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Conceptual Model for Sustainable Planning and Development of Waste Management with Material Flow Analysis (MFA) and Analytical Hierarchy Process (AHP) Methods

Murwan Widyantoro[1,2], Suprihatin Suprihatin[2*], Nastiti Siswi Indrasti[2], Tajuddin Bantacut[2]

[1] Department of Industrial Engineering, Faculty of Technology, Bhayangkara Jakarta Raya University, Bekasi 17121, Indonesia
[2] Department of Agro-industrial Engineering, Faculty of Agricultural Technology, Bogor Agricultural University, Bogor 16680, Indonesia

Corresponding Author Email: suprihatin@apps.ipb.ac.id

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ABSTRACT

The waste management in the Bogor Region, particularly concerning the Galuga Landfill, requires a thorough assessment of its operational efficiency and environmental impacts to address the complex issues it presents. Despite ongoing efforts to enhance waste management techniques, significant shortcomings remain in the effectiveness of the current system. This study aims to propose a viable solution to mitigate the issue of overcapacity at Galuga Landfill, hence prolonging its operational lifespan. This study utilizes material flow analysis (MFA) in conjunction with other methodologies, particularly the analytical hierarchy process (AHP), which is especially relevant in solid waste management (SWM). The study on the waste management system design in the Bogor Region indicates that the technical elements of waste management have not adopted the concepts of integration and sustainability, as per the study's findings. This is evident in the phases of waste management, which include sorting, processing, transportation, and ultimate disposal.

1. INTRODUCTION

The waste management in the Bogor Region, specifically regarding the Galuga Landfill, necessitates a comprehensive evaluation of its operational capabilities and environmental repercussions to tackle the intricate problem it poses. Notwithstanding continuous endeavors to improve waste management methods, substantial deficiencies persist in the efficacy of the existing system. The Galuga Landfill, an essential waste disposal facility for the region, is nearing its maximum capacity, raising worries about overcapacity and potential adverse environmental effects, including leachate and greenhouse gas emissions [1].

Recent research by Hidayat et al. [2] indicates that leachate from the Galuga Landfill poses a substantial risk to the quality of surrounding water sources. This encompasses the possible contamination of surface water, soil, and groundwater in adjacent regions. Leachate, a consequence of trash decomposition, can lead to considerable pollution if inadequately handled, underscoring the necessity for immediate scrutiny of landfill operational methods [2]. Furthermore, the lack of a well-defined waste stream management strategy, including waste creation from its source to final disposal, highlights a critical area that necessitates improvement. An integrated approach is essential for effective waste management, as stated in the study [3]. This strategy must encompass trash reduction, recycling, and appropriate disposal techniques to mitigate environmental concerns.

The participation of waste pickers in the recycling process, beginning at the household level and extending to various collection stations, illustrates the informal sector's role in waste management in Indonesia. To properly address these difficulties, researchers must concentrate on formulating a comprehensive waste management strategy. This approach must include several components, including public engagement and education, with a focus on trash segregation and recycling methodologies [3].

Material flow analysis (MFA) is widely recognized as a valuable tool for decision-making in waste and resource management. It provides valuable insights into the efficiency and sustainability of waste management systems, as highlighted by previous studies [4, 5]. Integrating MFA with other methodologies, such as the ansalytical hierarchy process (AHP), has been extensively studied in the field of waste management. Research has shown that this integration can significantly improve decision-making processes by offering a more comprehensive understanding of environmental impacts and resource flows.

The AHP, on the other hand, is a multi-criteria decision-making framework that enables researchers to systematically evaluate different factors that influence waste management decisions. The research employs a hierarchical structure to organize decision criteria and utilizes pairwise comparisons to assess the relative importance of each factor [6]. This methodology is particularly useful in waste management contexts where decisions must consider both quantitative data (from MFA) and qualitative factors, such as stakeholder preferences and environmental considerations [7].

Previous research has shown that the combination of MFA and AHP has proven to be effective in different waste management situations. Research has demonstrated that the combined approach mentioned in the previous statement can effectively enhance the selection of waste treatment technologies. This is achieved by evaluating various criteria such as cost, environmental impact, and social acceptability. The study conducted by El Toufaili et al. [8], provides evidence supporting this claim. By combining the strengths of both methodologies, researchers can gain a more comprehensive understanding of the waste management system. This is crucial for effectively tackling complex issues like landfill overcapacity and resource recovery [9].

Based on the findings, it can be concluded that the integration of MFA with AHP offers a strong framework for improving decision-making processes in the field of waste management. The combined approach employed in this study enables a comprehensive analysis of material flows, while also integrating stakeholder perspectives and environmental considerations. As a result, it contributes to the development of more efficient and sustainable waste management strategies. This study uses MFA to assess Bogor's waste management system.

This project seeks to investigate how waste moves from the neighborhood to the Galuga landfill. This study evaluated the waste management system. This research has major benefits. The data can be used to improve waste management in the Bogor Region by minimizing landfill waste. This report also proposes a remedy to Galuga Landfill's overload or excess capacity to extend its lifespan. This research will give local administration and environmental management organizations scientific bases and reliable data for decision-making. The findings should also raise public awareness and engagement in sustainable trash management. This research will add to waste management literature by focusing on MFA in Indonesia.

