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Abstract: FW has a detrimental impact on the environment and holds potential for energy recovery through its utilization. Surabaya implement waste-to-energy (WtE) as a sustainable solution for waste management and energy needs. This research highlights the environmental concerns of FW and the potential for energy generation. This implies that existing waste management practices might not be fully addressing the energy recovery potential of FW in Indonesia especially in urban cities. The primary objective of this study was to analyze the energy potential of FW in Surabaya City using Material Flow Analysis (MFA). Black Soldier Fly (BSF), composting, anaerobic digestion (AD) generates substantial material and energy. Landfill and gasification were generated with a capacity of 2 Megawatt (MW) and 11 MW, respectively. This study uses a graphical MFA to provide fundamental information for assessing the sustainable management feasibility of converting FW into energy in Surabaya.

Keywords: food waste; waste-to-energy; urban cities; material flow analysis

1. Introduction

According to data from the Indonesian Ministry of Environment and Forestry[1)], in 2022, there was a substantial increase in food waste generation, accounting for 40% of the overall waste output. This waste is produces throughout the supply chain, from distribution to consumption. In the distribution and marketing phase, the annual amount of wasted food ranges between 3.2 to 7.6 million tons, and during the consumption stage it ranges from 5 to 19 million tons[2)]. This upward trend in food waste generation has been observed over the past two decades, with recent years showing a particularly noticeable increase.

The increasing amount of food waste has become a pressing concern in urban areas, leading to a growing urgency in managing this waste. This is primarily due to the sheer volume of waste generated and its detrimental impact on the environment[3)]. However, despite its negative consequences, food waste also presents an opportunity for energy recovery through its potential utilization[4)].

The waste-to-energy (WtE) programs in Indonesia were in various stages of development and implementation. The Indonesian government has recognized the potential of converting waste into energy as a sustainable solution to address both waste management and energy challenges[4–7)]. Researchers could improve the opportunities for harnessing food waste as a renewable energy source by examining the energy potential of food waste.

Several technologies such as BSF, LFG, AD, Gasification, and composting is usually implemented in urban city. Black Soldier Fly (BSF) larvae offer a biological conversion process, transforming FW into biomass that can be further processed into biodiesel or utilized as animal feed. This method not only reduces waste volume but also facilitates resource recovery through the creation of valuable products. Landfill gas (LFG) capture systems play a crucial role in mitigating the environmental impact of landfills, where a significant portion of FW ends up. These systems collect methane, a potent greenhouse gas generated during anaerobic decomposition, and convert it into usable forms of energy, such as electricity or heat. Anaerobic digestion (AD) provides a controlled approach to FW management, breaking it down in an oxygen-free environment to produce biogas, primarily composed of methane. This biogas can then be utilized for energy generation, offering waste reduction and renewable energy production benefits. Gasification presents another thermochemical conversion technology with the potential to transform FW into syngas, a combustible gas mixture. This syngas can be used for various purposes, including electricity generation and industrial processes. Finally, composting remains a well-established method for FW management, promoting its aerobic decomposition into a nutrient-rich soil amendment. While not directly producing energy, composting effectively diverts FW from landfills, thereby reducing greenhouse gas emissions and contributing to soil health.

Material Flow Analysis (MFA) aimed to gain insight into the existing management systems in Surabaya and identify potential improvements or alternative strategies that could maximize energy recovery from food[8,9]. The MFA study is necessary to assess the feasibility and implications of food waste-to-energy conversion in Indonesia. Through such an analysis, a detailed understanding of input-output patterns, waste generation rates, and potential energy outcomes can be gained. This research was carried out in Surabaya City.

MFA is a technique used to track and quantify the movement of materials within a defined system. In the context of waste management, it's a valuable tool for understanding the flow of waste materials, from generation to final disposal or treatment. MFA helps determine the quantity and composition of waste generated in a specific area. This information is crucial for planning WtE facilities with the appropriate capacity to handle the incoming waste stream

This study aims to determine the energy potential of food waste generation and at the same time develop a food waste processing technology by analyzing the material cycle for food waste processing. Investigate the potential conversion of food waste to energy in Indonesia, focusing on Surabaya as a case study. The findings of this study will serve as a informed decisions regarding waste management strategies and the adoption of food waste while simultaneously capitalizing on its energy potential.

2. Methodology

2.1 Surabaya City (Metropolitan City Study Case)

Based on the 2008 Government Regulation[10], a metropolitan area is an urban area surrounding functional interconnections connected by an infrastructure network system. Integrated regions with a total population of at least 1,000,000 (one million) people. The population of Surabaya City is 2.87 million peoples[11,12].

Several compelling reasons underpin the selection of

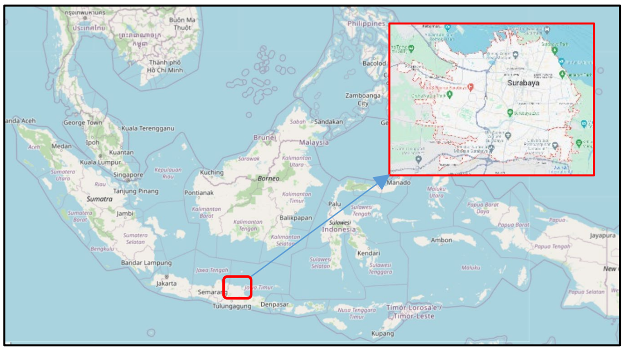

Fig. 1: Maps of the location of Surabaya City in Indonesia
Source: Modified from openstreetmap.org[16]

Surabaya (Fig. 1) as a focal point for this study. Surabaya holds the distinguished status of being one of the prominent metropolitan cities in Indonesia, a characteristic that significantly contributes to its representation of urban complexities and challenges. Second, the city boasts the second-largest population in Indonesia. This demographic attribute not only underscores its significance on a national scale but also adds layer of complexity to managing resources and services. Furthermore, Surabaya has been recognized as a an environmental stewardship, having received an impressive seven Kalpataru awards from the Ministry of Environment and Forestry up to the year 2023[13]. Surabaya has been honored as an ASEAN Environment Sustainable City, a testament to its prowess in sustainable environmental management when compared to other major cities in the ASEAN region[14]. This esteemed recognition positions Surabaya as a vanguard in the pursuit of sustainable urban development. The city of Surabaya emerges as an exemplar in effective waste management practices, setting the stage for an in-depth exploration of food waste management in this study.

