed but are still being used as the primary method of disposal (Indonesia: Improvement of Solid Waste Management to Support Regional and Metropolitan Cities Environmental and Social Management Framework (ESMF), 2019; Meidiana & Gamse, 2011; Wang et al., n.d.). Inadequate waste management practices lead to leachate formation and endanger scavengers, as demonstrated by the 2005 landslide at the Leuwigajah dumpsite (Lavigne et al., 2014) --the endangerment of human safety and environmental health result from inadequate MSWM practices. The lack of infrastructure and appropriate waste management practices can generate disasters such as this, as a fatal methane explosion killed 143 people and left 71 homes buried due to inadequate organic waste management (Lavigne et al., 2014). The trapped methane gas causing the explosion resulted from decomposing organic and food waste in a landfill, an inappropriate measure for

waste management. This explosion not only killed individuals but also destroyed nearby communities within a 1 km parameter of the mountain (Lavigne et al., 2014).

Organics comprise 70% of landfilled waste in Indonesia, says Greenpeace Indonesia campaigner Muharram Atha Rasyadi, with no proper infrastructure to mitigate and support proper disposal (Shahab, 2021). Although initiatives like the WtE program, which aims to convert organic waste into energy and reduce landfill waste (EESI, 2017; Reuters, 2019; Wachpanich & Coca, 2022), the adoption of biogas technologies, with only 0.02% of Indonesia's final energy consumption in 2021 coming from biogas (Ministry of Energy and Mineral Resources, 2021) and landfill gas recovery (LFG), proposed as a means to reduce waste and associated emissions through power generation, potentially acting as a carbon sink, remains low (Yodha et al., 2018). The valorization of food waste to bioenergy offers an attractive solution to various problems surrounding climate change issues but requires a supportive supply chain; only then can alleviation of adverse effects occur for local economies (Randolph et al., 2017; Suhartini et al., 2022). In major cities, it is estimated that accumulated waste could produce just under 80MW of energy from LFG (Yodha et al., 2018). The Government of Indonesia has collaborated with organizations like the World Bank and GIZ to find management solutions. However, more actions are needed to address the environmental burden caused by MSWM (Yodha et al., 2018).

Indonesia faces a range of environmental challenges, including air and water pollution, soil erosion, biodiversity loss, and the depletion of the ozone layer (Environmental Issues Faced by Indonesia, n.d.). In Jakarta, landfills are estimated to produce seven million tons of CO2eq from MSW, posing dangers to the environment and the health of citizens due to inadequate management (Yodha et al., 2018).

With its thousands of islands and vast coastal regions, Indonesia is highly vulnerable to climate risks such as rising sea levels and pollution (IMF, 2021). The World Bank reports that sea-level rise could affect 42 million Indonesians living within 10 meters above sea level (Vulnerability, Risk Reduction, and Adaptation to Climate Change-Indonesia, 2018). Considering its vulnerability, Indonesia is ranked as the sixth most vulnerable country to high-impact natural hazards in the 2021 INFORM Global Risk

Index (IMF, 2021). Additionally, the country is ranked as the world's twentieth most polluted country, with pollution levels exceeding WHO guidelines and affecting 91% of the population (AQLI, n.d.).

Indonesia's NDC includes commitments to reduce GHG emissions, with an unconditional target of 29% and a conditional target of up to 41% reduction from the Business-as-Usual (BAU) rate by 2030 (Anwar et al., 2021; Indonesia Green Growth Program, n.d.; Republic of Indonesia, 2015). With Indonesia's emissions increasing by 140% between 1990 and 2017 (excluding land use) (Climate Transparency Report, 2020) and reported 9.2 tons per capita emissions in 2015, the need for action is strong. The waste sector targets under the NDC focus on treating MSW and domestic liquid waste, landfill gas recovery, composting, 3R (reduce, reuse, recycle), and WtE potentials (Anwar et al., 2021; Enhanced Nationally Determined Contribution Republic of Indonesia, 2022). Composting is said to help reduce MSW emissions by nearly 25%, offering it as a potential solution to help Indonesia meet their targets (Salam et al., 2021). However, this may be attributed to the mismanagement within the waste sector, resulting in improperly managing the 194,002 tons of waste produced daily in Indonesia (ASEF, 2021). To achieve these targets, Indonesia requires financial and technological capacity-building support. The estimated financial needs from 2018 to 2030 are around 285 billion USD, with private sector agents supporting these efforts alongside existing public climate financing (Anwar et al., 2021). Tensions continue to exist within the energy sector, with hopes to improve public transportation, renewable energy sources, and eco infrastructure (Development Bank, 2020; Enhanced Nationally Determined Contribution Republic of Indonesia, 2022). Collaboration between sectors can mitigate waste management challenges and support sustainable energy generation.

The table (6) provided below offers valuable insights into GHG emissions across different categories in various regions. In Indonesia’s organic waste management context, it is important to consider these statistics. For instance, Indonesia contributes approximately 14% of its emissions from agriculture, with Asia accounting for 24% of the continent's emissions (Center For Global Development, n.d.; Climate Transparency Report, 2020). The agricultural industry can further understand that rice cultivation is a major economic gain sector, and the heavy

reliance on synthetic fertilizers supports agricultural demands (Naik, 2023; Prastiyo et al., 2020). Rice cultivation accounts for nearly 50% of all crop related GHG emissions (Prakash, 2022). As Asia agricultural demand for rice increases, these emissions can expect to rise, further contributing to global methane emissions.

Additionally, the substantial meat consumption in developed countries, such as North America and Europe, highlights the potential for reducing GHG emissions by addressing food waste and meat consumption. Indonesia is a low meat-consuming country, exemplifying the sensitivities of meat-reliant nations like the USA or China on GDP levels. As consumption patterns alter, demanding more variety and deals will further distance individuals from their food supply chain and increase food waste within SEA (Lavigne et al., 2014). These statistics underscore the significance of implementing effective organic waste management strategies to mitigate GHG emissions and promote sustainability in Indonesia.

	Global	Developed Country	Indonesia	Asia	Developing Country
Food Consumption kCal	2960 kcal/person/day[30]	3540 kcal/person/day[31]	2884 kcal/day/person[32]	SEA: 2828 kcal/person/day[33]	2860 kcal/person/day[34]
Meat Consumption kg/capita	34.1 kg/capita[35]	98.5 kg/capita (North America)[36]	17.99 kg/capita/year[38]	Asia: 46.3 kg/capita[39]	Insufficient Data

[30] (Galler, 2022)
[31] (United Nations, 2022b)
[32] (Al Hasan et al., 2022)
[33] (Al Hasan et al., 2022)
[34] (*The Broad Picture: Historical Developments and Present Situation 2.1.1 Progress Made in Raising Food Consumption per Person*, n.d.)
[35] (Statista, 2021a)
[36] (ADB, 2021)
[38] (FAO, 2023b, 2023a)
[39] (Statista, 2021b)

		63.2 kg/capita (Europe)[37]			
Global GHG Emissions from Agriculture	25-35%[40] 57% from meat[41]	37%[42]	14% of Indonesia's emissions [43]	24% of the continent's emissions[44]	63%[45]
GHG Emission per person	6.82 tons/person [46]	38.73 tons/person[47]	7.43 tons/person[48]	6.41 tons/person[49]	2.33 tons/person[50]
Total Food Consumption Kg/capita/year	675kg/capita/year[51]	Europe: 780.6kg/capita/year[52] North America: 861.8kg/capita/year[53]	Insufficient Data	679.7kg/capita/year[54]	Insufficient Data
Meat vs. Non-Meat consumption	45.3 kg/year	Meat: 100.1 kg/year Of total kcal 72.10% Veg	Insufficient Data	South Asia: 11.7 kg/year East Asia: 58.5 kg/year	36.7 kg/year Of total kcal

[37] (Statista, 2021b)
[40] (Mrówczyńska-Kamińska et al., 2021; Reavis et al., 2022; Ritchie, 2019)
[41] (Milman, 2021)
[42] (Center For Global Development, n.d.)
[43] (*Climate Transparency Report*, 2020)
[44] (Rahut et al., n.d.; Ritchie & Roser, n.d.)
[45] (Center For Global Development, n.d.)
[46](Ritchie & Roser, n.d.; Worldometer, n.d.)
[47] (Kochhar, 2015; Ritchie & Roser, n.d.)
[48] (Data Commons, 2022; Ritchie & Roser, n.d.)
[49] (Ritchie & Roser, n.d.; World Counts, n.d.)
[50] (Ritchie & Roser, n.d.; Unctad, 2017)
[51] (Good Seed Ventures, 2021)
[52] (Good Seed Ventures, 2021)
[53] (Good Seed Ventures, 2021)
[54] (Good Seed Ventures, 2021)

		27.89% Meat[55]			87.43% Veg 12.56% Meat[56]
Food Waste kg	147 kg/capita/year[57]	Europe & North America: 95-115 kg/capita/year[58]	63.25-101.2 kg/capita/year[59]	11 kg/capita/year[60]	6-11 kg/capita/year[61]
GHG emissions from FLW Per person	323 kg/person[62]	Insufficient Data	270.38 kg/person[63]	Insufficient Data	Insufficient Data
Meat waste losses (in kg)	1.38 kg/person[64]	Insufficient Data	Insufficient Data	Insufficient Data	Insufficient Data

Table 6

GHG emission from different sources in different countries.