2. MATERIAL AND METHOD

2.1 Materials

Waste management in Bogor Regency continues to adhere to the traditional paradigm, characterized by a typical collection-transport-disposal system. The current state of Integrated Waste Processing Place (Tempat Pengolahan Sampah Terpadu / TPST) in Bogor Regency is suboptimal, as thirty sub-districts (Table 1) remain unserved.

Table 1. Integrated waste processing place in Bogor regency

No.	Name	Sub-District	District
1	TPS 3R Citra Mandiri	Kertamaya	Bogor Selatan
2	TPS 3R Mutiara Bogor Raya	Katulampa	Bogor Timur
3	TPS 3R Darmais	Kencana	Tanah Sereal
4	TPS 3R Bhakti Warghana	Genteng	Bogor Selatan
5	TPS 3R Taruna Kompos	Mulyaharja	Bogor Selatan
6	TPS 3R Ciparigi 2	Ciparigi	Bogor Utara
7	TPS 3R Mutiara Kayumanis	Kayumanis	Tanah Sereal
8	TPS 3R Kembang Setaman BCC	Cibadak	Tanah Sereal
9	TPS 3R Kayumanis 2	Kayumanis	Tanah Sereal
10	TPS 3R Ciparigi 1	Ciparigi	Bogor Utara
11	TPS 3R Ceremai Cipaku	Cipaku	Bogor Selatan
12	TPS 3R Kencana BKP	Kencana	Tanah Sereal
13	TPS 3R Tunas Rancamaya	Rancamaya	Bogor Selatan
14	TPS 3R Cibadak	Cibadak	Tanah Sereal
15	TPS 3R Rusunawa Menteng	Menteng	Bogor Barat
16	TPS 3R Benteng Hijau	Lawang Gintung	Bogor Selatan
17	TPS 3R Anugerah	Tanah Baru	Bogor Utara
18	TPS 3R Griya Melati	Bubulak	Bogor Barat
19	TPS 3R Rangga Mekar	Ranggamekar	Bogor Selatan
20	TPS 3R Paledang	Paledang	Bogor Tengah
21	TPS Griya Katulampa	Katulampa	Bogor Timur
22	TPS 3R Bumi Indraprasta	Bantarjati	Bogor Utara
23	TPS 3R Asri Bubulak	Bubulak	Bogor Barat
24	TPS Taman Sari Persada	Cibadak	Tanah Sereal
25	TPS Kayu Manis 3	Kayumanis	Tanah Sereal
26	TPS 3R Rusunawa Tanah Baru	Tanah Baru	Bogor Utara
27	TPS 3R Melati_Warban-5	Bondongan	Bogor Selatan
28	Rumah Kompos Cipaku	Cipaku	Bogor Selatan
29	TPS 3R Gerbang Mulia Berseri	Bojongkerta	Bogor Selatan
30	TPS 3R Mekar Mandiri	Mekarwangi	Tanah Sereal

The focal point of the environmental service government for waste management is confined to Bogor District, as it serves as the city center of Bogor Regency. The current waste management practices have not been executed efficiently across all facets. The initial aspect pertains to the operating technique, which encompasses multiple subsystems. In the initial sub-system, referred to as containerization, the community currently does not distinguish between organic and inorganic trash. Each residence contains a singular trash can. The second subsystem is the collection. The Bogor Regency Environmental Agency possesses a collection fleet with 55 three-wheeled motorbikes and 215 refuse wagons. This fleet is inadequate for garbage management across Bogor Regency, operates sub-optimally, and is exclusively available in Bogor District. The third sub-system pertains to garbage removal, with a significant amount of refuse remaining on the roadside. The fourth sub-system pertains to transportation, which lacks a definitive route, necessitating regular collection. The final sub-system is processing, with only one TPS3R and no waste processing at the Galuga landfill. Bogor Regency possesses alone the Galuga landfill as its exclusive garbage ultimate processing facility. The state of Galuga Landfill, as observed during field surveys, continues to employ the open dumping approach without significant pre-landfill waste reduction. Both operational procedures and other facets necessitate more optimal planning to enhance the waste management system in Bogor Regency.

2.2 Material flow analysis (MFA)

MFA methodically evaluates the inventory process and material movement inside a system, allowing for precise definition in terms of time and area. All elements are interconnected in this material flow analysis, encompassing the source, trajectory, and conclusion of the flow/material. MFA demonstrates that a comprehensive and coherent dataset is observable in the inventory and flow within a system. The visibility of balanced inputs or outputs, environmental loads, and waste flows allows for the identification of their usage from the sources of material depletion or accumulation. The material stock serves as a means for early detection to establish preventive measures or to enhance future consumption and accumulation [5]. The MFA methodology can be utilized in waste management systems with the subsequent objectives [6]:

- Evaluate modifications to the framework.
- Conduct analyses and execute calculations for material or energy efficiency inside systems.
- Facilitate the material flow analysis by overseeing the opportunity analysis to allocate the waste flow according to technical, economic, and ecological parameters.
- Formulate strategies for optimization and critical point assessment of flows.
- Establish baseline scenarios for subsequent evaluation.