The average waste generation in Surabaya is 0.33 kg per day per person. In Surabaya, the predominant components include food waste (64.18%), plastic (10.79%), paper waste (9.24%), and diapers used (6.97%). Food waste includes leftover raw vegetables, fruit skins, fruit seeds, expired bread, and food ingredients[15]. Figure 1 represents the location of Surabaya City.

2.2 Research Framework

Figure 2 is research framework conducted in this study. Goal and scope stage is the initial stage defines the overall objective and boundaries of the research. In data collection, involves gathering data on food waste flows within the designated urban centers of Indonesia.

The framework acknowledges that food waste can be processed using various technologies. The research will likely consider the most common ones employed in Indonesian cities. Data Analysis refers to employing a software tool called STAN 2.7 to analyze the data collected on food waste flows. This software program designed for Material Flow Analysis (MFA).

Literature review conduct the framework incorporates a review of relevant academic literature to contextualize the research findings within the existing body of knowledge on food waste management and energy recovery. A benchmark will be established, which represents the existing baseline for food waste management and energy recovery in Indonesian cities. This will serve as a reference point to evaluate the potential improvements. Model prediction conduct the MFA model, constructed using STAN 2.7 and the collected data, will be used to predict the potential for recovering energy from food waste streams. The model will likely estimate the quantity of energy obtainable based on the amount of food waste processed.

In the final stage, this study will interpret the results of the model prediction and data analysis. This will involve drawing conclusions about the potential for using food waste as an energy source in Indonesian cities.

FW energy recovery potential refers to the anticipated outcomes of the research. The study aims to assess the potential for Indonesian cities to recover energy from food waste using an MFA approach. Overall, the research framework outlines a systematic approach to evaluating the feasibility of using food waste as a renewable energy source in Indonesian urban city. By employing Material Flow Analysis and considering various food waste treatment technologies, the research can provide valuable insights for policymakers and waste management practitioners.

2.3 Data collection

Waste generation data was constructed from the total population of Surabaya. Waste composition such as food waste (FW) and non-food waste (NFW) is extracted from percentage data from National waste management information system (SIPSN)[17]. Non-food waste (NFW) such as plastics, metal rubber, etc. Waste handling data is collected and analyzed from Environmental Services of Surabaya (2020-2021)[18]. Data collected in all various waste treatment facilities operated by the Surabaya government, such as compost plants, landfills, waste banks, recycle centers and temporary waste plants (3R) spread throughout the Surabaya area. Details of data collection is represented in Table 1. Figure 3 is details location waste treatment in Surabaya City and become the location site data collected.

Data were extracted from 2020 to 2021[18]. In 2021, was initiated for waste treatment as a pioneering "Waste to Energy" program from Indonesia's Government with Gasification and Landfill Gas. This study does not include waste that remains unmanaged by the government, be it generated by individuals or organizations. Any waste not under governmental management is beyond the scope of this research.

Table 1. Data collection in various waste treatment in Surabaya

No	Waste Treatment Facility	Number (sites)
1	Composting Plant	26
2	Recycle Center	2
3	Temporary waste plants (3R)	7
4	Landfill	1

2.4 Material flow analysis (MFA)

MFA is a crucial tool in evaluating the efficiency and effectiveness of waste management systems, including food waste recycling. This study implements the MFA study using the STAN 2.7 software version[19,20] to analyze material flows in waste recycling management of Surabaya.

STAN is commonly utilized to visually represent the mass movements of goods and substances using Sankey arrows. The model graph, presenting flows as Sankey arrows where the width corresponds to their respective values, can be easily printed or exported in multiple graphical formats. This method provides the benefit of instantaneously identifying the most substantial material flows. The outcomes of the computations are clearly presented in the form of a Sankey diagram within the drawing area[19].

Implementing this methodology can potentially improve the integration of food waste management. Additionally, it offers the ability to delineate the waste flow from individual processing units, enabling the identification of specific areas for the development of targeted waste processing. By applying this approach, food waste management can be streamlined and facilitate a detailed understanding of waste flow at various processing units, pinpointing specific areas that warrant focused development within the waste processing system [8,21–23].

3. Results and Discussions

3.1 Food waste management in Surabaya

Researchers conducted a study in Indonesia to analyze the management of food waste recycling. The MFA study identified the FW (Food Waste) and Non Food Waste (NFW), because food waste management in Indonesia is integrated and is not separate from waste management within city[3].Therefore the mass balance of FW in MFA could improve the clarity of FW management.

