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CASE STUDY

Food waste reduction strategies in composting and recycling centers based on material flow analysis

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ABSTRACT

BACKGROUND AND OBJECTIVES: Food waste has major environmental, economic, and social impacts, contributing to greenhouse gas emissions, soil depletion, global food insecurity, and rising food prices. Addressing the global challenge of food waste necessitates a heightened focus on food waste treatment. This investigation analyzed the extent of food waste reduction achieved at composting and recycling centers in Surabaya. The objective of this study is to evaluate the effectiveness of food waste reduction at composting and recycling facilities.
METHODS: The study utilized material flow analysis to assess food waste reduction at the Wonorejo composting and the Jambangan recycling centers. The present analysis examines the quantity and dynamics of food waste, starting with i) the pre-treatment stage that encompasses sorting, shredding, and sieving; ii) the composting process, which involves the generation of compost and the loss of water; and finally, iii) the bioconversion process facilitated by black soldier fly larvae, highlighting the production of larvae biomass and frass.
FINDINGS: At the Wonorejo composting and Jambangan recycling centers, composting served as the main approach for the treatment of food waste. At the Wonorejo composting center, over 99 percent of food waste was composted, whereas 0.22 percent was managed through black soldier fly larvae bioconversion. Within this composting center, the conversion rates revealed that 70.71 percent of the food waste was processed into mature compost. Furthermore, 0.03 percent was utilized for larval biomass production, 24.94 percent was lost to moisture, and 4.32 percent remained as residual waste. At the Jambangan recycling center, 85.74 percent of food waste was composted, whereas the remaining 14.26 percent was handled through black soldier fly larva bioconversion. Approximately 40.03 percent was transformed into mature compost, 1.37 percent into larval biomass, 29.26 percent lost as moisture, and the remaining 29.34 percent was landfilled.
CONCLUSION: Material flow analysis revealed that compost and recycling center facilities preferred composting over black soldier fly larva bioconversion for food waste reduction. Composting proved to be an effective method for processing over 85 to 99 percent of food waste, while the application of black soldier fly larvae bioconversion resulted in a mere 0.2 to 14 percent of food waste being treated. In light of the significant volume of food waste that continues to be disposed of in landfills, it is imperative for the Surabaya City Government to establish additional composting facilities in various locations. Furthermore, the implementation of supplementary strategies, including the management of surplus food distribution and the encouragement of composting at the household level, is essential for enhancing food waste management throughout the supply chains.

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INTRODUCTION

Food waste (FW) includes discarded, wasted, spoiled, or decomposed food that occurs in the final stages of the food supply network (i.e., distribution, market retail, and consumption) (Kavitha *et al*., 2020). Annually, 1.6 billion tons of food—one-third of worldwide food production—are wasted. This amount is estimated to rise to 2.1 billion tons by 2030 (Hegnsholt *et al*., 2018). Conversely, in 2022, between 691 and 783 million individuals globally faced starvation or malnutrition as a result of inadequate or constrained food resources (WHO, 2023). This situation highlights that the global increase in FW corresponds to significant economic losses and highly inefficient use of resources (FAO, 2024). Both industrialized and developing nations may experience increases in WF resources, though the magnitude of such increases can vary significantly due to factors including income disparities, levels of urbanization, and the pace of economic growth (Chalak *et al*., 2016). Therefore, prioritizing FW prevention and reduction is critical to optimizing resources use, ensuring food security (FAO, 2022), and reducing hidden impacts such as climate change, eutrophication, water depletion, agricultural land occupation, land transformation fossil depletion, terrestrial acidification, photochemical oxidant and particulate production, and adverse health effects to humans (Skaf *et al*., 2021). As a developing nation with a population exceeding 260 million, Indonesia has experienced analogous issues. In 2023, FW accounted for 41.7 percent (%) of the total solid waste generation (MEFRI, 2024). From 2000 to 2019, Indonesia's food loss and waste (FLW) generation reached 23–48 million tons annually (MNDPRI, 2021). An increase of approximately 15% in the generation of FW was identified during the distribution and consumption processes, with the consumption phase accounting for the largest share, estimated between 5 and 19 million tons per year. The economic loss caused by food loss and waste are estimated to be between 213 trillion and 551 trillion rupiahs per year (4–5% of Indonesia's Gross Domestic Product). Surabaya alone generated FW of approximately 0.37 million tons per year (t/y) (MEFRI, 2024). In order to tackle the problem of FW and reduce the volume of organic waste directed to landfills, the Surabaya City Government routinely implements food and organic waste management strategies at composting facilities, recycling centers, and gasification systems located in proximity to landfill sites. Surabaya has 24 compost centers and 2 recycling center facilities. Between 2021–2023, the average amount of solid waste processed by composting centers was 32101.19 tons, while recycling centers handled 9105.39 t/y (MEFRI, 2024). Composting was the primary waste treatment in these facilities. the bioconversion process utilizing black soldier fly larvae (BSFL) was introduced whitin facilities dedicated to recycling and composting. The introduction of this new method changes the ratio of solid waste treatment in composting and recycling center facilities from 100% composting (by 2021) to 80:20 composting: BSFL (by 2022) and 76:24 composting: BSFL (by 2023). Composting has been recognized as an effective approach to waste treatment (Lai *et al*., 2024). The degradation of organic materials by microorganisms occurs in regulated environments, including moisture content, carbon-to-nitrogen (C/N) ratio, temperature, potential of hydrogen (pH), oxygen, and particle size, to produce reasonably stable compost that is pathogen-free and can be beneficially applied as a soil fertilizer. Throughout the composting process, it was necessary to either manually or mechanically mix the composting materials to ensure the introduction of oxygen and fresh air. Additionally, water was periodically introduced to sustain an optimal moisture level the compost pile. Microorganisms generate heat during active composting, releasing carbon dioxide (CO_2) and moisture into the atmosphere (Oshins *et al*., 2022). Conversely, the black soldier fly (*Hermetia illucens*) has been widely renowned for its efficacy in waste valorization. Many studies have found that BSFL can convert FW (Fadhillah and Bagastyo, 2020; Kim *et al*., 2021), human feces (Gold *et al*., 2020), animal manure (Lalander *et al*., 2019), and other types of organic waste (Gao *et al*., 2019; Raksasat *et al*., 2022) into body mass. BSFL is rich in fat and protein and can partly replace traditional animal feedstuff or be used for biofuel production (Barragan-Fonseca *et al*., 2017). Moreover, BSFL bioconversion can be completed in two weeks (Song *et al*., 2021), faster