The essential components are articulated by a straightforward technique of modeling a material flow diagram. A valid assumption must exist within the system to alter the material flow of the arriving or leaving system. The subsequent input may be affected by the preceding output [7].

2.3 Analytical hierarchy process

The AHP component of this integration was employed to prioritize the identified risks according to their relative importance. AHP allows decision-makers to methodically evaluate different failure modes by giving ranks according to multiple criteria, including cost, safety, and operational impact [10]. The weighting was carried out by experts with a background in municipal waste management.

3. RESULT AND DISCUSSION

Bogor is situated at coordinates 106° 48' East and 6° 26' South, centrally positioned inside Bogor Regency. Bogor has an average maximum elevation of 330 m and a minimum of 190 m above sea level. The climatic conditions of Bogor have average monthly temperatures ranging from 25℃ to 27℃, with minimum temperatures from 18℃ and 22℃ and maximum temperatures from 33℃ to 36℃. The mean air humidity is 80% [11].

The topography of the Bogor region predominantly ranges from flat to hilly, with elevations between 0-200 meters above sea level to over 300 meters above sea level. The regions of Bogor with an altitude over 300 meters above sea level are predominantly situated in the southern sector, at the base of Mount Salak. The minor variation in altitude renders Bogor an exceptionally favorable region for developmental roles, as seen by its long-standing infrastructure. The slope in Bogor predominantly falls within the flat and mild categorization, comprising 25%, which encompasses 884.9 hectares or around 7.45% of the area.

Bogor encompasses an area of 11,850 hectares and comprises an administrative division consisting of 6 sub-districts, 31 villages, 37 wards, 210 hamlets, 623 neighborhood units (RW), and 2,712 community units (RT), bordered by the Bogor Regency Region as follows: 1. To the north, it is surrounded by Kec. Kemang, Bojong Gede, and Kec. Sukaraja in Bogor Regency. The eastern boundary is delineated by the Sukaraja and Ciawi sub-districts of Bogor district. The western boundary is delineated by the Darmaga and Ciomas sub-districts of Bogor district. 4. South of the boundary with Kec. Cijeruk and Kec. Caringin, Bogor Regency (Figure 1). The final waste disposal facility (TPA) located in Galuga Village. The Cibungbulang District in Bogor Regency has been established since 2011, encompassing an area of 31.8 hectares. The Bogor City Government (Pemkot) and the Bogor Regency Government (Pemkab) employ Galuga TPA.

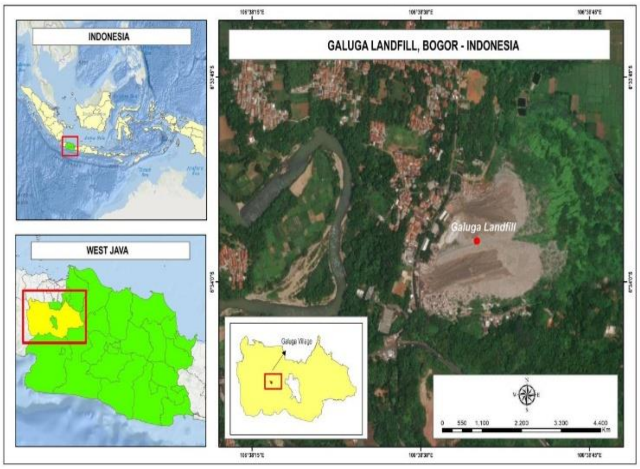


Figure 1. Study location

The waste management paradigm in the Bogor Region continues to rely heavily on the traditional model of collecting, transporting, and disposing of waste primarily through landfilling. This method, which has been prevalent in many developing regions, is characterized by a linear approach to waste management, where waste is simply moved from one location to another without significant processing or recycling efforts. The Environmental Agency's reported achievement of handling 57.88% of waste, translating to 396.39 tons per day from 2021 to 2023, underscores the reliance on this outdated paradigm [12, 13].

Landfilling remains the predominant method for waste disposal in the Bogor Region, similar to practices observed in other parts of Indonesia and developing countries. This is largely due to the high organic content of municipal solid waste (MSW), which can range from 75% to 97% in these regions [14]. The inefficiency of this method is compounded by the environmental risks it poses, such as groundwater contamination from leachate and the generation of greenhouse gases [1, 15]. Studies have shown that improper landfill management can lead to significant health risks, including pollution of groundwater sources that many communities depend on for drinking water [16].

Moreover, the lack of an integrated waste management strategy that includes recycling and composting exacerbates the challenges faced by the Bogor Region. While some regions in Indonesia, such as Bandung, have begun to implement more comprehensive waste management systems that incorporate recycling and waste diversion strategies, Bogor has yet to adopt such measures effectively [17]. The current reliance on landfills not only limits the potential for waste reduction but also contributes to ongoing environmental degradation and public health concerns [1, 15].