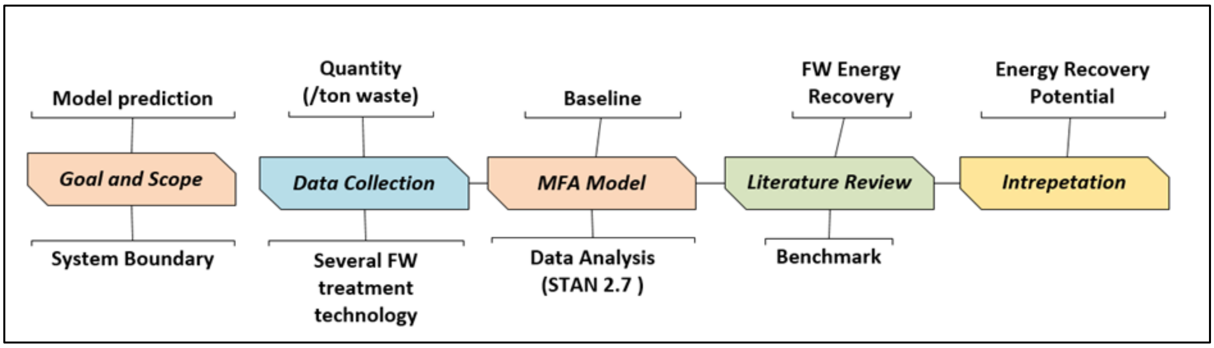

Fig 2: Research Framework develops in this study

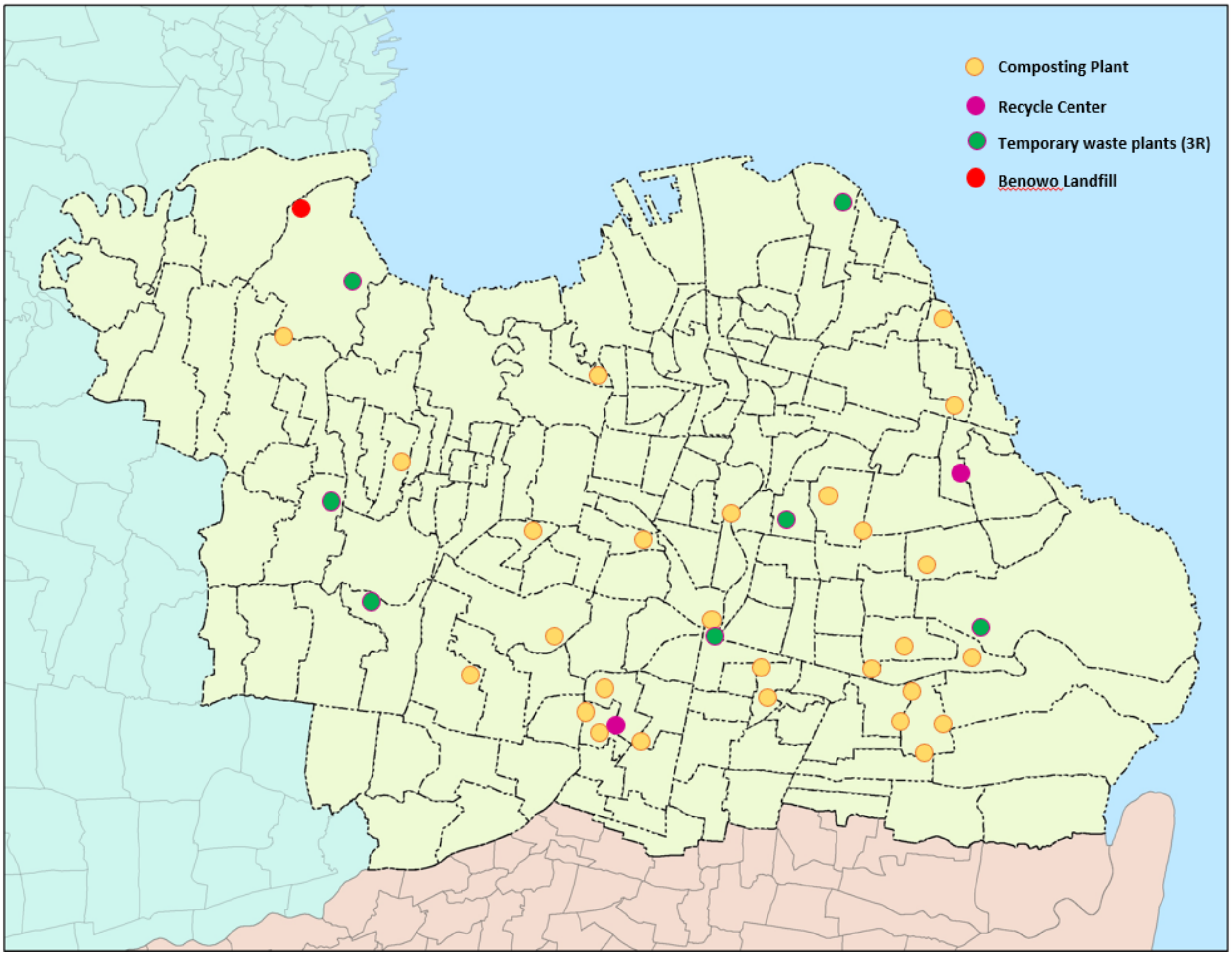

Fig 3: Data collection sites of food waste treatment in Surabaya

Data collection was undertaken at waste processing facilities in Surabaya (Fig. 4 and Fig. 5), specifically at establishments such as the Recycling Center (RC), the Compost Plant (CP), and the Temporary Waste Collection (TWC3R) and Waste Bank (WB), and Benowo Landfill. Notably, all RC implemented a composting process as part of their waste management strategy for handling food waste (FW). In contrast, only a limited number of TPS3R facilities were observed to have incorporated a composting process into their waste management operations. BSF application is integrated in RC Bratang, RC Menur, RC Jambangan, and RC Wonorejo. The parameter of MFA is in ton/year, while the red line represents the FW, and the blue line represents the NFW until the last treatments unit (Fig. 4 and Fig. 5).