than aerobic composting. Several studies have utilized material flow analysis (MFA) to assess, simulate, and investigate the movement of municipal solid waste (MSW). In Indonesia, this analysis has only been done in Bali Province (54.06% of total MSW was properly managed) (Widyarsana *et al.,* 2020), and rural cities like Batang (with 49.32% waste reduction) (Budihardjo *et al.,* 2023) and Klaten (up to 85% waste reduction was simulated) (Ratnawati *et al*., 2023). There is a notable deficiency in studies focused on the reduction of FW. Furthermore, the use of material flow analysis in examining particular FW streams remains underexplored.. Surabaya, the second largest city in Indonesia, is a metropolis with approximately 3 million inhabitants. It has a high generation of FW (57.03% of the total MSW), which has the potential to be analyzed. A material flow analysis was executed in this case study to assess the trajectory and amount of FW processed in the waste treatment facilities located in Surabaya. The study aims to analyze the effectiveness of FW treatment employed in the largest composting and recycling facilities. FW management was also evaluated to develop strategies to tackle FW problems. This study was carried out in Surabaya, Indonesia, in 2023.

MATERIALS AND METHODS

Study area

Surabaya, located at 7°14'57.01" South latitude and 112°45'2.99" East longitude, is covered by a total area of 335.93 square kilograms (km^2) and is characterized by a tropical climate with an average temperature ranging from 27.4 to 30.7 degrees Celsius (°C). This study focuses on two of the largest waste treatment facilities in Surabaya, specifically the Wonorejo composting center and the Jambangan recycling center, which have been chosen as the primary study sites (Fig. 1). In 2022, the Wonorejo composting center received approximately 9288.16 t/y of solid waste, while the Jambangan recycling center processed about 2268.08 t/y (MEFRI, 2024). The Wonorejo composting center obtains FW from the Keputran traditional market, the Sutorejo recycling center, and the nearby culinary center. Conversely, the Jambangan recycling facility receives mixed solid waste sourced from local households, traditional markets, and the catering sector, and it separates FW from two community organizations.

FW treatment

The FW treatment scheme at the Wonorejo composting and Jambangan recycling centers is illustrated in Fig. 2. Although the Wonorejo composting and Jambangan recycling centers implement similar FW treatment methods, the proportion of FW treated by composting and BSFL bioconversion was quite different. The Wonorejo composting facility employs a composting method for food waste derived from the Keputran traditional markets and the Sutorejo recycling centers, whereas the bioconversion of FW using BSFL is exclusively applied to the FW from the culinary center. Likewise, the Jambangan recycling center uses composts FW from households, traditional markets, and the catering industry. The application of BSFL bioconversion was utilized for merely a small proportion of predominantly that obtained.

Data collection and composition analysis

Over the course of eight consecutive days, primary data were gathered to evaluate the amount and characteristics of waste entering the two facilities. The FW from each source was directly sorted into 10 categories (i.e., fruits, vegetables, fish and seafood, meat, legumes, bakery products, dairy products, dried foods, mixed foods, and others) and then weighed. The calculation of FW for each category can be done using Eq. 1 (Zakarya *et al.,* 2021):

$$Food\ \ waste\ per\ category = \frac{\sum_{i=1}^{n} Xi}{\sum_{i=1}^{n} Yi} \times 100\% \quad (1)$$

Xi refers to the weight of each category of FW in kilogram(kg), and *Yi* is the total weight of FW in each waste treatment facility (kg).

Mass balance analysis

On days 10 and 40 of the treatment, further primary data were collected following the execution of the BSFL bioconversion and composting processes. The weights of various products, such as BSFL frass, larvae biomass, compost, and residue, were assessed to calculate the percentage of FW reduction in both facilities, utilizing Eqs. 2 and 3