Source	Remark of Indonesia and SEA Food Waste	Date	Author
Study Report: Food Loss and Waste in Indonesia: Supporting the Implementation of Circular Economy and Low Carbon Development	63.25-101.2 kg/capita/year[65]	2021	MINISTRY OF NATIONAL DEVELOPMENT PLANNING/BAPPENAS
Food Waste Index Report	Indonesia, Surabaya 77kg/capita/year[66]	2021	United Nations Environment Programme

[55] (FAO, n.d.-b)
[56] (FAO, n.d.-b)
[57] (Safdie, 2023; Worldometer, n.d.)
[58] (FAO, 2011)
[59] (Ministry of National Development Planning/Bappenas, 2021)
[60] (FAO, 2011)
[61] (FAO, 2011)
[62] (Porter et al., 2016)
[63] (*Indonesia Green Growth Program*, n.d.; Ministry of National Development Planning/Bappenas, 2021; Ritchie & Roser, n.d.; Worldometer, 2023)
[64] (FAO, n.d.-a; Karwowska et al., 2021)
[65] (Ministry of National Development Planning/Bappenas, 2021)
[66] (UN Environment Programme, 2022)

	20 938 252 tons per year this is households		
Annual per capita household food waste of selected countries worldwide as of 2020	82kg/capita/year SEA[67]	2020	Ian Tiseo & Statista
High-Level Multi-Stakeholder Consultation on Food Losses and Food Waste in Asia and the Pacific Region	11 kg/capita/year in low-income Asian countries 80 kg/capita/year in high-income Asian countries [68]	2013	Food and Agriculture Organization of the United Nations
Global Food Losses and Food Waste	11 kg/capita/year for SEA[69]	2011	Food and Agriculture Organization of the United Nations

Table 7

Reflecting on the validity of critical data.

Table 7 above presents the various conflicting data surrounding food waste in Indonesia and Asia. Various reports from both national and international sources from the past ten years bring forward estimations ranging from 11kg to 101.2kg of waste per capita per year in Indonesia. The lower range is based on averages for SEA, so when comparing with relevant information for Indonesia, it is difficult to understand why Indonesia is experiencing much higher food waste rates than other SEA countries. The lack of data collected in Indonesia further challenges these understandings, hence why this table is provided above for context. This paper will use 63.25 kg to 101.2 kg per capita per year to assess the research question (Ministry of National Development Planning/Bappenas, 2021). This has been used due to its ability to capture potential amounts across the options offered and its recency.

Under the unconditional scenario of the NDC, the waste sector aims for 17,721 Gg of CO2 in 2020 and 11,348 Gg of CO2 by 2030 (Anwar et al., 2021). Some technologies needed to mitigate the environmental stressors of Indonesia are LFG

[67] (Statista, 2023a)
[68] (FAO, 2013)
[69] (FAO, 2011)

recovery, in-vessel composting, bio-digesters, Mechanical biological treatment (MBT), thermal conversion and composting (Anwar et al., 2021; Enhanced Nationally Determined Contribution Republic of Indonesia, 2022). Since 2020, alternative processes like biodigesters have experienced growth in Indonesia, managing 300 tons of waste per year and was expected to increase to 3800 tons per year by 2022, further producing around 1000 tons of energy materials yearly (Farahdiba et al., 2023). As for the compost, this is strongly used on a community basis, where both large- and small-scale plants have been used across Indonesia, such as in Surabaya (Farahdiba et al., 2023). In some cases, collaboration between sectors could mitigate waste management and support sustainable energy generation.

While Indonesia has vast natural resources and exports commodities like oil and gas (Arfani & Sulistyaning, n.d.; Suryantoro & Manaf, n.d.) continued reliance on fossil fuels will put further pressure on the environment and have long-term costs for Indonesia (Development Bank, 2015; Larasati, 2023; Ministry of Energy and Mineral Resources & Ministry of Finance, 2019). The management over energy is of the state command, thus mitigating control of energy through the state and the decentralized nature of waste management will have to be navigated collaboratively in order to be successful in aspirations of valorization and climate action in line with targets, paradigms, may have to be altered here (Suhartini et al., 2022). Poor resource management, weak infrastructure, and minimal environmental protections will lead to increased waste generation and hinder Indonesia's sustainable development (Jain, 2017; Vidyaningrum, 2020).

Proper management of organic waste is crucial to mitigate the generation of methane and the pollution of leachate. Currently, methods, including open burning, dumping, and landfilling, release methane, which is 28-34 times more potent than CO2 (The Challenge, n.d.). The environmental stress of Indonesian waste is estimated at 32.6 tons of MSW per square kilometre (Waste Atlas, n.d.), making implementing sustainable and healthy waste management measures challenging. Factors such as inadequate solid waste collection, lack of household waste separation, and insufficient treatment facilities contribute to these improper management techniques (Jain, 2017; Susilo et al., 2021). However, there are ongoing community-level projects in Indonesia aimed at demonstrating the utilization

of organic waste and diverting it from disposal sites, leading to greater GHG reduction, energy recovery, resource efficiency, and employment generation (Jain, 2017). While the Government of Indonesia continues implementing environmental protection enforcement regulations, enforcement levels remain low (Sukardi et al., 2022; Widodo et al., 2019).

As a highly vulnerable country to climate change with a high readiness score, according to ND-GAIN (n.d.), Indonesia must urgently respond to climate change impacts, including those related to the organic waste sector. Current droughts, floods, and pollution are causing significant disasters in Indonesia, and these events are expected to become more frequent without intervention (Yodha et al., 2018). Excessive subsidizing fertilizers, which accounted for 50% of the Ministry of Agriculture's budget in 2016 without increasing productivity, poses an additional challenge (Yodha et al., 2018). Fertilizers eat up budgets and contribute to eutrophication (Adiansyah et al., 2021; Suteja & Purwiyanto, 2018; Suwarno et al., 2014; Yodha et al., 2018). Reassessing the budget allocation for fertilizers and exploring alternative fertilizers and price adjustments may help address this issue.

In conclusion, Indonesia's mismanagement of organic waste is detrimental to the environment and exacerbates global climate change. As one of the largest greenhouse gas emitters, Indonesia must prioritize assessing organic waste management and exploring valorization pathways. The flow of organic waste in Indonesia is depicted in Figure 12.

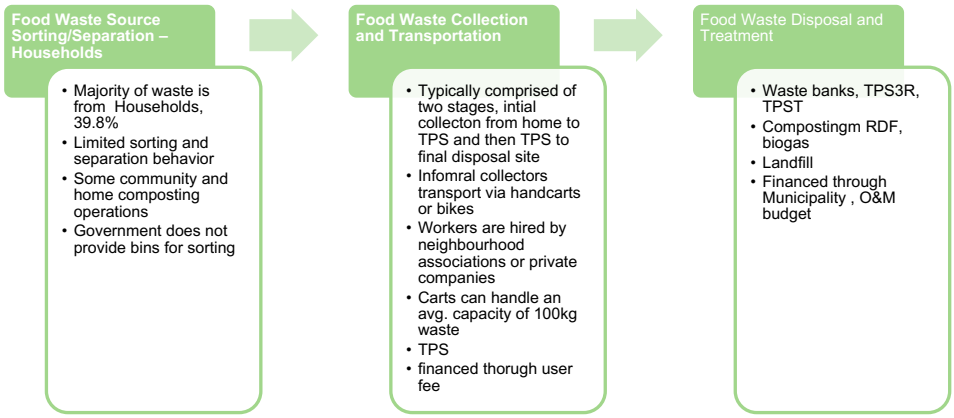

Figure 12

Overview of the Current Food Waste Management Process – Indonesia.

4 Insights and Implications

This section provides key takeaways from the case study on Indonesia's organic waste management, highlighting findings from economic, social, and environmental perspectives.