The current statistics from the Environmental Agency highlight the urgent need for reform in waste management strategies to mitigate environmental impacts and improve public health outcomes. The waste composition data for the Bogor Region is presented in Table 2.

Table 2. Waste composition

No.	Waste Composition	Percentage
1	Leftovers	48.00%
2	Others (Household Waste / Electronic Waste)	29.20%
3	Textile	6.57%
4	Paper	6.32%
5	Glass	4.48%
6	Rubber and leather	3.40%
7	Plastics	1.89%
8	Metal	0.12%
9	Wood, twigs, leaves	0.02%

The projected amount of waste produced at the source in 2023 is 3000 kg per day. The figure is derived from the calculation of the estimated population in 2023, which is 738.264 individuals, multiplied by the waste generation unit value of 0.44.

Waste Management

The Gather-Take-Dispose paradigm in waste management is a methodical framework that includes the gathering of garbage at its origin, its conveyance by sanitation staff, and its ultimate disposal at specified processing locations, commonly known as TPA (Tempat Pemrosesan Akhir/Landfill). This framework is essential for facilitating efficient waste management, especially in urban areas characterized by substantial and ongoing garbage production.

The preliminary stage of this paradigm, collecting waste at the origin, is crucial for reducing the quantity of waste necessitating transport and disposal. Effective source segmentation can improve recycling initiatives and diminish the volume of waste directed to landfills. Research highlights the significance of waste segregation to enhance disposal and reprocessing, which can markedly influence environmental health by diminishing the risk of infectious diseases linked to poor waste management [18]. Moreover, the execution of systematic waste management techniques, encompassing community education on trash segregation, is essential for enhancing the efficacy of the Gather-Take-Dispose paradigm [19].

Transporting garbage is the next essential step in this paradigm. Efficient trash transportation systems are required to reduce logistics costs and environmental impact. According to research, the design of waste transportation networks must take into account a variety of elements, including the proximity of trash producing sites to disposal facilities as well as the types of garbage transported [20].

Finally, trash disposal at TPA is an essential component of the Gather-Take-Dispose model. To reduce harmful effects on human health and the environment, disposal sites must be managed in accordance with environmental standards and best practices. For example, inappropriate disposal of hazardous waste can pose considerable environmental problems, necessitating a strategic approach to site selection and waste processing [21]. Furthermore, the increasing volume of garbage generated, particularly in urban settings, highlights the need for sustainable disposal solutions, such as energy recovery from non-recyclable waste [22]. The use of Life Cycle Assessment (LCA) to evaluate waste management practices can also provide insights into the environmental implications of various disposal strategies, promoting more sustainable choices [21].

To summarize, the Gather-Take-Dispose paradigm is a complete framework for waste management that highlights the significance of each phase gathering, transportation, and disposal. Municipal waste management systems can be improved, environmental impacts reduced, and public health promoted by employing effective techniques at each level.

Waste at Source

The types of containers used by the community in Bogor Region in the waste collection process at the source are plastic bags, garbage cans, etc. In Bogor, household waste management frequently involves indiscriminate disposal, such as discarding waste in various locations, including gutters, water channels, or the sea; incinerating waste; burying it; selling it to collectors; converting it into fertilizer; utilizing it as animal feed; recycling; or depositing it in trash receptacles for transport to the TPA (Final Disposal Site) (Figure 2).

Figure 2. Waste management at source

Waste at Integrated Waste Processing Place (Tempat Pengolahan Sampah Terpadu / TPST)

Part of the waste collected from the source will first be transported to the TPST using three-wheeled waste motors. There are 27 waste motors used and they are capable of transporting waste with a maximum carrying capacity of 500 Kg. TPST engages in a range of waste processing activities, including collection, sorting, reuse, recycling, processing, and final processing of waste (Figure 3 and Figure 4).

Figure 3. Waste management condition in TPST

Figure 4. The condition of waste management at the Waste Transportation Site

The process of transporting waste from source to landfill in the Bogor Region is served by vehicles such as dump trucks, arm rolls, crank trucks, and pick-up trucks (Figure 5). According to the waste weighing officer at the Galuga landfill, currently, part of the waste transportation process from the source or TPST is still carried out with open tub conditions.

Figure 5. Waste transportation

Landfilling of Waste at the Landfill

The waste disposal process in Bogor Region is done by open dumping, where the waste is only leveled without being filled with soil cover (Figure 6). According to the head of UPTD (sUnit Pengolahan Terpadu Daerah/ Regional Integrated Processing Unit) Galuga, currently the Galuga landfill has accommodated waste that is beyond the maximum storage limit.

Figure 6. Landfilling waste in the landfill

3.1 Analysis of waste management in Bogor region

TPST is a place for waste management starting from the collection, selection, and reuse of waste which aims to reduce the amount of waste that goes to the landfill. This TPST transports waste from nearby sub-districts whose access is difficult to reach by dump truck and arm roll modes. Waste that enters TPST Bogor Region is served by three-wheeled motorcycles and garbage carts. There are two TPSTs owned by Bogor Region, namely TPST Residences and TPST Market. After the waste enters the TPST, it will then be transported by the arm roll mode to be transported to the landfill. Meanwhile, the transportation process from the source to the landfill is served by dump trucks and ankle trucks (Figure 7).