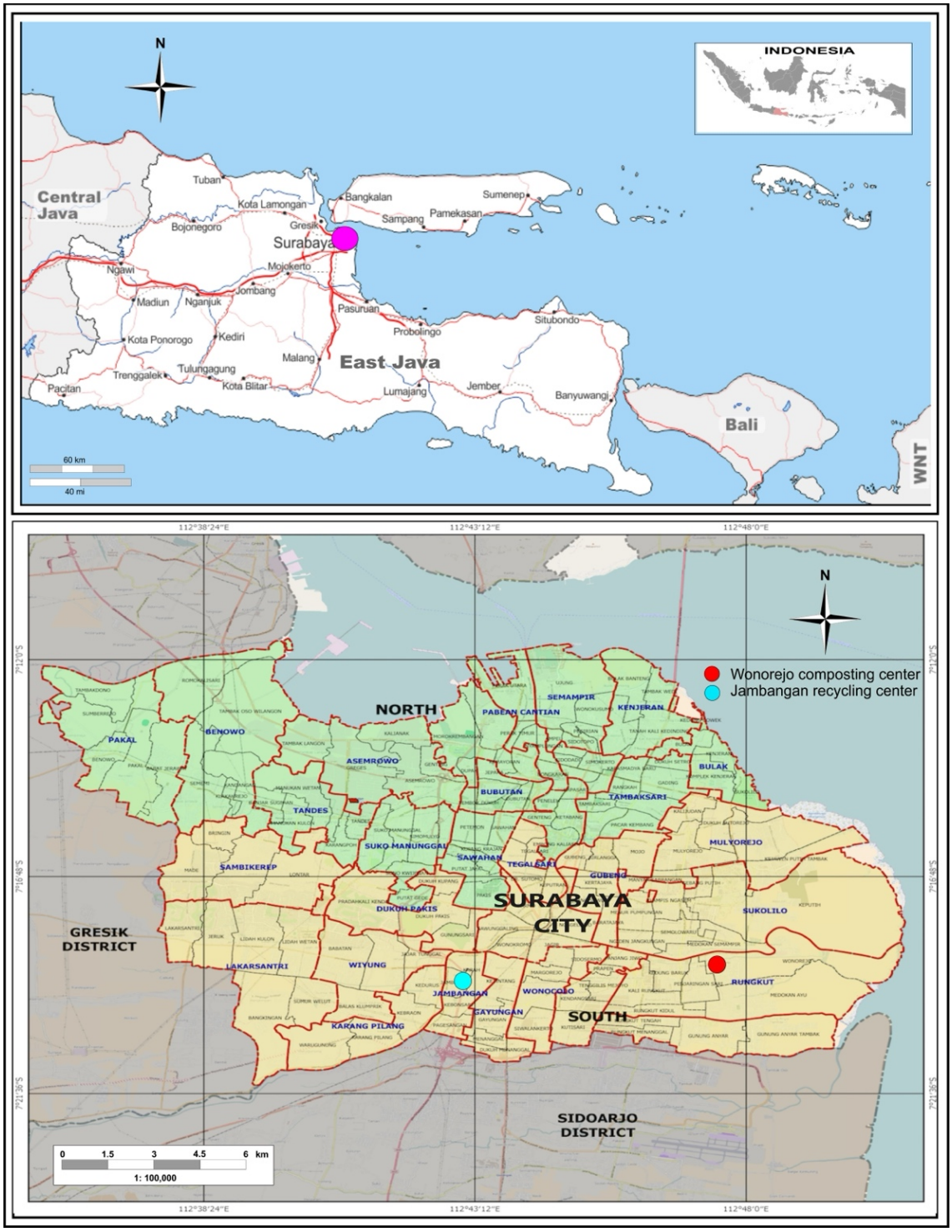


Fig. 1: Geographic location of the study area in Surabaya (Wonorejo composting center) the Jambangan recycling center) in Indonesia

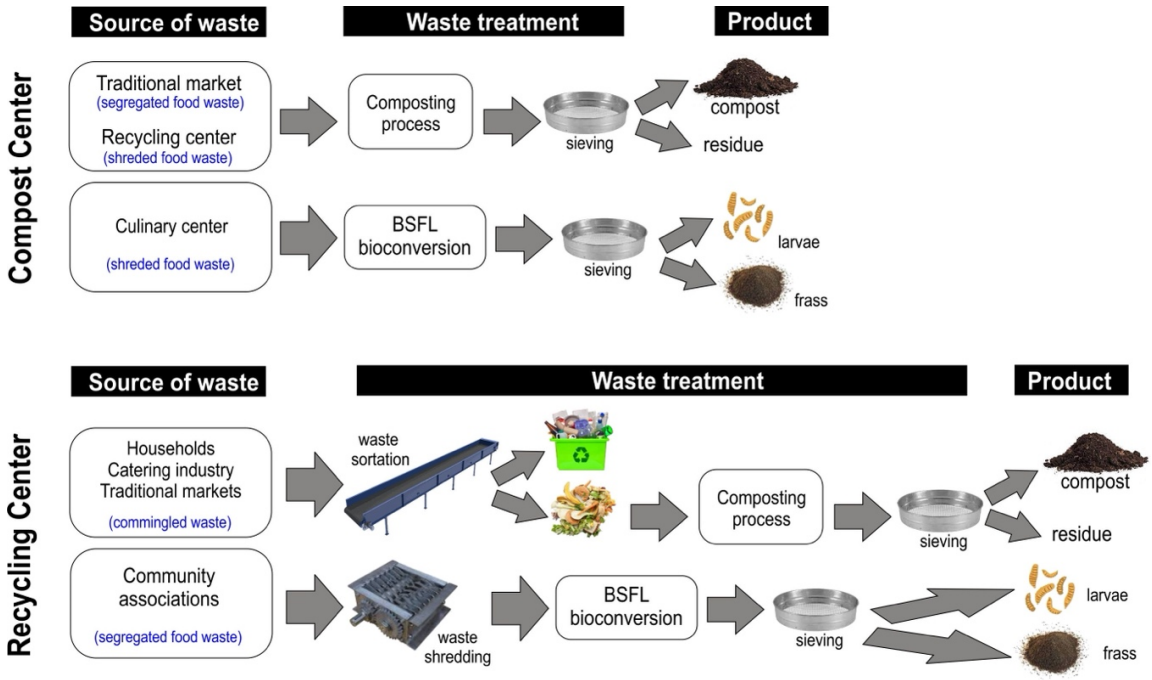


Fig. 2: General waste treatment scheme at the (a) Wonorejo composting center and (b) Jambangan recycling center

Table 1: Average quantity of waste in composting and recycling centers

Waste management facilities	Waste characteristics	Source of waste	Average waste quantity	
			(kg/d)	(%)
Wonorejo composting center	100% segregated	The traditional Keputran market	6476.25	84.65
		Sutorejo recycling center	1158.12	15.14
		Culinary centers	16.51	0.22
Jambangan recycling center	94.82% were commingled, 5.18% were segregated	Households	337.56	40.63
		Catering industry	322.50	38.82
		Traditional markets	127.60	15.36
		Community associations	43.10	5.18

(Zahra, 2023):

$$Mass\ of\ FW_{in\ ending\ time\ of\ the\ periode} = Mass\ of\ FW_{in\ a\ given\ period} - Mass\ of\ FW_{in\ a\ beginning\ time\ of\ period} \quad (2)$$

$$\%\ FW_{reduction} = \frac{Mass\ of\ FW_{in\ ending\ time\ of\ period}}{Mass\ of\ FW_{in\ a\ beginning\ time\ of\ period}} \times 100 \quad (3)$$

Material flow analysis

The MFA of FW was conducted using STAN 2.7.101 (substance flow analysis software, Technische Universität Wien). MFA is a generally used methodical analysis of a given system's material and stock movements at a particular moment and location (Brunner and Rechberger, 2016). This technique is often employed to facilitate policy-making processes in the domains of waste, resource, and environmental management. The results of the MFA can be verified through material balance by comparing material flows, including input, pathway, intermediates, and output generation.