4.1 Overview

Due to urbanization, population growth, and economic expansion, Indonesia faces significant waste management challenges. With urbanization comes environmental decline and an increased accumulation of trash, which must be dealt with adequately to achieve set ambitions (Dethier, 2017). The rapid increase in waste generation, driven by increased consumption patterns, has led to a surge in social and environmental concerns as behaviors shift to a more urban city ideology, shopping behavior transforms, causing a concept of spatial distance from the supply change, which generates dissonance, making it more difficult to understand why food waste prevention is so important (Suhartini et al., 2022). These large gaps between actors within the food waste journey result from this ongoing urbanization, distributing agents beyond continents and further losing touch with how food is created and disposed of (Soma, 2017b). Soma (2017b) states that this displacement is a severance of the circular economy of food systems, challenging the capacity to return nutrients from organic waste to the environment from a more local container.

Projections indicate that Indonesia’s annual SW production of over 65.8 million tons will reach 83.8 million tons by 2050 (Anwar et al., 2021; Ministry of Environment Denmark, 2022; Wang et al., n.d.). Managing such massive waste while harnessing its potential for valorization is crucial as the country strives for sustainable development. Table 7 summarizes the main insights from the case study on Indonesia's organic waste management. Insights suggest that successful food waste management operations rely on marketing incentives for valorized products,

encouraged utilization of the valorized products within communities, and acceptance from the community (Amir et al., 2016).

4.2 Insufficient Waste Management

The case study reveals that organic waste accounts for over 60% of the waste composition in Indonesia (Jain, 2017). The escalating waste production and inadequate waste management infrastructure present a crisis for Indonesia, impacting human health, environmental resilience, and economic prosperity. Alarming statistics indicate that only 60% of urban residents in Indonesia have access to essential waste collection services, with even worse conditions in rural communities (EPR Indonesia, 2022). The study by Soma (2019) reiterated this fact, stating that the ability to compost is not supported by infrastructure, making it more difficult for residents to conduct sustainable waste management practices onsite, further pushing people to get rid of their waste in unsanitary ways quickly. Weak policy frameworks, limited infrastructure, and scarce public awareness pose significant challenges to effective measures implemented along the pathways of MSWM. The lack of government funding, inadequate technologies, and limited citizen awareness hinder efforts to address organic waste management issues and undermine the impact of regulatory frameworks imposed by governments.

4.3 Household Waste and the Need for Sustainable Decision-making

Understanding the economic implications of household organic waste is significant for making informed, sustainable decisions. Households contribute the largest share of organic waste in Indonesia, approximately 36%, where it is either unseparated and disposed of or donated to a community/personal compost bin, although the latter is less common and dependent on personal choice (Khair et al., 2019; Khansa Hafsah & Maria Sri Asih, 2021). However, a study in 2014 revealed that only 18.84% of household respondents conducted waste separation, and a staggering 62% were unaware of the dangers associated with food waste mismanagement (*Badan Pusat Statistik*, n.d.; Khansa Hafsah & Maria Sri Asih, 2021). While government regulations exist regarding household waste management and source separation, most

residents refrain from engaging in these practices, and waste separation mostly occurs at TPS and landfills by scavengers. It is important to note that the average food waste from households is found to be highest among lower-middle-income countries (91kg/capita/year), followed by high-income countries (79 kg/capita/year), emphasizes the need for improved food waste management and higher levels of citizen awareness/education (Prakash, 2022). Shockingly, only 5.1% of all waste in Indonesia undergoes 3R processes, and 26.2% is openly burned despite known negative consequences (Anwar et al., 2021). These findings indicate a lack of awareness among Indonesian citizens regarding proper organic waste management procedures and a failure to recognize the value of waste from both governments and citizens. Despite many initiatives implemented, such as waste banks, waste-to-energy programs, and IRRC, many of these efforts fail to reach their full use potential or have proven effective.

4.4 Government Initiatives and Challenges

The Indonesian Government is committed to environmental sustainability through their NDC and collaborations with international organizations such as the World Bank and the RCEP (RCEP Agreement Enters into Force for Indonesia - ASEAN Main Portal, 2023). Several policies and regulations have been introduced to address waste management issues and associated environmental stressors resulting from such inadequate systems. The RPJMN prioritizes inclusive and sustainable growth, sustainable utilization of natural resources, environment quality improvement, disaster mitigation, and tackling climate change. The plan encourages green city development, sets goals for reducing GHG emissions, and enhances community resilience. However, more infrastructure is needed to improve proper organic waste management, preventing Indonesia from achieving its goals. Fiscal decentralization adds complexity to the enforcement of these measures, weakening policy frameworks, public awareness, and infrastructure development. This decentralization further influences information dissemination, financing, and resource allocation (Fiddin et al., 2018; Wardhana, 2019). A lack of data availability and accessibility persists in these challenges and the implementation of alternative measures to MSWM. There are minimal studies across the Global South regarding

post-consumer food waste, which strengthens the narrative that the loss occurs before households.

It is important to build a well-rounded picture to understand the current situation in the Global South and not assume it is essentially different from the Global North as urbanization is rapidly occurring. The Ministry of Environment/National is responsible for pollution-related policies, programs, regulations, standards, and monitoring and control. Meanwhile, the private sector and community collect, transport, and dispose of.

4.5 Inequalities, Marginalized Workers, and Gender Gap

The case study identifies significant levels of inequality and a gender gap in the workforce in Indonesia (Oxfam International, n.d.; World Economics, n.d.). Informal waste workers, predominantly women, play an important role in waste management processes but face additional risks associated with unhygienic practices in SWM. The same women are the primary individuals responsible for purchasing food and the preparation process, making this waste management supply chain very gendered (Som Castellano, 2015; Soma, 2019). The informal sector carries a stigma and exposes workers to health and environmental challenges, further marginalizing these individuals. Women are found to be more actively engaged in conducting waste management practices overall, such as waste separation in the home (ASEF, 2021). Understanding how to support these inequalities and marginalized individuals working in the waste management sector could prove to be a beneficial solution to the end-of-pipe complications of improper organic waste management. Addressing persistent inequalities and poverty requires strengthening efforts in educating citizens and implementing supportive measures to protect informal waste workers while also improving infrastructure to enable proper organic waste management.

4.6 Organic Waste and Climate Crisis

Organic waste significantly contributes to methane emissions, exacerbating the climate crisis. Indonesia ranks fourth in total GHG emissions, where methane emissions could be due to the poor disposal of organic waste in landfills, their growing population, and rapid urbanization (Indonesia: GHG Emissions and Climate

Change Policy, 2023). Landfilling remains the primary disposal method, with over 70% of waste going to landfills being of organic composition, decomposing and releasing methane (Shahab, 2021). Many landfills in the country are nearing their maximum capacity or required closure, with 21% expected to shut down within two years (Sabarinah & Djaja, 2017). The Bantar Gebang landfill, spanning 120 hectares, with over 3000 families living onsite, exemplifies this issue (Waste360, 2018). Bantar Gebang, Terjun, and Suwung landfills are only a few facing overcapacity challenges, leading to potential fires, landslides, and health and environmental complications (Christiani, 2021; Koelsch et al., n.d.; Timmerman, 2021). Although the Jakarta government acknowledges the overcapacity issue, efforts to increase capacity or identify new locations persist, with 53% of landfills yet to determine a new location (Sabarinah & Djaja, 2017). Inadequate infrastructure and treatment processes burden communities and hinder Indonesia's progress in achieving sustainable development initiatives, which fail to address the root challenges of organic waste management and contribute to rising sea levels, land and air pollution, and natural disasters. The burden on informal workers and landfills significantly pressures communities and the environment. Inefficient resource management leads to increased waste generation, while inadequate systems hamper Indonesia’s sustainable development and climate resilience efforts. To mitigate these risks, Indonesia must prioritize proper organic waste management as part of its comprehensive sustainable development agenda. These main findings are summarized below in Table 8.

Takeaway	Challenge	Opportunity
Increasing Waste Production	• Overwhelming amounts of waste are being produced without adequate management practices. • Population increase,	The potential to valorize produced waste through new technologies, improve soil through compost, generate energy and move away from fossil fuels.

	urbanization, and economic growth, • +65.8 million tons of solid waste produced annually, and is estimated to reach 83.8 million tons in 2050[70]	
Predominate composition of organic waste	• Improper waste management processes to dispose of, treat, or valorize. • Producing large amounts of methane when insufficiently disposed of. • Mainly from households, 39.8%[71] • Only 5.1% of all waste is undergoing 3R processes.[72] • 26.2% is still being openly burned.[73]	Potential valorization streams, energy, compost, etc.