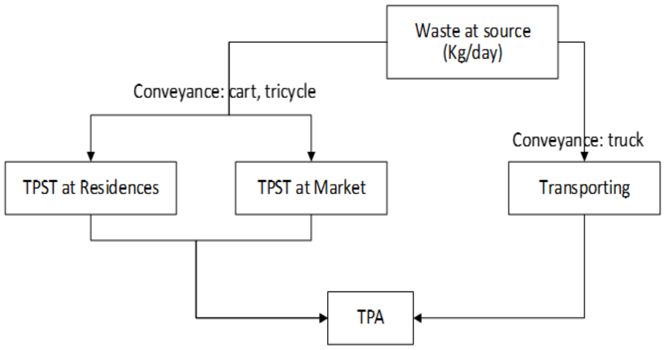


Figure 7. Waste management in Bogor city region

Waste at source

The types of containers used by the community in Bogor Region in the waste collection process at the source are plastic bags, garbage cans, etc. These types of containers are commonly used due to convenience and economy. These types are commonly used due to convenience and economic factors. In the existing condition, there are still people who throw garbage on the side of the road which makes the aroma and aesthetics of the surrounding area worse. According to Ratnawati et al. [17], waste that accumulates due to a lack of public awareness can have a negative impact, both directly and indirectly.

Waste in TPST

Part of the waste collected from the source will first be transported to the TPST using a three-wheeled garbage motor. There are 27 waste motors used and they are capable of transporting waste with a maximum carrying capacity of 500 Kg. Usually, waste motors are used to transport waste from places that are difficult to reach by arm roll cars. In addition to being transported using three-wheeled motorcycles, waste that enters the TPST is also transported using garbage carts carried out by janitors.

Waste Transportation

The waste transportation process from the source to the landfill in Bogor Region is served by vehicles in the form of dump trucks, arm rolls, crank trucks, and pick-up cars. According to the waste weighing officer at the Galuga landfill, currently, some of the waste transportation process from the source or TPST is still carried out with open tanks. This can cause waste loss because it allows waste to fall and scatter onto the road, which certainly disturbs the comfort and safety of residents and road users.

Landfilling of Waste in the Landfill

The waste disposal process in Bogor Region is carried out by open dumping, where the waste is only leveled without being filled with soil cover. According to the head of the Galuga UPTD, the Galuga landfill currently holds waste that is beyond the maximum storage limit. The waste in the landfill is then left unattended until the condition around the landfill site becomes messy and the potential for landslides and fires. The emergence of pungent odors and pollution of water bodies and leachate water is common when it rains. This shows that the landfill has polluted the environment because it is not managed properly.

3.2 Alternative waste management system design

Scenario 1 (Existing) Waste Management System Based on Technical Aspects Using the MFA Method

The waste composition includes 324,387 kg/day generated at the source and approximately 222,205 kg/day documented entering the TPA (Figure 8). The total value can be determined by aggregating various waste categories, which include: food waste at 106,680 kg/day, paper at 14.46 kg/day, plastic at 4,200 kg/day, metal at 267 kg/day, glass at 9,957 kg/day, rubber and leather at 7,556 kg/day, textile fabrics at 14,602 kg/day, wood, twigs, and leaves at 44.45 kg/day, and residual waste at 64,897 kg/day. From these activities, there is waste transportation to Residential Integrated Waste Disposal Sites, Market Integrated Waste Disposal Sites and Landfills using transportation equipment and requiring fuel. This causes CO_2 emissions.

Total carbon dioxide emissions are determined by assessing the emission load associated with each transportation mode. This calculation incorporates the frequency of trips per mode on a daily basis, yielding a total of 233.94 $kgCO_2$.

Transportation activities:

Source to TPA

Mode of transportation: Dump truck

Weight of waste transported (kg) = 39.342 kg

Maximum capacity of transportation mode (kg) = 25.000 kg

Distance: 16 km

Fuel consumption (km / l) = 2.4

Gasoline Emission Factor ($kgCO_2$ / l) = 2.2 (because dump trucks use diesel)

Therefore:

Number of Truck Units Required (unit)

= (Total Weight of Waste Transported (kg)) / (Maximum Capacity of Transportation Mode (kg)) Number of Truck Units Required (unit)

= (39.342 kg) / (25.000 kg) = = 1.57 ≈ 2 units

Total Fuel Consumption (l)

= (Distance (km)) / (Fuel Consumption (km / l)) = (16 km) / (2.4 (km/l)) = 6.67 liters

Vehicle Emissions = Required Truck (units) × Total Fuel Consumption (liters) × Gasoline Emission Factor ($kgCO_2$/l) = 2 × 6.67 × 2.2 = 29.3 $kgCO_2$

Scenario 2 Waste Management System Based on Technical Aspects Using the MFA Method

In this second scenario, the waste management flow is directed not solely to the TPA, since it incorporates two waste reduction processes: the composting process and TPST-3R management (Figure 9). The composting method is employed due to the prevalence of organic waste, primarily food waste, in the Bogor Region [23].