RESULTS AND DISCUSSION

Solid waste quantity and composition

On average, the Wonorejo composting center

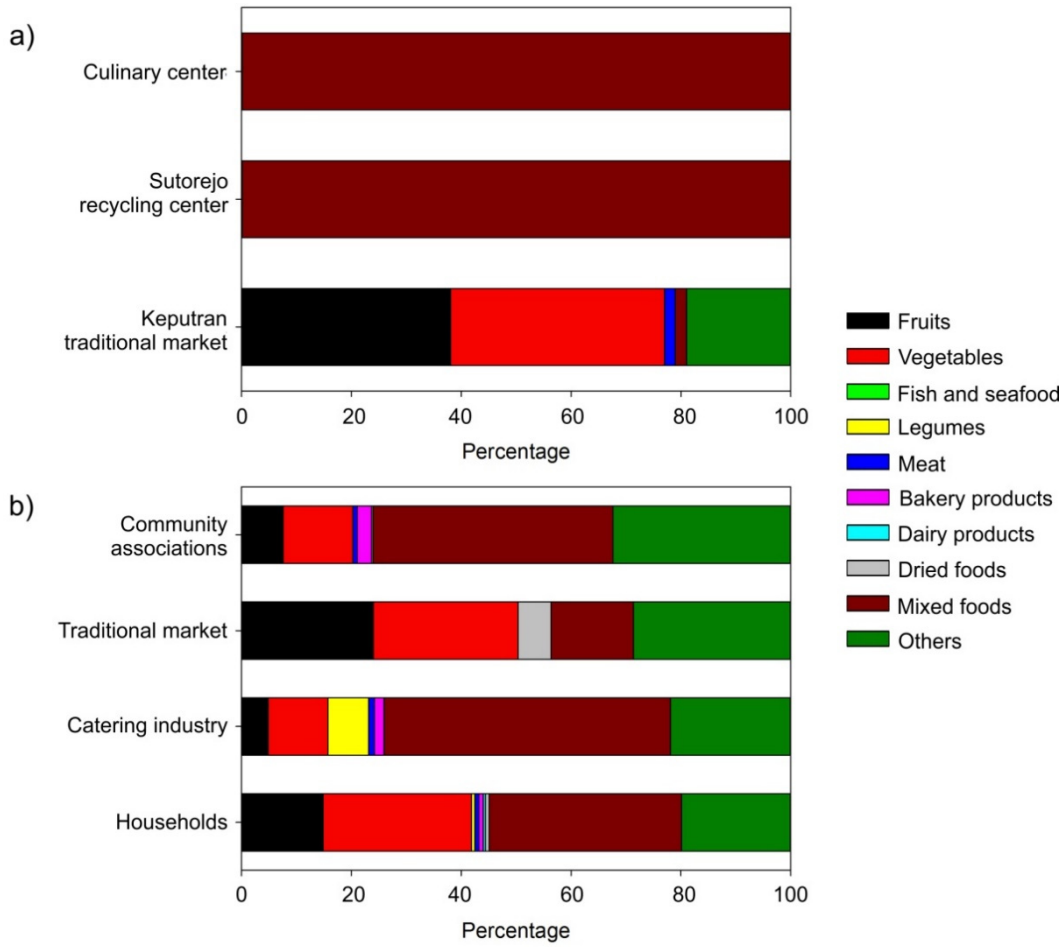


Fig. 3: Average composition of FW obtained from the (a) Wonorejo composting center and (b) Jambangan recycling center

received FW with a quantity of 7,650.89 kilogram per day (kg/d), while the Jambangan recycling center received 830.72 kg/d of MSW (Table 1). It is estimated that approximately 84% of the FW received by the Wonorejo composting center was sourced from the Keputran traditional market. The largest proportion of FW from the Keputran traditional market was fruits and vegetables (~38% each), whereas mixed foods, meat and dried foods accounted for up to 2% of the total FW (Fig. 3a). At the Sutorejo recycling and culinary center, the waste stream was exclusively made up of mixed waste. In the Jambangan recycling center, around 94% of the municipal solid waste was similarly categorized as mixed waste, while a mere 5% from the community association was fully separated. After sorting, the ratio of FW to recycled waste was 1:2. Waste from households, the catering industry, and the traditional market was predominantly mixed food (34.05% on average) (Fig. 3b). The waste generated by community associations was comprised of 43.70% mixed food items, 12.66% vegetables, and 7.61% fruits. In comparison to a different recycling facility, the organic waste composition at the Jambangan recycling center was found to be 8% lower than that recorded at the Batu recycling center in Indonesia (Muktiningsih *et al.,* 2023).