[70] (Jain, 2017; Wang et al., n.d.)
[71] (ASEF, 2021)
[72] (Anwar et al., 2021)
[73] (Anwar et al., 2021)

Waste sorting and separation behavior	• Lack of public awareness and education regarding food waste management practices and complications.	• Educational initiatives for communities regarding organic waste complications and how to properly mitigate and valorize such waste streams.
Decentralization	• Minimal stakeholder collaboration. • Fiscal decentralization has impacted regional GDP per capita in many ways, with cash transfers and natural resources revenue sharing bringing many adverse effects.	• The ability for communities to take the lead and acknowledge the requirements of their community. • Potential for more vital collaboration between both informal and formal sectors.
Inequality and Informal worker	• Stigma and further segregating individuals. • Strong presence of women in the informal waste sector	• Potential to capture a new workforce and encourage effective waste management processes.

	• Marginalized groups work in poor conditions like pollution and sanitation.	• Support female workers and encourage recognition of informal workforce contributions.
Overburdened Landfills	• Many landfills have reached maximum capacity, creating unsafe conditions for on-site and nearby residents. • Governments continue to increase regulations or attempt to generate new landfill sites without addressing the root issue.	• Opportunity to switch mechanisms for waste management. • Close the landfills for good and make alternative investments into more circular approaches to waste management.
Lack of Infrastructure	• Indonesia does not have enough alternative waste management processes facilities. • Landfills are overburdened, and open burning continues regardless of the	• The potential of launching pilot programs to evaluate alternative waste management systems for organic waste processing.

	negative consequences. • 40% of Indonesian urban residents do not have access to essential waste collection services.[74]	
Limited Funding	• Decentralization limits the amount of budget used by municipalities and leaves it to the degression of the municipality. • Budgets reflect the required financing for adequate waste management processes poorly.	• Reevaluate budgeting for waste management. • Look further into waste reduction operations. • The potential valorization of waste can help generate economic gains and reduce budget needs in other sectors.

Table 8

Overview of challenges faced by Indonesia regarding organic waste management.

The Case Study Revealed:

1. **Current Practices**: Indonesia's organic waste management practices must be revised and aligned with circular economy principles. Organic waste goes unsorted and separated, going to landfills or is openly burned. Furthermore,

[74] (Sulistyowati & Astuti, 2019; SYSTEMIQ, 2021)

the improper management of this waste stream contributes to GHG emissions, specifically methane, stressing environmental conditions. Moreover, the lack of segregation at the source and facilities for composting or anaerobic digestion of organic waste is limited, thus missing out on the potential economic opportunities of waste valorization.

2. **Challenges:** Many challenges hinder the sufficient management of organic waste in Indonesia. Some main areas presenting challenges are inadequate funding, minimal infrastructure, equipment and technologies, low public awareness, and need for enforcement from policy and regulatory frameworks.
3. **Opportunities:** Regardless of the current challenges faced by Indonesia in terms of organic waste management, the potential of leveraging organic waste through circular operations remains. This includes potential valorization operations such as waste-to-energy, quality compost, and feedstocks. The research found a growing interest among stakeholders to implement circular economy approaches to waste management in Indonesia, and thus this should encourage such technologies and operations. This could look like improved IRRC facilities or fertilizer marketability.

Furthermore, Indonesia needs to shift towards circular economy practices to achieve sustainable development and overcome the challenges of resource extraction. The following section with strengthen this discussion by looking at some examples of global best practices in organic waste management.

5 Global Best Practices

Learning from global best practices can provide valuable insights into effectively harnessing the potential of organic waste and promoting a circular economy. This section explores diverse approaches to organic waste management in different countries and draws lessons that may be applied in Indonesia. The main objective is to identify strategies and potential avenues for replication. The key findings from the global case studies are summarized in Table 9. These examples highlight successful

strategies such as compositing, waste separation, public-private partnerships, and marketing campaigns.

1.1 Examples from around the Globe

5.1.1 Ningbo, China

Ningbo, China, has implemented innovative approaches and infrastructure development to address organic waste management. One noteworthy initiative results-based financing (RBF) to incentivize households to separate their organic waste and recyclables (The World Bank, 2014). In Ningbo, 85.2% of people said they do not conduct waste separation at home, so by encouraging waste separation, and the government aims to reduce landfilling and promote recycling, thereby achieving cost savings. A critical project in Ningbo is the organic waste treatment plant, funded by the World Bank, focusing on purifying organics through a mechanical presorting system, anaerobic digestion, and aerobic composting. The RBF program in Ningbo sets realistic targets and employs education, outreach, and advocacy to promote waste separation. Despite these efforts, achieving large-scale separation remains challenging, highlighting the complexity of behavior change (The World Bank, 2014). This example identifies the importance of awareness and education as a prerequisite to infrastructure adjustments. It is not enough to offer technologies and transform financing structures. Still, it is integral that citizens are aware and informed on how to participate in this waste management system correctly.

5.1.2 Dhaka, Bangladesh

Bangladesh, experiencing rapid urbanization and population growth, is becoming one of the most populous cities in the world and faces significant waste management challenges (CCAC, n.d.-a). Despite adopting an SW master plan, Bangladesh struggled with low collection waste and processing infrastructure (CCAC, n.d.-a). Waste Concern initiated a community-based composting operation in Dhaka in 1995, promoting organic waste management and generating jobs for around 16,000 people, particularly women (Enayetullah, 2004). This project, funded by the Ministry

of Environment and Municipalities, operates a waste collection and processing infrastructure, offers consulting services, and runs a recycling training center and compost laboratory while only costing households an average of 20-35 cents USD per month for waste collection (Enayetullah, 2004). Despite subsidies for synthetic fertilizers and marketing obstacles, Dhaka implemented a decentralized composting model, generating significant revenue from the sale of compost and certified emission reduction credits (CER). Each plant transformed 2-3 tons of household waste into 500-600 kg of compost daily, where each 50kg bag sells for anywhere between $2.USD 4.500 USD (Enayetullah, 2004). The sale of compost contributed to 75% of revenue, while the remaining 25% resulted from the sale of CER (United Nations, n.d.-d). Concern's community-based composting model has also been successfully replicated in areas, like Barisal and Jessore (Enayetullah, n.d.).

Additionally, the government of Bangladesh has approved a national policy and municipal solid waste rules that mandate waste separation into dry, wet, and hazardous categories. The government has also conducted awareness campaigns and distributed free bins to promote source segregation of waste. These decentralized initiatives have fostered public, private and community partnerships igniting action and ensuring quality compost and community participation in organic waste management. These initiatives aim to reduce the reliance on chemical fertilizers, promote sustainable agriculture, and address the challenges associated with organic waste management in Bangladesh.

5.1.3 Vienna, Austria

Vienna, Austria, has emerged as a leader in organic waste management, boasting the highest recycling rates in Europe. The country’s waste management sector accounts for 4% of climate-relevant emissions (CCAC, n.d.-b). With a collection rate of 100% through the formal sector, Vienna generates approximately 1,024,407 tons of MSW per year (CCAC, n.d.-b). Austria achieved remarkable results by promoting home composting, reducing waste transport, lowering costs for citizens, and reducing treatment expenses for municipalities. The recovery rates of composted food waste reached 22.1% in 2016 (CCAC, n.d.-b). Since 1995, Austria has enforced a policy of source-separated collection of organic MSW, ensuring proper segregation

at the point of generation (Herczeg et al., 2013). All processing of waste is financed through household fees and EPR.

Moreover, Austria emphasizes the production of high-quality compost, which not only allows for competitiveness in the market but also minimizes adverse environmental impacts (Herczeg et al., 2013). The compost is monitored according to the Compost Ordinance, FLG || Nr. 292/2001, offering three quality classes based on heavy metal content (Trois & Simelane, 2010). Through these measures, Austria has achieved impressively low rates of less than 3% of their biodegradable municipal waste being sent to landfills, surpassing the requirements set by the EU Landfill Directive (European Commission, 2014). Instead, nearly 1,000,000 metric tons of organics are treated annually in composting facilities. Austria also implements strict landfill bans on untreated waste to promote a closed loop and strengthen sorting efforts, where waste landfilling with a total organic carbon content of over 5% and landfilling fees for such waste fees have steadily increased over the years resulting in a significant decrease in landfill use (Herczeg et al., 2013). The fees for landfilling such waste were EUR 44 in 2001 to EUR 87 in 2006, resulting in a strong correlation between decreasing rates of landfill use for MSW (Herczeg et al., 2013). These fees for collection and separation depend on the volume and frequency of emptying, where the minimum fee per household in Vienna comes to around 164,32 EUR per month (Kisliakova, 2005).

The Austrian Compost Ordinance, considered Europe's first "end of waste" regulation, ensures the production of high-quality compost by clearly defining inputs, processes, and finished product criteria. Bio-waste and green manure contribute to 94% of Austria’s compost production, highlighting the country’s commitment to quality (Kaza et al., 2016). Financing compositing facilities follows a decentralized cooperative model, with multiple actors contributing to site development and equipment costs and government subsidies provided to facility operators (Kaza et al., 2016). These progressive policies, decentralized composting, landfill bans, high-quality compost standards, and cooperative financing models have collectively positioned Austria as a global leader in solid waste management, significantly reducing organic waste sent to landfills.