Figure 4 serves as a depiction of the Material Flow Analysis (MFA) for food waste (FW) in its baseline condition. It is pertinent to note that, during the specified timeframe, neither the Gasification process nor the utilization of Landfill Gas (LFG) has been implemented in this context. Figure 5 illustrates the Material Flow Analysis (MFA) for food waste (FW) incorporating the processes of Gasification and Landfill Gas Utilization (LFG) in the year 2021.

There is a marginal resemblance in the processing capacities for food waste observed across treatment units, specifically in the Black Soldier Fly (BSF), Recycling Center (RC), Temporary Waste Collection (TPS3R), and Waste Bank, during the years 2020 and 2021.

In 2020 (Fig. 4), exhibited The Recycling Center (RC) manages 0.355%, handling 6608.89 tons/year. The Compost Plant (CP) significantly dominates the food waste processing, accounting for 0.91% with a volume of 7368.91 tons/year. Similarly, Temporary Waste Collection (TPS3R) deals with 0.236%, equivalent to 1943 tons/year of food waste. While these capacities may seem limited, they offer alternative solutions to divert food waste from landfills and promote more sustainable waste management practices. The predominant disposal method for waste involves directing a substantial portion, specifically 327933.1 tons per year, directly to the landfill. Total waste dumped in landfill reach 607768.49 tons/year.

The predominant method of dealing with food waste involves direct processing in landfills, constituting 76,47% of the overall waste treatment. This research underscores that 40,42% of food waste is directly funneled into landfills, equating to a staggering 327943.69 tons of wasted food. This points to a significant reliance on conventional disposal practices, specifically highlighting the substantial amount of food waste through direct landfill disposal. Additionally, the research revealed that a proportion of food waste, which is 3.93%, is utilized in the composting process. This signifies a positive step towards reducing waste and harnessing the nutrients from food waste for beneficial purposes.

A noteworthy discovery arising from this study is the implementation of the Black Soldier Fly (BSF) in processing food waste, marked by a modest implementation rate of merely 0.01% that handle 96.93 ton/year of FW. This indicates a promising avenue for further investigation and enhancement of this environmentally friendly and effective waste processing approach. This finding opens up a potential space for further exploration and refinement of the environmentally conscious BSF method in handling food waste.

MFA analysis in 2021, shown in Fig. 5, shows that the Indonesian government has prioritized the implementation of WtE processing in several cities, with Surabaya being one of the cities chosen for this initiative. This strategic move aims to accelerate the country's transition towards alternative energy sources. In Surabaya, specifically, the fuel of choice for the conversion of WtE is gasification technology, which efficiently transforms waste materials into valuable energy resources[3)].

In 2021, Gasification and Landfill Gas Utilization (LFG) were implemented at 73% and 27%, respectively. A total of 173202 tons/year of mixed waste, comprising both food waste (FW) and non-food waste (NFW), was managed, with 607768 tons/year being utilized in the Landfill Gas (LFG) process and 468287.17 tons/year incinerated in Gasification process.

Surabaya's waste management system has significantly improved, particularly in waste intake and processing. In the same year, the city has successfully adopted thermal processing techniques, enabling them to convert approximately 30% (equivalent to 173,220 tons/year) of total waste entering the final processing unit into usable energy[18)]. However, despite these advancements, it is imperative to note that roughly 70% of the waste still requires disposal in the landfill processing unit.

The primary source of food waste processed in Surabaya's waste plants was identified from traditional markets. Surabaya's city government takes the lead in processing food waste from traditional markets, considering it the most effectively managed waste category. Collecting waste from traditional markets proves more feasible than household waste due to centralized management by the Surabaya city government, overseen by the PD Pasar Surya unit[24)]. Additionally, certain markets have dedicated compost processing units, facilitating waste management or transportation to the centralized composting facility[25,26)]. This indicates a coordinated effort in waste management with a focus on traditional market-generated waste. A recent MFA study conducted in Surabaya, was used to trace the movement of plastic and paper waste materials from waste banks to the recycling industry. This study's findings revealed that a significant amount of residual waste was generated as a byproduct during the recycling process. This waste material emerged as a result of the processing procedures[27)].

Decision-makers can gain insight into the efficiency and performance of the food waste recycling process by examining the material flows within these facilities. The MFA analysis could comprehensively understand the material flows within the food waste recycling management[23]. This analysis can provide valuable information on the performance of each facility, highlighting areas for improvement, and identifying opportunities for optimization[28]. The government of Surabaya can make informed decisions regarding its food waste recycling management, ensuring that resources are allocated efficiently and environmental impacts are minimized using MFA [23,29].

3.2 Energy Potential from Food Waste Management in Indonesia

Black soldier larvae (BSF)

The BSF has been integrated into the Surabaya Recycling Center plant. This innovative approach involves using these larvae to break down food waste. BSF larvae are highly efficient in consuming organic waste, converting it into valuable byproducts such as larvae biomass and fertilizer[30]. Their inclusion in the recycle center allows the diversion of a significant portion of food waste from the landfill, reducing environmental impacts and promoting more sustainable waste management practices[31].