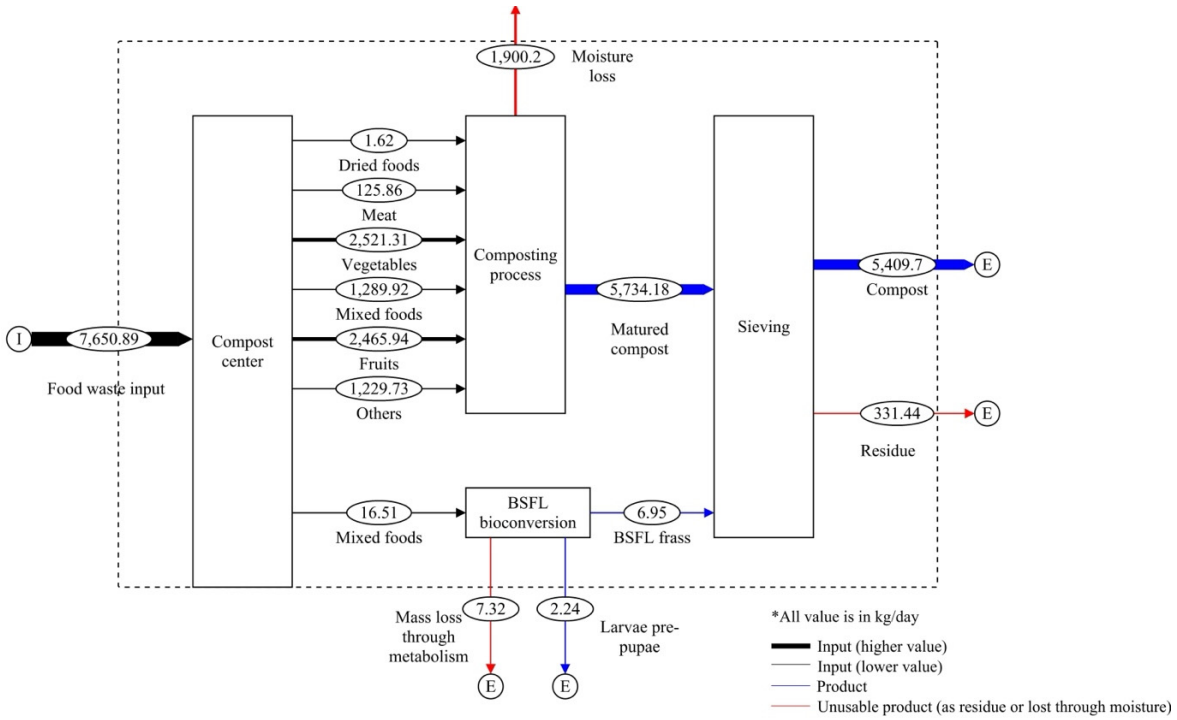


Fig. 4: MFA of the FW at the Wonorejo composting center

MFA in the Wonorejo composting center

The material flow of FW in the Wonorejo composting center is shown in Fig. 4. The composting process effectively treated more than 99% of the total food waste, which equated to 7634.38 kg per day, over a period of roughly 40 days. This process facilitated the transformation of approximately 74% of the food waste, specifically 5734.18 kg per day into mature compost. FW from the culinary center, which accounted for 0.22% of total FW, was treated using BSFL bioconversion for approximately 10 days. This process converts 0.03% FW into larval biomass and 0.09% FW into BSFL frass. BSFL frass has a compost-like structure and consists of mixtures of excrement, feeding materials, part of larval biomass, dead eggs, and substances from dead larvae (EU, 2021). The frass generated by BSFL shares characteristics with compost, exhibiting a high concentration of dry organic material and being rich in nutrients, chitin, and microorganisms that facilitate the uptake of nutrients by plants (Setti *et al.*, 2019). The application of BSFL frass in its raw form is discouraged due to its immature and biologically unstable nature, which may harbor phytotoxins detrimental to plant growth (Basri *et al.*, 2022; Elissen *et al.*, 2023).

Considering the small amount of BSFL frass produced, mature compost and BSFL frass were mixed and sieved together. Overall, the FW reduction at this center reached 95.67%, leaving 4.33% (331.44 kg/d) of FW as residue that goes into landfills.

MFA at the Jambangan recycling center

The material flow of solid waste in the Jambangan recycling center is illustrated in Fig. 5. On average, the Jambangan recycling center received 830.73 kg/d of solid waste. After the segregation process, the amount of recyclable waste that could be recovered was 528.67 kg (63.64% of the total solid waste), while the amount of FW that required treatment was 302.06 kg (36.36%). It is estimated that around 85.74% of the total FW was processed via composting techniques. Moisture loss accounted for approximately 21.34% of the total FW, leaving 64.40%—or 194.52 kg—effectively converted into

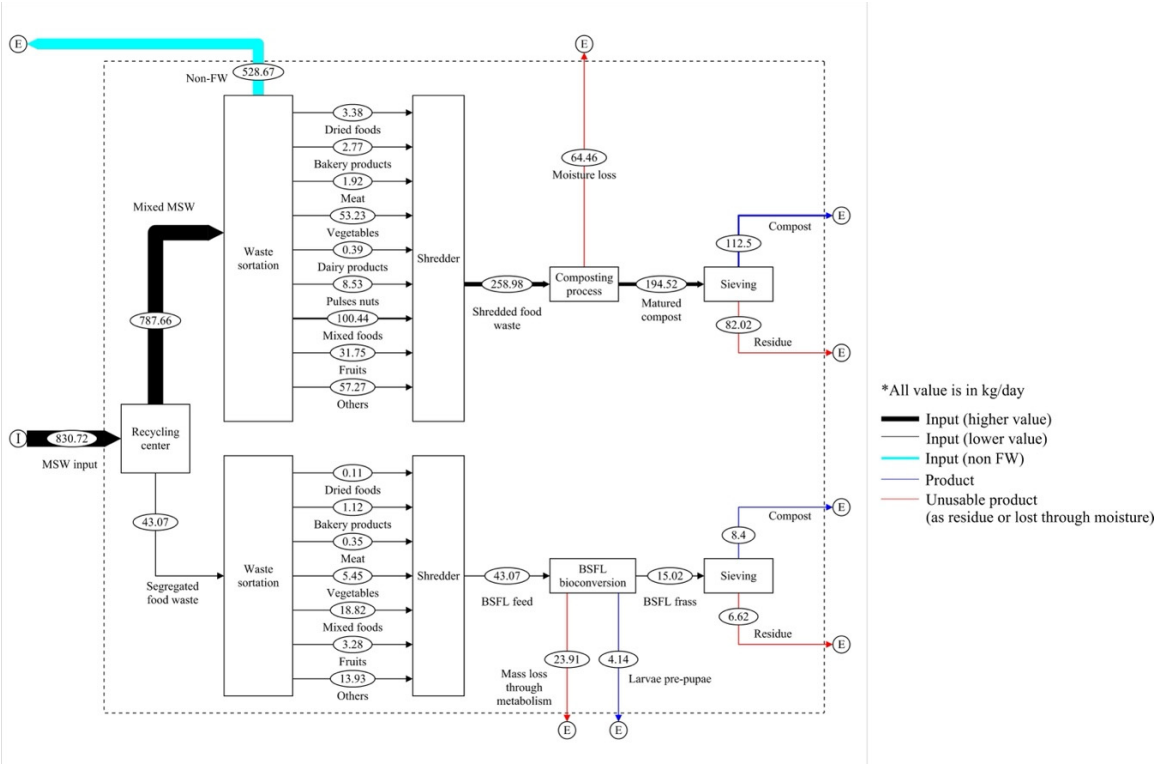


Fig. 5: MFA of the FW at the Jambangan recycling center

mature compost. After sieving, the residue from the composting process amounted to 82.02 kg (27.15%).

In contrast, only ~14% of the total FW was treated using BSFL bioconversion. This portion of FW was entirely contributed by the community association. The segregation process was unnecessary since the FW) had already been pre-sorted. The bioconversion of FW by BSFL resulted in the transformation of roughly 1% of the FW into larval biomass, while less than 5% was converted into BSFL frass. Overall, the FW reduction achieved through composting and BSFL bioconversion was 70.65%.