5.1.4 Milan, Italy

Italy has implemented successful organic waste management strategies, focusing on MBT and separate FW collection. Over the past two decades, Italy has established over 100 MBT plants, treating approximately 25% of MSW (WMW, 2007). However, Milan's impressive waste management statistics are not solely attributed to MBT. The city has undertaken an aggressive strategy to mitigate food waste through awareness-building campaigns, distribution of free bins, and fines for mismanagement, leading to its remarkable FW collection rates (Condamine, n.d.). The city provided 120-litre and 35-litre bins on loan, as well as provided with ventilated kitchen baskets (Heinrich, 2017). Fines were given when non-conformity occurred, and if buildings did not comply, all residents would be fined, creating an incentive for adequate sorting (Heinrich, 2017).

Collaborating with AMSA, Milan has implemented meticulous waste sorting practices and achieved a high-quality compost with only a 5% contamination rate (Condamine, n.d.). As a result, 20% of the created compost is provided free to households and farmers (Condamine, n.d.). Additionally, accumulated debris is transported to an integrated AD and composting facility, generating biogas for electricity and biomethane for the gas grid. It can generate around 11,200,000m3 of biogas for AMSA transportation (Condamine, n.d.). The key to Italy's achievements is citizen engagement, extensive communication, and education. Citizens were informed of this transformation via letters, leaflets, community meetings and even an app for further information (Heinrich, 2017). AMSA conducts marketing, collection, and waste processing, including inspecting waste before transportation. Through this, the city has managed to save around 30 EUR per ton diverted from disposal by opting for AD or composting food waste (Condamine, n.d.).

Italy's experience serves as a model for regions aiming to enhance their organic waste management strategies and transition towards a circular economy. The city of Milan is an impressive example of circularity in Europe. After one year, it has saved around 9000 tons of CO2 per year from FW collection per inhabitant (Condamine, n.d.). Through AMSA campaigning, Municipal funding and supportive legislation, Milan has been an early adopter of FWM and has quickly achieved the EU's goals.

Milan's separate waste collection showcases the potential in large, densely populated cities through community engagement and education. These initiatives, supported by EU directives and community engagement, have led to significant waste reduction, resource recovery, and environmental benefits nationwide.

5.1.5 Seoul, South Korea

South Korea has implemented a robust and intricate system to address food waste, utilizing innovative strategies and technologies to tackle the challenge head-on. The city adopted a complex volume-based collection process incorporating RFID technology, pay-as-you-throw systems, high-tech central community bins, and home waste bins embedded with RFID chips (South Korea: Wastage of Food Reduced Using RFID, n.d.; World Economic Forum, 2019). The city has implemented high-tech central community bins equipped with RFID chips and weighing systems, which automatically charge residents based on the weight of their food waste.

This solution has helped South Korea achieve impressive recycling rates of 84.4% for MSW, one of the highest among the OECD countries (Kaza et al., 2016). In 2012, with a population of 10.3 million residents and 4 million households, Seoul generated 9,189 tons of waste per day, equivalent to 0.88kg per person, and achieved food waste recycling rates of almost 100% compared to less than 3% in 1996 (Shank, 2023; Yu, n.d.).

Implementing RFID chips is one of many solutions to South Korea's food waste challenges. It is complemented by supportive legislation such as the Waste Management Act (2007), the Act on Promotion of Resources Saving and Recycling (2008), a Food Waste Reduction Policy (EC, 2014c) and Extended Producers Responsibility (EPR) (Ng, 2013; Yoo et al., 2019). In addition, South Korea banned direct landfilling of food waste in 2005 (Kaza et al., 2016; D. S. Kim, 2019; World Economic Forum, 2019). The Seoul Metropolitan Government is responsible for implementing policies and providing support, while local districts play a role in developing waste management plans and enforcing fees and penalties (Kaza et al., 2016). Technological innovations and government policies support Seoul's organic waste management system (Yoo et al., 2019).

Collected food waste in Seoul undergoes various treatments, including conversion into animal feed, composting, and anaerobic digestion. Nationwide, 240 facilities for food waste treatment are available (Yoo et al., 2019). In Seoul, the daily 3,000 kg of food waste is allocated to approximately 60% for animal feed, 30% for compost, and 10% for anaerobic digestion (Yoo et al., 2019). To further encourage waste reduction and resource recovery, Seoul promotes community composting through partnerships with NGOs, district competitions, and urban farms, aiming to convert organic waste into compost or animal feed (Kaza et al., 2016; Yoo et al., 2019).

The success of Seoul's MSWM can be attributed to the collaboration between different levels of government and the adoption of innovative technologies such as high-tech community bins and RFID-based weighing systems (Yu, n.d.). The comprehensive approach employed by Seoul is a model for other cities and countries seeking to improve their waste management practices (Yoo et al., 2019). The South Korean model offers ease of use, accessibility, and a range of policy measures, including the ban on food waste in landfills, designated food waste collection buckets, and the enforcement of biodegradable bags for food disposal, with proceeds funding the MSWM system (M. S. Kim, 2022).

Country	Income Level	Waste Composition	Solution	Results
Ningbo, China	**Medium**	• 1.19 million tons [75] • 52.8–65.3% kitchen waste, 3.5–11.9%	• Waste Separation • Transportation • Treatment plants Data collection through IOT on kitchen waste	• 17.54% recycling rate (from 0%)[77] • 94% awareness of waste separation[78] • 193,200 tons/year of

[75] (Urban et al., 2019)
[77] (*The World Bank Urban, Resilience And Land Global Practice East Asia And Pacific Region*, 2020)
[78] (*The World Bank Urban, Resilience And Land Global Practice East Asia And Pacific Region*, 2020)

		paper, and 9.9–19.1% rubber & plastics[76]		kitchen waste was separated[79] • Kitchen waste to biogas helped save an estimated 50,404 tons/per year.[80]
Dhaka, Bangladesh	**Low**	• 54.92% organic waste, 14.70% plastic, and 12.60% paper[81]	• Community-based composting • Private-public-community partnerships	• Disposal costs and prolongs the lifetime of landfill sites. • Reduces the harmful environmental impact of landfill sites because organic waste is responsible for groundwater contamination and methane gas emissions.

[76] (Ding et al., 2021)
[79] (*The World Bank Urban, Resilience And Land Global Practice East Asia And Pacific Region*, 2020)
[80] (*The World Bank Urban, Resilience And Land Global Practice East Asia And Pacific Region*, 2020)
[81] (Harun & Rashid, 2019)

				• Urban soil improvements
Vienna, Austria	**High**	• 9% organic waste[82] • 45 kg per inhabitant collected[83]	National Framework and Legislation	• Less than 3% of biodegradable waste in landfills[84] • Improved composting with A+ quality[85] • 100% collection rates[86]
Milan, Italy	**High**	90kg per inhabitant collected[87]	• Provided bins. • Communication strategy • Biogas production and use for MSW transport and grid. • 20% compost free of charge to households and farmers[88]	• 62.6% collection rate[89] • 9000 tons of CO2saved per year[90] • 40,000 tons of compost/per year[91] • 16.000.000 m3 of biomethane produced.[92]

[82] (CCAC, n.d.-b)
[83] (Mater-Bi, n.d.)
[84] (Herczeg et al., 2013)
[85] (CCAC, n.d.-b; Herczeg et al., 2013)
[86] (CCAC, n.d.-b)
[87] (C40, 2015)
[88] (Condamine, n.d.)
[89] (Condamine, n.d.)
[90] (Condamine, n.d.)
[91] (Condamine, n.d.)
[92] (Condamine, n.d.)

			• Extensive MBT plants	• 11,200,000 m3 of biogas potential[93] • 30 EUR per ton of food waste saved from disposal.[94]
Seoul, South Korea	**High**	• Unclear	• 930 g/person/day is thrown out, 40% is food waste.[95] • 130 kg/capita food waste a year[96] • 14,388 tons/day of food waste and 3,075 tons/day in Seoul alone.[97]	• Close to 100% recycling rates compared to 2.6% in 1996[98]

Table 9

Findings from Global Best Practices.

These global leaders show that organic waste can revitalize economies and communities. Through strong governance and robust regulations, many countries have been capable of deterring the landfilling of organic waste. However, enacting regulatory frameworks is insufficient if no supportive solution exists for the overall mitigation. Composting has been a highly active technology leveraged in all nations.