In recent years, there has been a growing interest in sustainable waste management practices, particularly in food waste. An innovative approach involves the utilization of BSF larvae for processing food waste. Research indicates that BSF larvae are highly efficient at converting organic waste into valuable products, with their end products being notably rich in protein and fat[32]. Specifically, studies have shown that BSF larvae can produce biomass containing 20-50% protein and 15-30% fat as embedded energy from domestic waste and food waste from cafetaria. BSF have generate potential approximately 800 grams of larvae biomass per 4 kilograms of food waste that could produce larvae 387 kg/year in Surabaya[33]. This nutritional profile makes BSF products an attractive and sustainable option for various applications, including aquaculture and poultry farming[34].

In addition, the use of BSF larvae in waste processing aligns with the larger goal of creating a circular economy, where organic waste is converted into valuable resources. The potential benefits of integrating BSF larvae into waste management systems extend beyond nutritional content, encompassing environmental impact reduction and resource efficiency promotion. As the body of literature on this subject continues to grow, further exploration of the economic viability, scalability, and potential ecological implications of employing BSF larvae in food waste processing is essential to advance sustainable practices in the agriculture and food industry.

Landfill Gas (LFG)

This waste management system is recognized as a significant contributor to pollution, notably exacerbating global warming and acidification[3]. However, a notable innovation in this context involves the application of landfill gas (LFG) technology, harnessing methane gas generated during landfill waste processing procedures. This unconventional approach challenges the conventional perception of landfills as ecological liabilities, introducing a dual-purpose solution by managing waste and simultaneously generating energy[35].

The generation of substantial amounts of landfill gas from solid waste in Indonesia revealed an estimated annual production of 875,130 tonnes of methane, generating around 54,142 MW of energy each year. The Bantargebang landfill modeling study further attests to the variability in LFG production rates, ranging between 0.05 and 0.40 m^3 per kg of landfilled municipal waste (MSW)[36].

Surabaya predicted produce 607,768 tons/year being utilized in the Landfill Gas (LFG) process could generate 243.107,2 m^3/year mehane potential. The Surabaya City Government has been able to produce electricity from waste at the Benowo Landfill in collaboration with PT Sumber Organic by utilizing Landfill Gas Installation technology which can produce electricity with a capacity of 2 MW, of which 1.65 MW is sold to PLN and 0.35 MW for landfill operations [37]

This pioneering approach not only addresses the critical issue of food waste management, but also underscores the potential to transform landfills into renewable energy sources, contributing to the overall goals of sustainable development of the nation.

Anaerobic digestion (AD)

Anaerobic digestion (AD) technology has emerged as a promising avenue for deriving energy from organic materials, providing an optimal environment devoid of oxygen and rich in heat and promoting the proliferation of microorganisms. Under conducive conditions facilitated by AD, these microorganisms effectively decompose organic matter, producing valuable byproducts in the form of biogas and nitrogen-rich fertilizers[38,39]. Beyond its waste reduction attributes compared to landfill disposal, AD has multifaceted economic and environmental benefits[40]. The projections indicate that the extensive adoption of large-scale anaerobic digestion (AD) applications could offer operational benefits and improve efficiency[41]. This is achieved primarily by reducing landfill expenses and simultaneously promoting economic advantages through the production of electricity, heat, and fertiliser[42].