Evaluation of composting and recycling centers for FW reduction

The findings from the material flow analysis conducted on the facilities for composting and recycling indicated that the composting center demonstrated a greater efficacy in minimizing FW. However, its effectiveness may not be sufficient to address the quantity of FW generated in Surabaya. Data from the Information System of National Waste Management (MEFRI, 2024) revealed that the amount of Surabaya MSW sent to composting and recycling centers in 2023 was only 32,998 and 63,569 t/y, respectively (representing 1–5% of the total MSW). If all compost centers were assumed to accept 100% FW, their combine capacity would still be only 8% of the total FW generation in the city. It is improbable that this is the case, as the compost center also processes organic waste generated from the trimming of street trees. Several studies have also conducted modeled material flow analyses of MSW. It was revealed that 20.13 t/y of MSW generated at boarding schools in Bogor, Indonesia, could be processed through composting and black soldier fly (BSF) maggot cultivation, resulting in 33% compost and 67% maggot production (Rimantho *et al.*, 2022). In Klaten Regency, approximately 26.39 tons/day (t/d) of compost could be simulated from 37.7 t/d of MSW (Ratnawati *et al.*, 2023). The findings of these studies indicate that both the waste treatment conditions and the volume of input materials have a substantial impact on the resulting



Fig. 6: Community compost bins (SES, 2020)

Table 2: Recommended strategies and practices for FW reduction

Stakeholders	Strategies and practices	Remarks
Households	Preparing for grocery shopping	The grocery shopping list is beneficial for reducing food waste and saving money. Take a list of which groceries are needed and which are currently available at home.
	Finish the meal	Take enough food portions.
Households, retail, markets, hospitality and culinary industries, etc.	Encourage good handling practices in food management	Proper food management can prevent food spoilage and reduce the number of leftovers. It is also useful to guarantee the safety, quality, and integrity of food.
	Donate surplus food to those in need	According to the Food and Agriculture Organization, approximately 17% of the total food that was accessible in 2019 was wasted by households, retailers, restaurants, and other similar food-related businesses (UNEP, 2021). Surplus food donation effectively relieves food insecurity, reduces FW, and decreases carbon emissions (Sundin *et al*., 2022).
Government	Create an online platform to assist in the distribution of excess food.	This platform connects shops, restaurants, caterers, hotels, etc., that have surplus food to communities in need.
	Add several composting centers that are 100% dedicated to FW treatment.	The added composting center added could increase the amount of FW that can be treated. A composting center located near a market could also be necessary to facilitate waste transport.
	Encourage households and communities to manage regional-scale composting and BSFL processing units (Farahdiba *et al*., 2023).	An on-site composting system and BSFL processing units can ensure direct FW treatment. Additionally, it decreases the need for transportation and waste storage infrastructure while reducing leachate. Ensuring proper waste collection, hygienic segregation, and employing skilled operators and laborers are essential to prevent contamination and odor, ensuring effective treatment and long-term sustainability of facilities.

products. Another study suggested that the utilization of landfills could be reduced by enhancing the percentage of waste that undergoes treatment (Thushari *et al.,* 2020). Raising the composting rate from 5.4% to 30% and the incineration rate from 2% to 30% could reduce the MSW amount sent to landfills by 63%.

Evaluation of Surabaya's MSW management

Surabaya's waste management follows the basic framework of the National MSW Management Policy and Strategy, as outlined in Presidential Regulation No. 97/2017 (Tetra Tech, 2021). The goal is to implement a fully effective solid waste management system in urban settings by advocating for the 3Rs (Reduce, Reuse, Recycle) and ensuring proper management of residential waste by 2025. Additionally, under the National Medium-Term Development Plan for 2020–2024, Indonesia aims to decrease 30% of solid waste via the implementation of the 3Rs and achieve a 70% reduction through sorting, collection, transportation, treatment, and disposal processes (Tetra Tech, 2021). The implementation of these frameworks aims to promote the practices of reusing and recycling household waste, as well as composting organic materials among residents. As of 2020, there were around 5,267 community compost bins distributed across Surabaya City (Fig. 6) (SES, 2020). However, a recent study (Bappedalitbang, 2022) showed that FW reduction is still far from meeting target goals. In the year 2021, a total of 2,720.14 tons of waste were produced, with organic waste constituting 55% of this total. The overall waste reduction achieved was merely 50.92%, which included a reduction of 4.18% attributed to recycling, composting, and BSFL bioconversion, alongside a significant 46.11% reduction resulting from gasification processes.

Meanwhile, in 2023, although the amount of MSW sent to landfill was reduced by 5% (from 1,700 to 1600 tons/day), 60% of the MSW was still composed by organic waste (SCG, 2023). This implies that the efforts to decrease food and other organic waste have not been fully effective. Consumer habits, such as a rise in the consumption of products and the practice of not finishing meals or having excess food, may also play a significant role in the considerable volume of FW generated in the city.

Suggestions and future directions for FW reduction

FW issues are significantly influenced by population growth, urbanization, economic growth, daily habits, and poor food management. FW will continue to increase unless a sustainable management approach is adopted. Therefore, several recommended strategies and practices must be implemented to address FW problems (Table 2).

CONCLUSION

The reduction of FW at the two largest Surabaya waste's treatment facilities was examined using material flow analysis based on waste input, segregation, transformation, and output. The Wonorejo composting facility processed an average of 7,650.89 kilograms of FW each day, whereas the Jambangan recycling center handled 830.72 kilograms of MSW on a daily basis. Approximately 84% of the FW generated in Wonorejo originates from the Keputran traditional market, with fruits and vegetables each representing about 38% of the overall waste. At the Jambangan recycling center, mixed waste made up about 94% of the MSW, with a 1:2 ratio of FW to recyclable materials. In Jambangan, mixed foods represented the most prevalent form of FW, making up 34.05% of the total. This situation highlights that the waste segregation process at the Jambangan recycling center necessitates more intensive effort than that required at Wonorejo. Overall, the waste treatment facilities are actively operated through the collaborative management of communities and the government. The application of organic waste management techniques, including BSFL bioconversion and composting, has yielded both social and environmental advantages, thereby advancing the principles of the 3Rs in support of a circular economy. The material flow analysis demonstrated that at the Wonorejo composting center, with over 99% of the total FW (7,634.38 kg/d) handled by composting, 74% of the FW successfully transformed into mature compost. The remaining 0.22% of FW treated using BSFL bioconversion was converted into larval biomass and BSFL frass at rates of 0.03% and 0.09%, respectively. In contrast, the Jambangan recycling center only converted >85%