[93] (Condamine, n.d.)
[94] (Condamine, n.d.)
[95] (Jackson, 2018)
[96] (Jackson, 2018)
[97] (Marshall, 2022)
[98] (M. S. Kim, 2022; World Economic Forum, 2019)

The involvement of communities in the workforce, governance for compost control and quality, and privatized sales help foster this valorization of organic waste. When fees equate to direct amounts of waste produced, it is shown to justify and support this organic waste management. During efforts by governments and municipalities to provide infrastructure such as bins, individuals can focus more on managing the waste than financing these processes. Throughout all these case studies, supportive governance via bins and technology infrastructure helps individuals focus on separating waste. It has been recognized overall that citizens need more awareness and education when it comes to organic waste management. Combining governance infrastructure, aware citizens, and valorizing sorted waste with supportive standards and sales helps create thriving organic waste management practices.

6 Discussion

6.1 Introduction

This section analyzes and interprets the research findings and case study on organic waste management in Indonesia. The aim is to answer the guiding research question, “How can municipal waste management systems leverage the potential of organic waste to contribute to sustainable development in Indonesia? “. The discussion clearly explains the existing constraints and opportunities for sustainable organic waste management in the country, offering analysis, comparison, evaluation, and recommendations.

6.2 Analysis of Current Organic Waste Management in Indonesia

After conducting a case study analysis of Indonesia’s organic waste management systems, many conclusions may be made Indonesia’s population growth and urbanization are not being supported by existing waste management infrastructure, leading to over 65.8 million tons of waste annually (Wang et al., n.d.). The spatial dissonance between food systems directly results from these statistics, making it

critical to assess how the country can foster sustainability at local levels regarding waste management. The predominant method of MSW disposal is landfilling, with organic waste constituting a substantial portion. However, the incompatible methods have been clearly defined through disasters like the methane explosion at the Leuwigajah open dump 2005. Organic waste management difficulties include limited government budgets, insufficient technologies, and minimal citizen education and awareness. At the same time, weak regulatory systems pose additional challenges to progressing the country's sustainable development goals.

From these findings, it becomes possible to identify various opportunities and constraints facing Indonesia’s organic waste management systems, including:

Opportunities:

1. Transitioning to circular waste management models can contribute to the country's sustainable development goals, increase GDP growth, and create job opportunities.

2. International collaborations and partnerships, such as the Regional Comprehensive Economic Partnership, offer opportunities for financial support and development programs in waste management.

3. Strengthening educational efforts and improving skills development can be crucial in building an advanced workforce and encouraging better waste management practices.

Constraints:

1. Insufficient government budgets and limited financial support for waste management result in increased costs in other sectors missed economic opportunities, and hampers technological development.

2. Weak policy frameworks, minimal infrastructure, and scarce public awareness hinder effective organic waste management in Indonesia.

3. The lack of integration between the informal and formal waste management sectors and the absence of recognition for informal workers impede effective waste valorization and circular waste management practices.

The outlook for organic waste management in Indonesia looks positive, with the constraints also offering an opportunity for development. However, improvements are necessary to overcome inadequate waste management practices ingrained within food systems, and major efforts are needed to achieve the sustainable objectives of the country.

6.3 Comparison with Global Best Practices

Comparing Indonesia's organic waste management to some global success stories reveals potential pathways for change. Successful countries like China, South Korea, Italy, Bangladesh, and Austria have implemented innovative infrastructures, encouraged behavioral change amongst citizens, received government support, and fostered collaboration amongst various stakeholders across waste management. The introduction of technologies such as mechanical pre-sorting systems, anaerobic digestion, composting, and MBT have enabled waste separation, processing, and recycling, leading to reduced landfilling and the promotion of recycling.

Awareness campaigns and education have helped contribute to effective waste management behavioral change from citizens. In Bangladesh, the government conducted campaigns to raise awareness and provided free bins to promote source separation. Similarly, AMSA ran intensive marketing initiatives in Milan, distributed flyers, and held community meetings to encourage education on organic waste management. The city also provided bins on loan, supporting citizens looking to get involved in proper management practices. Through government support and aggressive education/awareness campaigns, citizens have been shown to act in accordance with sustainable organic waste management practices, generating advocacy for waste separation and recycling. Through this, these countries have encouraged citizens to actively participate in waste management systems actively, increasing the effectiveness of organic waste management initiatives.

An additional aspect of success for these global successes in organic waste management is government support and strong policy frameworks. These countries' governments were crucial in supporting organic waste management efforts. Government support in Seoul helped encourage technological innovation, improving how organic waste is being managed. Coupled with supportive legislation and strongly enforced bans on improper waste management, citizens are encouraged to opt for the easy-to-use waste management techniques implemented. From the research, government support helps encourage positive decision-making regarding organic waste management by deterring inadequate management techniques.

Finally, one of the most important overall success factors is the collaboration and partnerships of the multi-level stakeholders involved in organic waste management. Effective waste management systems have been ensured through the establishment of public, private and community partnerships. In Austria, the division of financing through decentralized facilities created a cooperative investment modelling, alleviating pressures from one entity to the management of waste. Through citizen involvement, government subsidies, and private sector investment in equipment, Austria has seen impressive results in organic waste management. Similarly, in Dhaka, the community-based composting operation initiated by the waste concern generated thousands of jobs and fuel infrastructure development. The respective municipalities further help finance aspects such as collection fees, strengthening Bangladesh's collaborative environment of waste management. This collaboration between different levels of government, NGOs, municipalities, and facility operators has been crucial in implementing and sustaining organic waste management initiatives. The facilitation of resource sharing, knowledge exchange and mobilization of collective efforts can be attributed to these partnerships' efforts to achieve a common goal of organic waste management.

6.3.1 Similarities with Indonesia and Global Best Practices

One similarity between the Indonesian waste management environment and these global best practices is that Indonesia currently operates on a very decentralized basis. The financing options derive from various actors such as municipalities, communities, and external investment from international bodies. The challenge here

is coordination; where we can see places like Milan encourage a cooperative environment, how much discussion goes on with the various stakeholders engaged in waste management systems in Indonesia needs to be clarified. It was understood that informal and formal actors with waste management in Indonesia rarely interact, causing a disparity between operations. Indonesia has partnered with international bodies like the World Bank and GIZ to help support waste management systems. However, this level of support may become ineffective when other actors in the food system are engaged with a different vision.

Another similarity found is the potential for composting options; where in Dhaka, Waste Concern came to finance and instigated a business opportunity for the community, Indonesia faces a similar opportunity for composting. The challenge here has been found to deal with the level of subsidization on fertilizers and mass-produced composting options, making it difficult to value local compost at market levels. Low levels of composting are found within Indonesia and typically operate on a small scale within communities, limiting the potential. This is where organizations like Kebun Kumara help promote education on such waste management practices to encourage participation. Compost has been shown to help reduce emissions from MSW by almost 25%, further strengthening the argument to incorporate this technology widely. This is an opportunity for Indonesia to look at the type of work that took place in Bangladesh and assess whether this would be a business prospect for communities.

Indonesia's organic waste management could also be compared to Ningbo, China, where similar waste compositions exist, with high levels of organic waste disposed of. Understanding the waste composition is essential to assessing the relevancy of adequate technologies. It has been stated that landfilling, burning, and incineration are not ideal solutions for such a high moisture content of waste, requiring pretreatment possibilities like dehydration. However, pretreatment will be an additional cost instead of finding a sufficient organic waste management technology first. Similarly, education plays a major role in waste management behavioral change. Implementing more technologically innovative solutions helps alleviate confusion and encourage waste separation for future treatment, but problems still exist in ensuring citizens act according to such infrastructure. With waste separation

being deficient and organic waste management also low for households, this becomes a critical area requiring assistance, possibly beyond individuals but a more supportive landscape from other stakeholders.

Understanding the main differences between Indonesia and these other countries is important. Indonesia is a low-income Southeast Asian nation, producing more waste than can be managed. The country's location also makes it very susceptible to climate change disasters. It emphasizes the need for appropriate and immediate action to combat the potential adverse effects of waste mismanagement. The climate also challenges management techniques and processing times; with high humidity and heat, rotting, odors, and pests arrive faster than in other countries. The geography of Indonesia does not match cities like Milan or Seoul, and streets are easier to travel along for waste collection and transportation. A lesson from Milan includes repurposing the generated energy to fuel transportation means for waste management, and this could be encouraged to use bioenergy for transportation services, closing the loop even further (Suhartini et al., 2022). However, if Indonesia does not require large vehicles, how can the country support sustainable transport for motorbikes and hand-pulled carts within rural communities too? The existing infrastructure in Indonesia also varies, with additional storage facilities for waste to travel, complicating the direct movement or processing of the organic waste stream. The research suggests that improved technologies could benefit the organic waste management process but will require significant budget adjustments.