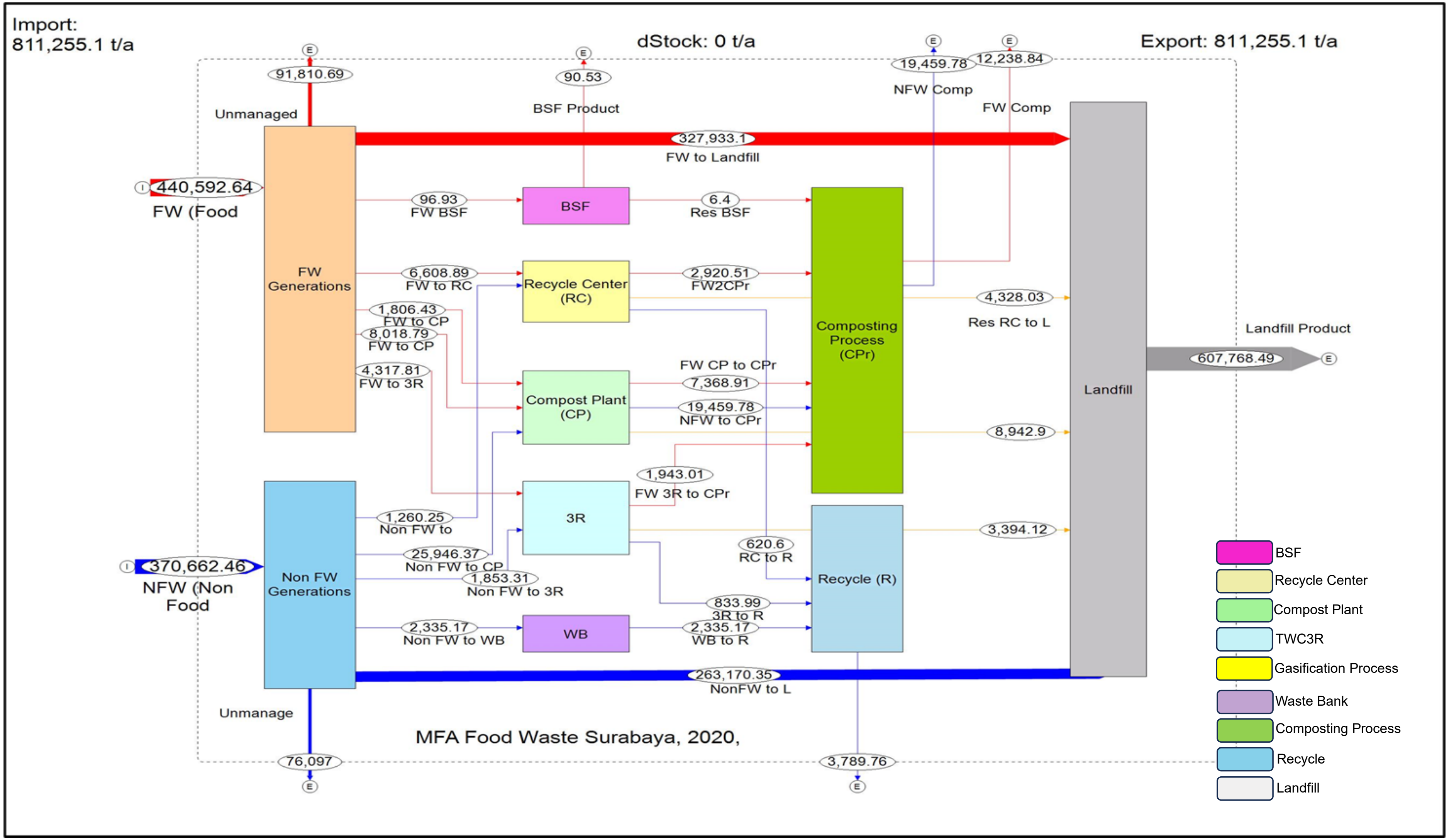

Fig. 4: Material flow analysis of Surabaya food waste in 2020

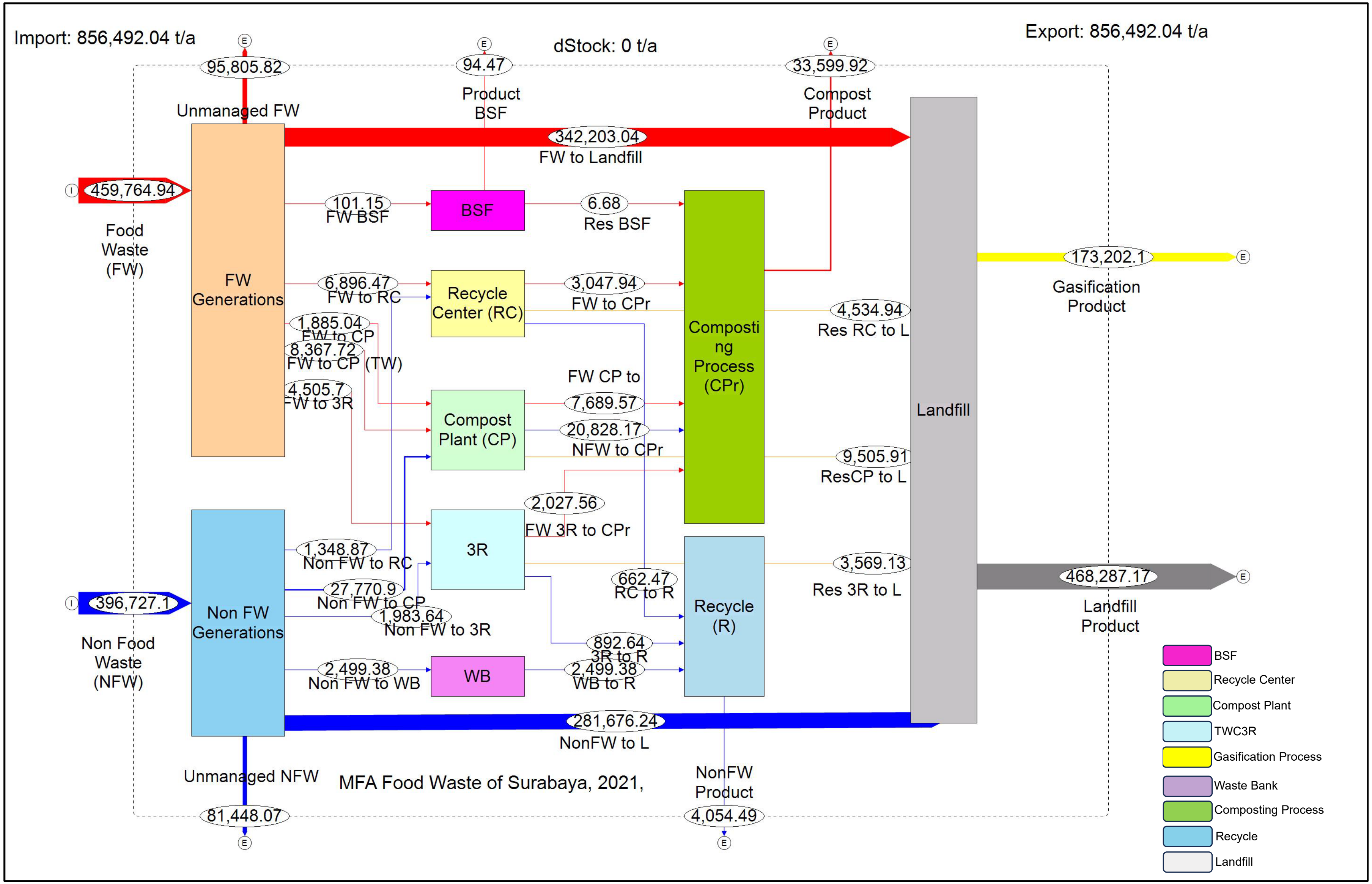

Fig. 5: Material flow analysis of Surabaya food waste in 2021

Despite the absence of an anaerobic digester unit in the city of Surabaya, this technology has become promising in various regions in Indonesia. One of the food waste treatment with AD implementation is at the Malang Integrated Resource Recovery Center (IRRC) in Malang Regency, East Java[43]. This technology is used to process traditional market waste and mixed with manure.