of FW into mature compost (64.40%) and moisture (21.34%), whereas approximately 14% of FW was transformed into larval biomass (1%) and BSFL frass (<5%). Based on the waste input, it can be concluded that the composting center processed more FW than the recycling center. To summarize, composting centers demonstrate the potential to decrease more than 95% of FW, in contrast to recycling centers, which can only achieve a reduction of 70% in food waste. Despite the composting center's effectiveness in FW reduction and the government's strategy for treating FW, the overall FW reduction in Surabaya remains below optimal levels. This emphasizes the importance of increasing public understanding of communal composting initiatives within the Surabaya community. Data in 2023 showed that 60% of the landfilled MSW was still dominated by organic waste, creating opportunities for the upcycling process in the treatment centers and alarming the communities' awareness to participate in the waste reduction campaigns. The patterns of consumer behavior, including tendencies toward overconsumption and the frequent practice of leaving food unfinished, may exacerbate the issue of FW in urban environments. These observations underscore the critical need for initiatives focused on waste reduction and proper segregation, beginning at the household level. Other strategies that can be implemented include planning before grocery shopping, finishing meals, promoting good food handling practices, donating surplus food, creating an online platform for food distribution, establishing additional compost centers dedicated to food waste treatment, and encouraging households and communities to manage regional-scale composting and BSFL processing units. The implementation of these strategies generates enhanced economic value and creates employment opportunities within the region, thereby providing local governments with viable recommendations for addressing the challenges associated with waste management. Furthermore, the implementation of efficient waste collection systems, the hygienic separation of materials, and the engagement of trained personnel are crucial for achieving effective waste management and ensuring sustainability over the long term.

AUTHOR CONTRIBUTIONS

S.C. Zahra contributed to data analysis and manuscript preparation. A.D. Anggrainy contributed to data curation and manuscript preparation. Z. Mohd-Zaki contributed to manuscript's review and editing. A.Y. Bagastyo, the corresponding author, has contributed to supervising the first and second authors in the manuscript's data analysis, review, and editing.

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CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest regarding the publication of this manuscript. In addition, the authors have fully observed ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy.

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ABBREVIATIONS

%	Percent
°C	Degree Celsius
BSFL	Black soldier fly larvae
C/N	Carbon-to-nitrogen
CO_2	Carbon dioxide
Eq.	Equation
EU	European Union
FAO	Food and Agriculture Organization
Fig.	Figure
FLW	Food loss and waste
FW	Food waste
IFAD	International Fund for Agricultural Development
kg	Kilogram
kg/d	Kilogram per day
km^2	Square kilometer
MEFRI	Ministry of Environment and Forestry, the Republic of Indonesia
MFA	Material flow analysis
MNDPRI	Ministry of National Development Planning, the Republic of Indonesia
MSW	Municipal solid waste
pH	Potential of hydrogen
SCG	Surabaya City Government
SES	Surabaya Environmental Services
STAN	Substance flow analysis
t/d	Ton per day
t/y	Ton per year
UNEP	United Nation Environment Programme
UNICEF	United Nation Chlidren's Fund
WFP	World Food Programme
WHO	World Health Organization

REFERENCES

Bappedalitbang, (2022). Surabaya City Sanitation Strategy 2022-2026. Surabaya. **(226 pages)**.

Barragan-Fonseca, K.B.; Dicke, M.; van Loon, J.J.A., (2017). Nutritional value of the black soldier fly (Hermetia illucens L.) and its suitability as animal feed - a review. J. Insects Food Feed. 3(2): 105–120 **(16 pages)**.

Basri, N.E.A.; Azman, N.A.; Ahmad, I.K.; Suja, F.; Jalil, N.A.A.; Amrul, N.F., (2022). Potential applications of frass derived from black soldier fly larvae treatment of food waste: A review. Foods. 11: 2664 **(19 pages)**.

Brunner, P.H.; Rechberger, H., (2016). Practical handbook of material flow analysis. Lewis Publisher.

Budihardjo, M.A.; Sumiyati, S.; Sawitri, D.R.; Octaviani, Y.N.; Wati, H.R., (2023). Using material flow analysis (MFA) for waste management planning in Batang Regency. IOP Conf. Ser. Earth Environ. Sci., 1239: 0012029 **(8 pages)**.

Chalak, A.; Abou-Daher, C.; Chaaban, J.; Abiad, M.G., (2016). The global economic and regulatory determinants of household food waste generation: A cross-country analysis. Waste Manage. 48: 418–422 (**5 pages**).

Elissen, H.; van der Weide, R.; Gollenbeek, L., (2023). Effects of black soldier fly frass on plant and soil characteristics – a literature overview. Wageningen, The Netherlands. **(23 pages)**.

EU, (2021). Commission Regulation. 2021/1925.

Fadhillah, N.; Bagastyo, A.Y., (2020). Utilization of Hermetia illucens larvae as a bioconversion agent to reduce organic waste. IOP Conference Series: Earth Environ. Sci., 506: 012005 **(11 pages)**.

FAO, (2022). Tackling food loss and waste: A triple win opportunity.

FAO, (2024). Food Loss and Food Waste. In: Policy Support Gov. Gatew.

Farahdiba, A.U.; Warmadewanthi, I.D.A.A.; Fransiscus, Y.; Rosyidah, E.; Hermana, J.; Yuniarto, A., (2023). The present and proposed sustainable food waste treatment technology in Indonesia: A review. Environ. Technol. Innov. 32: 103256 **(16 pages)**.

Gao, Z.; Wang, W.; Lu, X.; Zhu, F., Liu, W.; Wang, X.; Lei, C., (2019). Bioconversion performance and life table of black soldier fly (Hermetia illucens) on fermented maize straw. J. Clean Prod., 230: 974–980 **(7 pages)**.

Gold, M.; Cassar, C.M.; Zurbrügg, C.; Kreuzer, M.; Boulos, S.; Diener, S.; Mathys, A., (2020). Biowaste treatment with black soldier fly larvae: Increasing performance through the formulation of biowastes based on protein and carbohydrates. Waste Manage. 102:319–329 **(11 pages)**.