Through all these similarities, large disparities exist with Indonesia's current decentralized system infrastructure. The research results suggest that a lack of coordination and enforcement hamper the potential efforts of sustainable organic waste management. Nevertheless, even before undergoing support for processing, Indonesian citizens are limited in their knowledge of environmental protection through waste management. This is where more research needs to be conducted to understand why there is limited cooperation among stakeholders and how Indonesia may be able to look towards other countries, such as those mentioned, for guidance in enhancing organic waste management systems.

6.4 Recommendations for Improvement

Based on the above research and comparative analysis, a few recommendations are suggested to improve organic waste management in Indonesia. It is challenging to offer detailed recommendations given the limitations of this research and the lack of primary data; however, within the constraints of this research, some may be provided. These recommendations include financial assessments and budget alterations, awareness and educational campaigns, technological innovation, and a strengthened cooperative environment throughout the waste management system.

Previous research suggested that Indonesia's municipal budget allocation for waste management operations is well below average, potentially contributing to the inadequacy of operations. In 2022, the average budget for waste management was only 0.51% of the total budget in Indonesia, further placing pressure on individuals to make behavioral changes as opposed to governance support from funding (Farahdiba et al., 2023). It would be suggested that municipalities and governments review budgets and financing strategies and assess the quality of current finances. Funding for additional landfill locations could be better allocated towards improved working conditions for informal workers or the implementation of improved IRRC facilities. A study by Kristanto and Koven (2019) recommends an integrated composting AD technology which acts as a waste recovery center in Depok City. Under these circumstances, this option offered the lowest carbon emissions, proving it to be feasible and supportive of sustainable development goals. Acknowledging the discrepancies in the current financing of waste management in Indonesia could potentially alleviate pressures in mitigation costs of the adverse associated effects. Opening up to external funding opportunities and increased international collaborations and coalitions could offer numerous benefits similar to the community compost scheme in Dhaka.

With studies suggesting low levels of household source separation, an appropriate response would be to raise awareness about properly managing organic waste, helping to avoid inappropriate waste disposal practices. Without educated citizens, the segregation of waste becomes all the more challenging. The research shows that 53% of households continue to burn their waste (Sabarinah & Djaja, 2017), with only

18.84% of households separating waste (Sabarinah & Djaja, 2017), with only 18.84% of households conducting waste separation (Khansa Hafsah & Maria Sri Asih, 2021). Another study by Soma (2019) focused on composting and found that knowledge about conducting composting is as follows among various income groups, with 26.6% of low-income, 43% of middle-income, and almost 60% of high-income respondents knew how to do it; however, 92.6% of the respondents said they "never" undergo composting for their food waste. This dispersity between knowledge and action is staggering and of concern, which needs further examination. The study by Susilo et al. (2021) found that the lack of food waste separation could be related to the minimal knowledge of the negative effects of this mismanagement, further recommending that citizen awareness could benefit the remaining states of waste management. A study by Soma et al. (2020) offered insight into three leading approaches to assist in shifting behaviors in individuals to help reduce food waste; this includes passive (i.e., flyers), community engagement (i.e., discussion groups), and gamification (i.e., online interactive spaces). Incorporating information based on these three approaches could be leveraged to assist in building awareness among citizens across Indonesia. Not only can these approaches provide nudges to improve awareness but also help improve overall knowledge on better food waste management, prolonging efforts (Soma et al., 2021)

A Scenario and agent analysis is recommended to explore both future states of waste management under various scenarios while studying the various actors involved in the waste management system (Lang et al., 2010; Spoerri et al., 2009). By leveraging information from this analysis, a clearer image of the main actors involved in organic waste management can be understood as to how behavioral change factors into other system boundaries and processes (Lang et al., 2010; Spoerri et al., 2009). The mixed waste disposed of in landfills or burnt continues to affect public and ecological health adversely. The recommendation of awareness and education is suggested for these reasons. Community-based participation also plays a significant role in waste management in Indonesia. As emphasized in the article by Spoerri et al. (2009) collaboration, knowledge sharing, and stakeholder engagement are essential when it comes to strategic planning, leading to more effective and sustainable solutions. It is not only up to the government to drive sustainable practices by transforming the landscape for more sustainable practices,

but collaboration is encouraged to lead to improved efficiency and participation (Khair et al., 2019; Trihadiningrum et al., 2017). Encouraging community involvement, fostering stakeholder cooperation, and enhancing partnerships can bring positive change. It could be suggested to follow a similar strategy to Milan, where an external organization handles intensive marketing strategies, and the government helped alleviate expenses for infrastructure to help get citizens started.

Technological innovation helps ease the waste management process, with examples like RFID tracking, AI for sorting, and treatment techniques such as vermi-biofiltration or AD to boost the circularity of waste. The type of technology used depends heavily on the waste composition, and it must be properly situated for the local market conditions. Some challenges discussed by Indonesia are the need for technology to develop quality fertilizers, restore soil fertility, and increase grassland productivity for animal feed (Anwar et al., 2021). A study by Suhartini et al. (2022) suggests that using AD for food waste is ideal for generating biogas and methane for electricity and digestate, contributing to biofertilizer. Finding ways to optimize municipal organic waste into soil improvers through innovative technologies can offer economically viable value networks (De Schutter, n.d.). A Material Flux Analysis could be recommended to further analyze and describe the material balances within a system, helping to investigate the material flows in the organic waste management system (Lang et al., 2006, 2010; Scholz et al., 2014). Through developing a better perspective of the environment, this tool can leverage transdisciplinary to represent the associated challenges and opportunities (Scholz et al., 2014). As discussed in the state-of-the-art chapter, various sustainable technologies exist for managing organic waste, potentially solving these technological aims of Indonesia’s NDC.

Some specific strategies that became evident throughout the research were the need to make compost and fertilizer competitive on the market compared to the existing heavily subsidized products. The research reiterated these points through various articles and reports, claiming the difficulty of being successful in these operations coupled with the many benefits that may accompany them if successful. Further research to understand the demand factors is crucial to make sense of the barriers and strategic orientations available (Spoerri et al., 2009). Indonesia is encouraged to enhance fertilizer and compost marketability. The case study

described the current obstacles in the sale and sustainability of composting and the utilization of clean fertilizers throughout agricultural operations, such as high subsidies on chemical fertilizers deterring domestic production. Contaminated soils are found to be a complex challenge in Indonesia, which is only accelerated by insufficient MWM and the strong dependence on synthetic fertilizers. Compost is a natural fertilizer rich in organic matter, nutrients, and beneficial microorganisms. It enhances soil health, improves fertility, and increases crop productivity when applied to agricultural lands. Compost utilization helps rejuvenate soils by replenishing essential nutrients, enhancing soil structure, and improving water-holding capacity. However, this excessive subsidization of fertilizers was shown to account for 50% of the Ministry of Agriculture's budget in 2016 Indonesia without evidence of increased productivity (Yodha et al., 2018). With annual expenditure on these subsidized fertilizers sitting at nearly 2.3 billion, these fertilizers are demanding a massive allocation of budgets, which could be further reassessed for domestic production utilizing organic waste via compost (Adiansyah et al., 2021; Suteja & Purwiyanto, 2018; Suwarno et al., 2014; Waluyo & Kharisma, 2023; Yodha et al., 2018).

Therefore, if compost can be sold at a higher price, the profitability of the IRRC and ‘waste to compost’ projects will become more attractive, also from an investor’s point of view. Indonesia already operates on a decentralized basis, and IRRCs have a proven track record of being effective in mismanaging a variety of waste in developing countries, resulting in social, ecological, and economic value. These biofertilizers/compost help increase nutrient availability, reducing the need for additives from farmers and resulting in cost savings (Kaza et al., 2016). It was found that through composting strategies, direct social benefits of upwards of 2000 people can experience improved hygiene and job creation (Storey et al., 2013). Through strongly investing in more IRRC facilities, government budgets can be reduced when cleaning up mismanagement costs. Promoting the use of compost from IRRC facilities in agriculture supports circularity by closing the loop and utilizing organic waste as a valuable resource.

IRRC facilities can significantly meet Indonesia's energy demands by generating biogas and soil fertility through improved composting practices. IRRC facilities have

three sources of revenue, including the sale of compost/biogas/refuse-derived fuel (RDF), the sale of recyclables, and the collection fees (Storey et al., 2013). In Indonesia, RDF has a large potential due to its high composition of organic and plastic waste. Currently, projects for RDF units are occurring both privately and government-managed across Indonesian cities, with Cilacap processing the highest amounts of waste per day, generating around 54.89 tons of RDF per day (Bintoro, 2023; Farahdiba et al., 2023). However, RDF requires a higher upfront cost compared to other technologies. However, it does adequately match up with Indonesia's waste characteristics, given its large rice consumption, helping meet the criteria for operations.