Previous research conducted promising methane generation in conjunction with manure and Palm oil mill effluent (POME), producing methane at a rate of 0.30 L CH_4/g COD removed[40]. Furthermore, food waste substrates derived from canteens that exhibit elevated levels of fat, oil, and grease have shown the capacity to produce substantial methane yields, ranging from 127 to 485 ± CH_4/kg of VS per day[42]. These findings underscore the versatility of AD technology in the treatment of various organic waste streams and its potential for adoption to improve sustainable waste management practices[44].

Composting

Composting is a prevalent method used to transform food waste into valuable resources[45]. This eco-friendly approach not only produces energy products but also results in the creation of nutrient-rich compost containing essential elements such as nitrogen, carbon, and phosphorus[46]. The widespread adoption of composting in urban centers, including Surabaya, is attributed to its inherent advantages—requiring minimal energy input and the availability of operational simplicity, particularly when dealing with large processing capacities[47]. In Surabaya, a substantial portion of the city's food waste undergoes the composting process, intricately intermingling with twigs and leaf waste sourced from the meticulous maintenance of the city parks. In the year 2020, the composting operations at Surabaya yielded a total of 3,168.62 tons of compost products, and this figure increased to 3,599.92 tons in 2021. The process involved an intricate composting procedure, followed by a thorough screening mechanism, which effectively transformed the initially crude compost into a mature and high-quality product. This meticulous approach not only demonstrates a commitment to sustainable waste management practices but also underscores the city's dedication to producing compost of superior quality.

The advantages of composting products extend beyond waste reduction. Compost, as an organic fertilizer, contributes to enhancing soil structure and fertility, thereby promoting sustainable agriculture practices. Additionally, the use of compost aids in moisture retention in the soil, reducing the need for irrigation. Furthermore, the application of compost helps suppress soil-borne diseases, fostering a healthier and more resilient ecosystem[48]. By embracing composting practices, Surabaya not only addresses waste management concerns but also actively contributes to environmental conservation and sustainable agricultural practices, positioning itself as a model city in the pursuit of a greener and more sustainable future.

This symbiotic relationship between organic waste and natural elements not only underscores the city's commitment to sustainable waste management but also highlights the efficiency and scalability of composting as a pivotal player in the quest for environmentally responsible and energy-conscious urban ecosystems[49,50].

Thermal Treatment

Figure 5 elucidates Surabaya's adoption of thermal treatment through the initiation of a gasification process in 2021, facilitated in collaboration with PT Sumber Organic. This innovative approach encompasses the treatment of approximately 170,202 tons per year of waste, encompassing various waste streams, including food waste.

The intricacies of the gasification process in Surabaya involve the engagement of a third-party entity, Sumber Organic (SO), for managing the energy production aspects. This application has demonstrated the capability to generate 11 MW, of which 9 MW is channeled for sale to PLN (State Electricity Company), while the remaining approximately 2 MW is allocated for sustaining the operational needs of the Gasification treatment plant[37].

This strategic venture not only addresses waste management challenges but also underscores Surabaya's commitment to harnessing innovative technologies for sustainable energy generation, thereby contributing to both environmental and energy conservation endeavors. Furthermore, it is crucial to pay greater attention to the issue of food waste, given its elevated water content, which can potentially decrease combustion efficacy of combustion[3]. Enhanced waste management practices enable informed decisions and foster sustainable and eco-friendly solutions to recycle food waste with energy generation[7,28].

The process of generating heat by utilizing waste material, known as thermal oxidation, includes many techniques such as incineration. During the thermal oxidation process, the transmission of heat occurs to the boiler of the steam engine. The combustion process involves the conversion of hydrocarbons found in waste into various byproducts, including water and carbon dioxide. The composition comprises 46% combustible materials (such as food waste and plastic), 52% fine particles, and 2% incombustible materials (like metal and glass). The simulation outcomes indicate an extended investment return period, with the potential for generating 461.67 kW of electricity and a CO_2 emission rate of 0.18 kg/sec[51]. A thorough understanding of a substance's elemental composition, particularly its carbon, hydrogen, oxygen, nitrogen, sulphur, and ash constituents' content, is imperative before establishing an efficient combustion process. Thermal waste processing has the capacity to rapidly reduce substantial waste volumes and convert them into electrical energy beneficial for community use[52].

Air emissions from thermal treatment[53], containing dioxins and heavy metals, pose environmental concerns. The incineration process releases heavy metals such as Cd, Hg, Ni, Pb, Cu, Cr, and Zn into the waste stream. This results in the production of a significant volume of hazardous fly ash in the form of flue gas, leading to a negative public perception. Achieving more acceptable operating conditions, especially in terms of temperature and equivalence ratio, and optimizing specific reactor features are crucial for improved performance. Utilizing steam in the incineration process offers clear advantages in minimizing dioxin formation in existing plants[54)]. However, this approach prolongs the gasification process. Additionally, addressing the challenge of low moisture content in the feedstock necessitates energy-intensive pre-drying steps when handling wet wastes [55,56)].

3.3 Practical Implications for Other Cities and Regions

This research offers valuable insights that can be applied to other cities and regions seeking to implement similar strategies for converting food waste into energy. MFA framework serves as a replicable template. Other cities can adapt this framework to their specific contexts by defining their own system boundaries, collecting relevant data on food waste generation and management practices, and employing similar MFA software (e.g., STAN 2.7) to quantify their food waste flows.