The calculation of total carbon dioxide emissions is derived from the emission load associated with the transportation mode utilized. This is achieved by considering the number of trips per mode on a daily basis, leading to a total emission of 155.40 $kgCO_2$.

Scenario 3 Waste Management System Based on Technical Aspects Using MFA Method

In scenario three, the implementation process adopts scenario two but adds the Refuse Derived Fuels (RDF) process. The process is an alternative to waste inventory in the form of energy, one of which is as an alternative fuel. Thus, it will increase income from an economic perspective if managed properly (Figure 10).

Total carbon dioxide emissions are determined by assessing the emission load associated with the chosen transportation mode, factoring in the daily frequency of mode rotations, which yields a total of 135.82 $kgCO_2$.

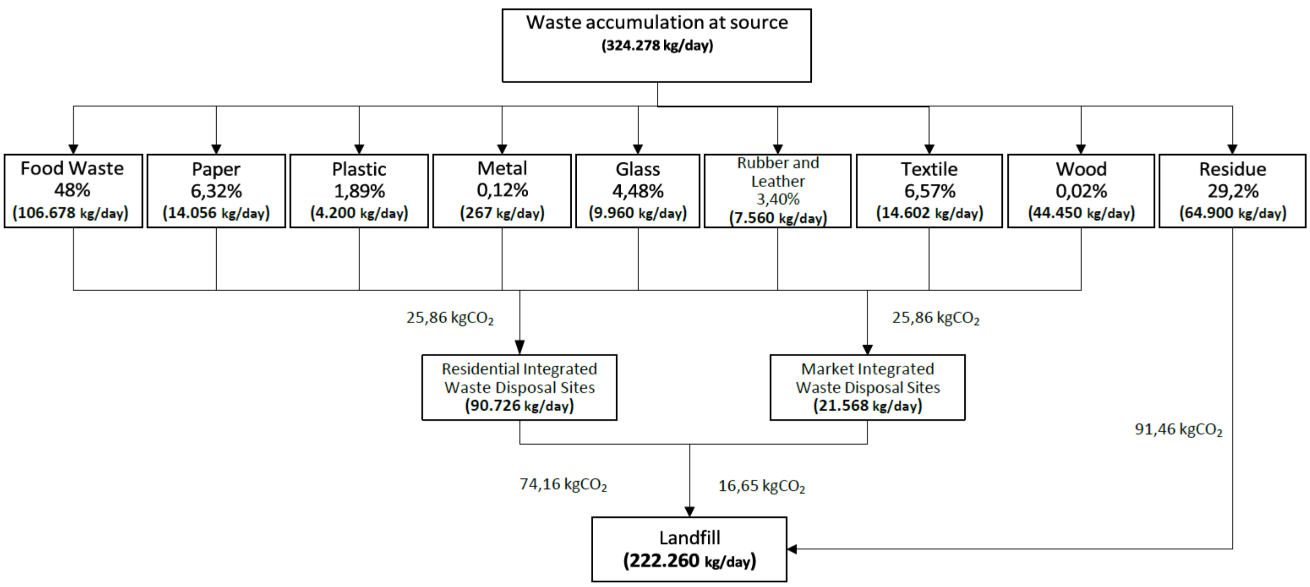


Figure 8. Scenario 1 waste management system (existing) based on technical aspects using the MFA method