Furthermore, the land requirements are minimal for IRRCs, with only 150-200 m2 of land needed for sustainable production and can help cut fuel costs since transport to landfill sites, typically far from cities, is no longer required (Storey et al., 2013). The success of these facilities further depends on government support and improved household waste separation. These IRRCs have been shown to provide effective waste management measures across developing nations in the APAC region, resulting in a cost-effective solution due to the potential of 80-90% of waste undergoing valorization for economic gain (Storey et al., 2013). The potential benefits include green job creation, better hygiene and improved urban environment, quality compost and biogas, soil health, reduced fertilizer demands, and leachate waste aversion (Storey et al., 2013).

Enhancing WtE strategies could also be a potential area for sustainable development and energy demands transformation in Indonesia. Indonesia’s GHG emissions constitute 1/4th of the energy sector and are projected to grow (ADB, 2021). Currently, Indonesia has minimal efforts in biogas production or other waste-to-energy initiatives, offering the opportunity to alleviate energy demands. Biogas is a renewable energy source produced by the anaerobic digestion of organic waste. Biogas can be used for various purposes, including electricity generation, cooking, and heating, by capturing and utilizing the methane gas released during decomposition. This can help reduce the release of methane while providing a clean source of energy for communities, reducing Indonesia’s dependency on fossil fuels. The energy sector in Indonesia was shown to be a major contributor to GHG

emissions, and the switch to more sustainable energy production could kill two birds with one stone here. Through strengthened policy for the segregation of food and new facilities for WtE operations, energy innovation and organic waste management can go hand in hand. The challenge here is to understand further why facilities have not been started until now or why biogas has not been used more than the reported 0.02% in the Third Biennial Report (Anwar et al., 2021). This presents a major opportunity for Indonesia to promote circularity and reach GHG emissions reduction goals.

Promoting IRRC facilities for compost and biogas generation supports Indonesia's sustainable development goals by addressing waste management, soil health, and renewable energy objectives. It fosters a circular economy where organic waste is managed sustainably, resources are conserved, and environmental impacts are minimized. By embracing these initiatives, Indonesia can pave the way for a more sustainable and resilient future.

A strengthened cooperative environment can help alleviate pressures from individual actors in the waste management process. By working with municipalities, communities, the private sector and international bodies, Indonesia could see numerous improvements in the financing and support for new waste management technologies such as composting initiatives, IRRC facilities, and biogas generation. Incorporating circularity techniques like composting in organic waste management practices offers the potential for significant reductions in GHG emissions, and valuable renewable energy can be generated. These benefits contribute to the overall sustainability of waste management systems and align with the global transition towards a low-carbon economy. It was also concluded that advancing neighbourhood development projects for closed-loop food systems could counteract the ongoing spatial distancing urbanization is bringing to global food systems, assisting sustainable food waste management within closer proximity (Soma, 2017b). By collaborating with ecological, social, and economic objective settings, these actors could transform the nature of organic waste management in Indonesia, like enhanced systems in Dhaka.

6.5 Conclusion of Findings

In conclusion, based on the research and comparative analysis conducted above, several recommendations can be made to improve organic waste management in Indonesia. Recommendations highlighted financial assessments and budget shifts, education and awareness campaigns, technological innovation, and the overall fostering of a cooperative environment through the waste management system.

The reallocation and the potential increase in budgets for organic waste management redirect funds toward improved working conditions and advanced waste treatment facilities, including integrated composting and AD centres, to support effective waste management and reach sustainable development objectives. This could encourage technological innovation to help enhance the circularity of waste through innovative technologies well suited for market conditions.

Awareness is also critical to proper organic waste management, supporting householder separation and discouraging inefficient processes like open burning. Various approaches like passive dissemination, community engagement, and interactive gaming can provoke knowledge and promote behavioral changes.

Another result was the desire to enhance compost and biofertilizer marketability, including reassessing national subsidies on synthetic fertilizers and finding ways to promote organic waste-derived compost. This could be supported by additional IRRCs, generating revenue through its various profit streams and addressing soil fertility. Furthermore, incorporating more WtE schemes could alleviate pressures in alternative areas contributing to GHG emissions and environmental degradation. Biogas can be produced from organic waste to help contribute to growing energy demands while reducing methane-related emissions and reliance on fossil fuels.

By creating a cooperative environment, municipalities, communities, international bodies, and the private sector can collaborate to support transforming organic waste management operations in Indonesia. By embracing circularity principles and incorporating composting initiatives, IRRC facilities, and biogas generation,

Indonesia can achieve waste management, soil health, and renewable energy objectives, contributing to a more sustainable and resilient future.

7 Conclusion

In conclusion, this study sheds light on the constraints and opportunities faced by Indonesia in its organic waste management systems, providing valuable insights for policymakers, practitioners, and researchers in developing countries with high organic waste compositions. The findings emphasize the need for improved municipal solid waste management practices to address the adverse effects on societal well-being, environmental health, and economic prosperity. By combining solutions that trickle into all aspects of concern for Indonesia, this research highlights the strength and potential of reaching the NDC objectives.

The implications of these conclusions extend beyond academia and have practical policy implications. Policymakers could prioritize allocating sufficient budgets for waste management operations, reviewing financing strategies, and exploring additional funding options based on the data provided. Raising awareness and educating citizens about proper waste management practices are crucial steps toward achieving sustainable outcomes, emphasizing the importance of behavioral change. Encouraging technological innovation tailored to the local context, including infrastructure development and appropriate technologies, can greatly contribute to effective waste management.

Furthermore, fostering collaboration and partnerships among stakeholders at various levels is essential for implementing and sustaining organic waste management initiatives. This includes cross-sector cooperation between energy and waste management through private IRRC facilities or collaborations with local farmers. These collaborative efforts can leverage expertise, resources, and knowledge, promoting successful organic waste management practices.

Additional research is strongly advised to ensure the success of these potential recommendations. Indonesia's lack of data and monitoring, particularly regarding MSWM and the OW stream, should be addressed through comprehensive data collection and monitoring efforts. Additionally, research should explore the coordination and cooperation among stakeholders in waste management systems, analyzing why limited collaboration exists and learning from successful organic waste management practices in other countries.

The research also highlights the need for understanding the barriers and opportunities for composting initiatives in Indonesia and the potential for WtE strategies, such as biogas, to meet sustainable energy demands. Addressing these research gaps and implementing the recommendations could lead to significant progress in transforming Indonesia's organic waste management systems, further contributing toward a circular economy, and mitigating the associated adverse impacts of waste mismanagement.

Organic waste is an inevitable part of society, and its management can be adapted and leveraged as a tool for economic, social, and environmental resilience in the pursuit of sustainable development. This research has identified the existing constraints and opportunities within Indonesia's organic waste management systems, suggesting potential solutions such as technological advancements, composting schemes, and educational campaigns. By valuing organic waste and implementing the recommended measures, Indonesia can harness various opportunities, including job creation, economic prosperity, and environmental resilience.

The methodology used for this research successfully uncovered the existing systems within organic waste management globally and specifically in Indonesia. However, due to research limitations, further primary research is necessary to understand the results' implications better. Conducting primary research within Indonesia would provide valuable insights by engaging with governments and communities and addressing the remaining questions and barriers identified in this study.

To reiterate the research results the following recommendations have been identified to enhance the ways of organic waste management in Indonesia potentially:

1. Review municipal budgets and financing strategies to allocate resources more effectively, considering additional landfill locations, improved working conditions for informal workers, and implementing advanced waste management facilities.
2. Increased awareness through intensive marketing strategies and government support for infrastructure, like successful campaigns in other countries.
3. Embrace technological innovation tailored to local waste compositions, focusing on developing quality fertilizers, restoring soil fertility, and increasing grassland productivity.
4. Foster a cooperative environment by strengthening collaboration among municipalities, communities, the private sector, and international bodies to support new waste management technologies, composting initiatives, and biogas generation.
5. Promote waste-to-energy strategies to meet sustainable development goals and reduce greenhouse gas emissions, exploring opportunities for biogas production and utilizing renewable energy sources.
6. Enhance marketability of compost and fertilizers by addressing subsidies on chemical fertilizers, incentivizing the use of organic alternatives, and promoting the profitability of integrated resource recovery centres.

In conclusion, this research hopes to contribute to municipal waste management by offering recommendations and insights into the potential of organic waste to contribute to sustainable development in Indonesia. Identified recommendations encompass budgets, financial strategies, awareness building, embracing technological innovation, and enhancing the marketability of compost and biofertilizers. As waste continues to grow alongside our population, the waste we create needs to be considered. By embracing circularity principles and incorporating composting initiatives, IRRC facilities, and biogas generation, Indonesia can achieve waste management, soil health, and renewable energy objectives, contributing to a more sustainable and resilient future. Generating value and reducing waste have the potential to achieve global sustainability objectives and transform the world!

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