The research emphasizes the importance of establishing a benchmark for existing food waste management practices. This approach can be replicated in other cities to evaluate their current waste management infrastructure and identify areas for improvement. The study explores the potential of various food waste treatment technologies like composting, anaerobic digestion (AD), and incineration with energy recovery. Other cities can utilize these findings as a starting point to assess the suitability of these technologies within their own contexts, considering factors like waste composition, infrastructure availability, and economic feasibility.

The research outcomes can inform policy decisions in other cities by highlighting the potential benefits of food waste-to-energy conversion. This data can be used to support policies that encourage waste segregation, promote investment in appropriate treatment facilities, and incentivize the adoption of sustainable waste management practices.

The success of these strategies may depend on the specific socioeconomic context of each city. Factors like community awareness, willingness to participate in waste segregation programs, and government funding for infrastructure development need to be considered.

3.4 Environmental Impact

MFA approach used in this research doesn't directly address the environmental impact of WtE. However, the findings from the MFA can be used to inform a more comprehensive assessment of WtE's environmental impact when combined with additional data and considerations.

The MFA data on food waste composition can be used to estimate the potential air pollutant emissions from a WtE facility. Different food waste components (e.g., fats, proteins) can contribute varying levels of pollutants during incineration. The MFA data on the quantity of food waste can be used to estimate the potential energy generation capacity of a WtE facility. This information, combined with data on WtE efficiency and emission factors, can be used to assess the overall environmental impact compared to traditional energy sources like fossil fuels. By integrating MFA data with a Life Cycle Analysis (LCA), researchers can create a more holistic picture of the environmental impact of WtE for food waste conversion. LCA considers the environmental burdens throughout the entire process, from food waste collection and transportation to WtE plant operation and waste product disposal.

3.5 Economic Impact Analysis

An economic impact analysis, combined with the MFA approach, can provide a more holistic view of the potential benefits of WtE for food waste management in Surabaya. MFA study regarding of WtE have significant impact in economic terms, such as the quantity of significant reducing waste management costs by diverting food waste from landfills and revenue generation from electricity or heat produced through WtE [35,36,57)]. This would involve estimating the costs associated with establishing and operating WtE facilities, including infrastructure development, technology acquisition, and operational expenses. The economic impact analysis can be effectively integrated with the MFA data. The MFA data on food waste quantities can be used to estimate the potential energy generation capacity of WtE facilities. This energy generation capacity, combined with electricity or heat prices, can be used to estimate potential revenue streams from WtE. The MFA data on food waste composition might influence the choice of WtE technology, which can have cost implications.

The inclusion of an economic impact analysis can significantly strengthen the argument for implementing WtE as a viable solution for food waste management in Surabaya. This comprehensive approach would equip policymakers and waste management authorities with the necessary information to make informed decisions. By simultaneously considering both the environmental and economic benefits associated with WtE, a more balanced and robust evaluation can be achieved [3,58)]. Furthermore, integrating an economic impact analysis with the MFA framework presents a valuable opportunity to gain a more holistic understanding of the potential advantages and drawbacks of WtE for Surabaya's food waste management system. Ultimately, this comprehensive assessment can serve as a crucial tool for decision-making, guiding the city towards a more sustainable future in waste management practices.

4. Conclusions

Implementing the MFA in Surabaya City's food waste recycling management system has allowed for a thorough analysis of material flows within various waste treatment facilities. MFA is employed to analyze the existing food waste management systems in Surabaya, providing insights into input-output patterns, waste generation rates, and potential energy outcomes. This study addresses the urgent concern of food waste management in urban areas, particularly in Surabaya City, Indonesia to assess the energy potential of food waste and explores waste-to-energy (WtE) programs as sustainable solutions for waste management and energy needs.

The study identifies various waste treatment methods, including Black Soldier Fly (BSF) larvae, composting, anaerobic digestion (AD), landfill gas (LFG), and thermal treatment (gasification). These alternative methods contribute to reducing the environmental impact of food waste and harnessing energy.

The potential for BSF larvae to produce biomass and fertilizer, contributing to waste diversion from landfills reach 387 ton/year. The application of LFG technology is highlighted as a dual-purpose solution for waste management and energy generation. Surabaya's utilization of LFG from landfill waste is explored, with the capacity to generate electricity in 2 MW and Gasification approach demonstrates the city's commitment to innovative technologies for sustainable energy generation that produce of 11 MW electricity. AD technology is not implemented in Surabaya, the study mentions its promising potential for deriving energy from organic materials, providing economic and environmental benefits. Composting is recognized as a prevalent and eco-friendly method for transforming food waste into valuable resources. Surabaya's commitment to composting practices is emphasized, with positive outcomes for soil fertility and sustainable agriculture.

However, success depends on the socioeconomic context, requiring consideration of factors like community awareness and government funding. Integrating an economic impact analysis with the MFA approach provides a more holistic view, enabling cost estimation, revenue stream evaluation, and informed decision-making to guide cities towards a sustainable future in waste management.

This research provides a replicable framework for cities to convert food waste into energy. Cities can adapt the MFA approach to quantify waste and evaluate practices, informing policies for waste segregation, treatment facilities, and sustainable management. Success hinges on socioeconomic factors, and a combined economic analysis with MFA strengthens the case for WtE by considering costs and revenue potential. Overall, this research empowers cities with tools for informed decision-making towards a sustainable waste management future.

It is imperative to acknowledge that additional research in the form of futures studies is required. Such research should focus on refining and optimizing existing waste treatment methods, exploring new technologies, and considering the environmental impact of these approaches. This forward-looking perspective is crucial to ensure the continued effectiveness, scalability, and ecological sustainability of food waste management practices in the pursuit of a more environmentally conscious and energy-efficient urban ecosystem.

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