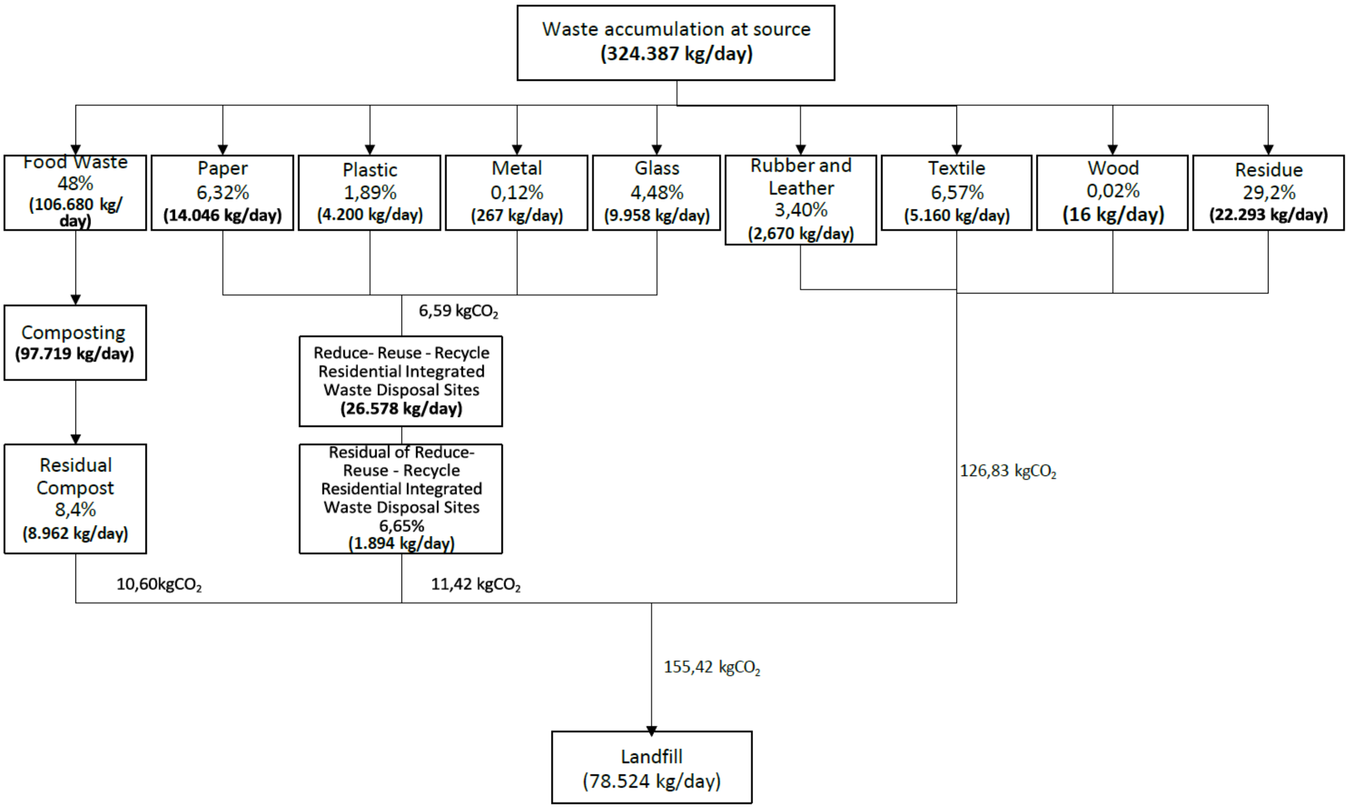
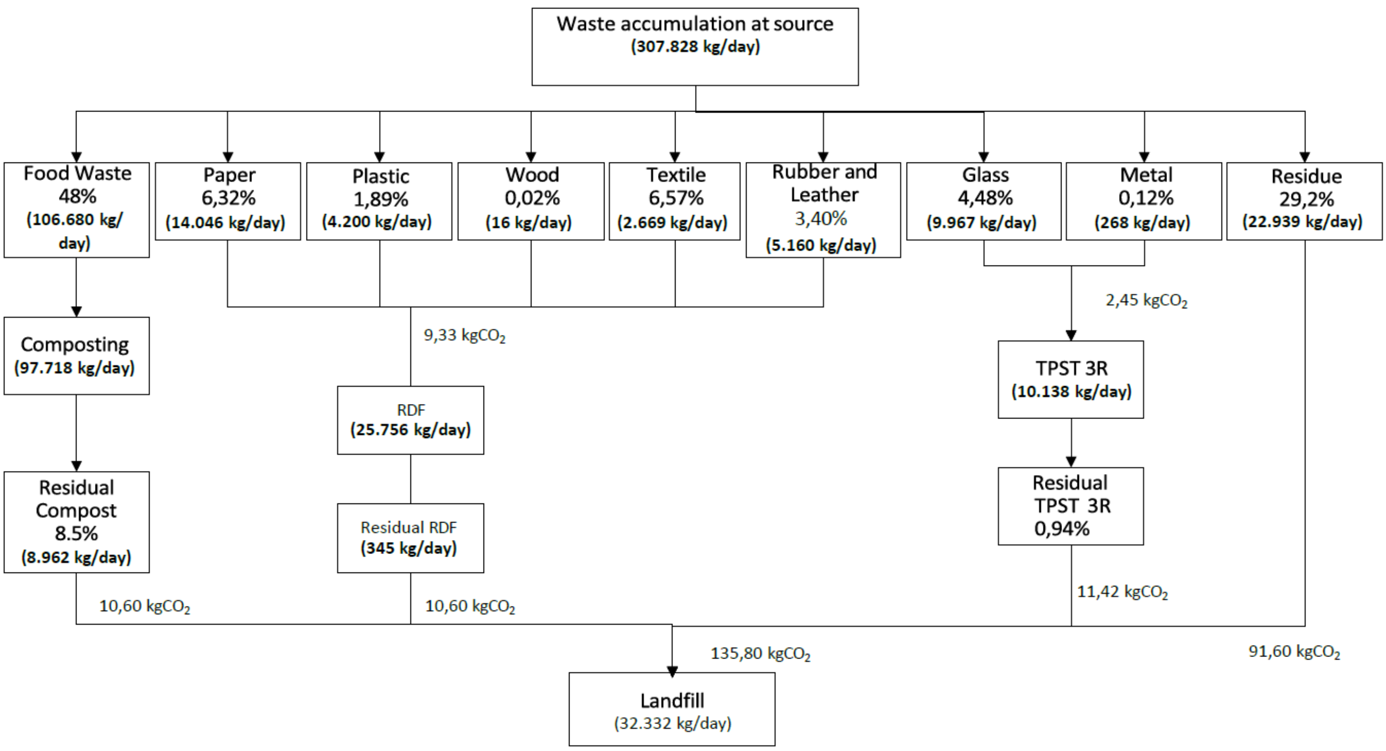