Hegnsholt, E.; Unnikrishnan, S.; Pollman-Larsen, M.; Askeldottir, B.; Gerrad, M., (2018). Tackling the

1.6-Billion-Ton food loss and waste crisis. The Boston Consulting Group, Food Nation, State of Green.

Kavitha, S.; Kannah, R.Y.; Kumar G.; Gunasekaran, M.; Banu, J.R., (2020). Introduction: sources and characterization of food waste and food industry wastes. In: Banu, J.R (ed.) Food Waste to Valuable Resources. Elsevier Inc., 1–13 **(13 pages)**.

Kim, C.H.; Ryu, J.; Lee, J.; Ko, K.; Lee, J., Park, K.Y.; Chung, H., (2021). Use of black soldier fly larvae for food waste treatment and energy production in Asian countries: A review. Processes 9(1): 161 **(17 pages)**.

Lai, J.C.; Then, Y.L.; Hwang, S.S.; Lee, C.S., (2024). Optimal aeration management strategy for a small-scale food waste composting. Carbon Resour. Convers., 7: 100910 **(10 pages)**.

Lalander, C.; Diener, S.; Zurbrugg, C.; Vinneras, B., (2019). Effects of feedstock on larval development and process efficiency in waste treatment with balck soldier fly (Hermetia illucens). J. Clean Prod., 208: 211–219 **(9 pages)**.

MEFRI, (2024). National Waste Management Information System. Ministry of Environment and Forestry of the Republic of Indonesia.

MNDPRI, (2021). Study Report: Food Loss and Waste in Indonesia, Supporting the Implementation of Circular Economy and Low Carbon Development. **(116 pages)**.

Muktiningsih, S.D.; Sekito, T.; Rahmaudina, S.; Dote, Y.; Prayogo, T.B., (2023). Material flow and waste recovery in a community-based waste management system city in Batu, Indonesia. IOP Conf. Ser. Earth Environ. Sci., 1165: 012005 **(7 pages)**.

Oshins, C.; Michel, F.; Louis, P.; Richard, T.L.; Rynk, R., (2022). The composting process. In: Rynk R (ed) The Composting Handbook: a how-to and why manual for farm, municipal, institutional and commercial composters. Elsevier Inc., 51–101 **(51 pages)**.

Raksasat, R.; Abdelfattah, E.A.; Liew, C.S.; Rawindran, H.; Kiatkittipong, K.; Mohamad, M.; Mohd Zaid, H.F.; Jumbri, K.; Lam, M.K.; Lim, J.W., (2022). Enriched sewage sludge from anaerobic pre-treatment in spurring valorization potential of black soldier fly larvae. Environ. Res., 212: 113447 **(8 pages)**.

Ratnawati, B.; Yani, M.; Suprihatin, S.; Hardjomidjojo, H., (2023). Waste processing techniques at the landfill site using the material flow analysis method. Global J. Environ. Sci. Manage., 9: 73–86 **(14 pages)**.

Rimantho, D.; Hidayah, N.Y.; Saputra, A.; Chandra, A.; Rizkiya, A.N.; Nashifah, G.; Fitriyani, P.; Wesha, D.M.P., (2022). Material flow analysis for assessing the sustainability solid waste management strategy. Int. J. Sustain. Dev. Plan., 7: 2271–2278 **(8 pages)**.

SCG, (2023). Volume Sampah Harian di Surabaya 60 Persen didominasi Organic.

SES, (2020). Information Document of Environmental Management Performance 2020 **(2318 pages)**.

Setti, L.; Francia, E.; Pulvirenti, A.; Gigliano, S.; Zaccardelli, M.; Pane, C.; Caradonia, F.; Bortolini, S.; Maistrello, L.; Ronga, D., (2019). Use of black soldier fly (Hermetia illucens (L.), Diptera: Stratiomyidae) larvae processing residue in peat-based growing media. Waste Manage., 95: 278–288 **(11 pages)**.

Skaf, L.; Franzese, P.P.; Capone, R.; Buonocore, E., (2021). Unfolding hidden environmental impacts of food waste: An assessment for fifteen countries of the world. J. Clean Prod., 310: 127523 **(9 pages)**.

Song, S.; Ee, A.W.L.; Tan, J.K.N.; Cheong, J.C.; Chiam, Z.; Arora, S.; Lam, W.N.; Tan, H.T.W., (2021). Upcycling food waste using black soldier fly larvae: Effects of further composting on frass quality, fertilizing effect and its global warming potential. J. Clean Prod., 288: 125664 **(14 pages)**.

Sundin, N.; Osowski, C.P.; Strid, I.; Eriksson M., (2022). Surplus food donation: Effectiveness, carbon footprint, and rebound effect. Resour. Conserv. Recycl., 181: 106271 **(14 pages)**.

Tetra Tech, (2021). Clean cities, blue ocean initial solid waste management assessment (ISWMA) | Indonesia. United States Agency for International Development. **(77 pages)**.

Thushari, I.; Vicheanteab, J.; Janjaroen, D., (2020). Material flow analysis and life cycle assessment of solid waste management in urban green areas, Thailand. Sustain. Environ. Res., 30: 21 **(17 pages).**

UNEP, (2021). Food Waste Index Report 2021. Nairobi. United Nations Environment Programme. **(132 pages)**.

WHO, (2023). The State of Food Security and Nutrition in the World. **(316 pages)**.

Widyarsana, I.M.W.; Damanhuri, E.; Agustina, E., (2020) Municipal solid waste material flow in Bali Province, Indonesia. J. Mater. Cycles. Waste Manag., 22: 405–415 **(11 pages)**.

Zahra, S.C., (2023). Material Flow Analysis of Food Waste in Jambangan Recycling Center and Wonorejo Compost House, Surabaya. Thesis. Surabaya. Institut Teknologi Sepuluh Nopember. **(79 pages)**.

Zakarya, I.A.; Yabainus, A.F.; Halis, R.; Beson, M.R., (2021). A comparative study on generation and composition of food waste in Kundasang, Sabah. IOP Conference Series: Earth Environ. Sci., 920: 012026 **(11 pages)**.

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