Figure 9. Scenario 2 waste management system based on technical aspects using the MFA method



Figures 10. Alternative waste management system design scenario 3 based on technical aspects using the MFA method

3.3 Selection of design alternatives using AHP method

The AHP method allows decision makers to express multi-factor interactions in complex and unstructured situations. AHP will produce a priority ranking order that indicates the overall preference for each decision alternative.

Following the computation utilizing the AHP approach on the three management possibilities, the highest weight value was identified. Scenario 3 exhibits the highest AHP value, namely in waste management utilizing the composting process, RDF, and TPST-3R. Consequently, for the selection of total waste value in the TPA, the projected revenue and utilization % should prioritize scenario 3 (Figure 11).

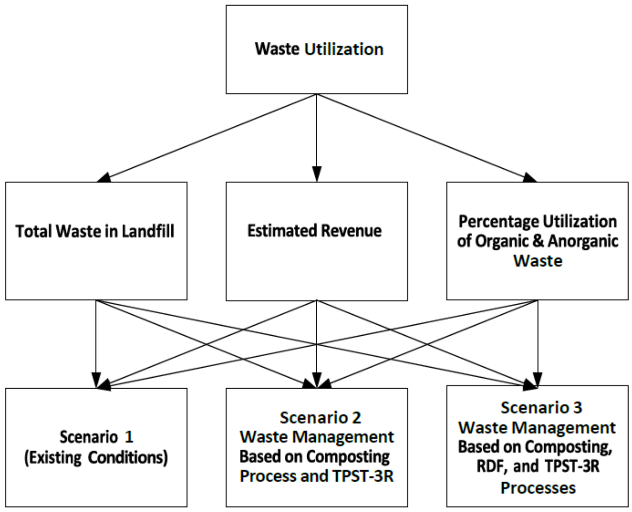


Figure 11. Alternative design selection using AHP method

The optimal management choice selected is waste management utilizing the composting process, RDF, and TPST-3R. The subsequent results pertain to the evaluation of the chosen alternative (Table 3).

The research findings emphasizing the necessity to enhance the capacity of Galuga Landfill and develop more efficient waste management solutions should be incorporated into municipal waste management policy. This necessitates cooperation among the municipal government, trash management entities, and the community. Proposed policies may encompass the establishment of enhanced infrastructure for waste processing, including sophisticated recycling facilities, and initiatives that motivate the community to minimize landfill discharge by implementing source trash sorting. Moreover, regulations must incorporate environmental education and awareness initiatives designed to enhance community engagement in trash management [24, 25]. The execution of these regulations necessitates augmented funds and resources, with continuous monitoring and evaluation to ascertain the efficacy of the proposed waste management solutions. By implementing these rules, it is anticipated that the Bogor Region will address the existing waste management difficulties and progress towards a more sustainable and efficient waste management system.

Table 3. Weighting results of alternative design selection using the AHP method

Alternative	Total Waste in TPA	Estimated Income	Percentage of Utilization of Organic and Inorganic Waste	Weight Criteria	Total Weight	Rank
Scenario 1	0.633	0.192	0.175	0.521	0.392	2
Scenario 2	0.532	0.101	0.366	0.289	0.376	3
Scenario 3	0.644	0.074	0.283	0.190	0.410	1

4. CONCLUSIONS

In conclusion, although the study done in the Bogor Region offers useful insights into local habits, it is crucial to acknowledge the constraints imposed by regional specificity. Behavioral and situational variations may be evident nationwide due to cultural diversity, socio-economic disparities, and environmental influences. Future studies should endeavor to encompass a wider geographical range to accurately reflect the diversity of human behavior in Indonesia.

The findings of the waste management system design in the Bogor Region indicate that the technical components of waste management have not adopted the principles of integration and sustainability, as per the study's conclusions. This is evident in the phases of waste management, which include sorting, processing, transportation, and final disposal.

The practices of MFA and AHP can facilitate the formulation of comprehensive waste management policies that are both efficacious and sustainable. In the realm of municipal solid waste management, a combined strategy can facilitate the identification of priority intervention locations, enhance resource recovery, and reduce environmental consequences. Moreover, involving stakeholders throughout the process guarantees that the resultant policies are both scientifically valid and socially acceptable, hence enhancing community engagement and adherence.

Considering the aforementioned constraints, subsequent study should use a more holistic approach that includes many regions throughout Indonesia. Through comparative studies, researchers can discern patterns and differences in behavior stemming from diverse cultural, social, and environmental contexts. This strategy would improve the validity and dependability of behavioral research findings and foster a more sophisticated comprehension of human behavior in Indonesia.

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