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**Development of Waste Management Strategies  
based on Recycling and Energy Recovery in Indonesia**  
資源・エネルギー回収に基づくインドネシア廃棄物管理戦略の構築

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## **ABSTRACT**

The global situation on municipal solid waste (MSW) is worsening and greatly affected by population number and Indonesia, like other Southeast Asian countries with high population growth, is needed to minimize both this problem and the related greenhouse gas (GHG) emissions. The Government of Indonesia set the reduction targets of MSW at 30% by 2025 and GHG emissions (of the waste sector) at 0.38% by 2030 and required to systematically deploy recycling and energy recovery oriented MSW facilities. However, the unavailability of a national plan on waste management to address the ranging population sizes in Indonesia hindered the development. Thus, the general objective of this research is to develop a national plan with specific strategies based on recycling and energy recovery to attain the national targets of landfilled waste reduction at 30% and the waste sector of GHG emissions reduction at 0.38% in Indonesia.

Indonesia is implementing different MSW facilities to improve recycling and energy recovery with waste banks (WBs) at the source where residents can obtain revenue by selling recyclables, transfer stations (TSs) as the majority starting point before transported to the landfill, Material Recovery Facilities (MRFs) with multiple types of equipment supporting the manual recyclable recovery, and incinerators as the acceleration of waste to energy programs, which are going to be established in the different population group of cities/regions (Areas). However, Indonesia has limited MSW data on the location and size of the facilities, transportation routes, and landfills information, which is essential to be analyzed in each Area. Therefore, Surabaya City, which stood out as one of the best cities in the MSW management aspect and has complete data as mentioned above, was determined as the pilot study to fill in the missing data by constructing Surabaya Model to be utilized in further analysis in this research.

Surabaya Model was developed as a prior study of national scale expansion model to evaluate both current and newly proposed MSW system, comparing the cost and GHG emissions generated by

focusing on replacement of TS to MRF, targeting the reduction of MSW at 30%. The geographic Information System (GIS) was used to deploy all surveyed TSs, MRFs, landfill, and the transportation route from each location to the landfill. The distance generated and frequency of transportation were then utilized to calculate the fuel for transportation cost. Four scenarios were analyzed and Scenario 3: Distributed MRF System was found to have the lowest overall cost at 59 billion IDR/y with the least number of MRF required at 26 units. However, the integration networking between TS and MRF in this system handicapped the fuel for transportation cost due to the longer total transportation distance. This shows that transportation cost is a sensitive aspect which affected directly on the position of starting point and the landfill. Both items would be highly necessary to successfully broaden the Surabaya Model for a national scale model.

WB promotes resource recovery at the source, yet the actual contribution to the MSW system is still unclear. This part of the research is targeted to clarify the role in the MSW system and its necessity to be implemented in the national model. Interviews were conducted with authorities of WBs in Surabaya for details on the performances. WBs in Surabaya recover 3.5 t/d recyclables from 35,068 households by 755-unit WBs which were considered low in impact, yet WB offered higher quality recyclables and necessary information for further revenue analysis.

Due to insufficient data of MSW facilities for the whole of Indonesia, centroids were used as a representation of starting point based on the residential and/or working (RA) area using QGIS in the Surabaya Model. This part of the research was divided into two goals, the compatibility check of utilizing centroids by comparing transportation cost, and scenarios development on the national plan of waste management in Indonesia using expanded Surabaya Model to address national targets on landfilled waste and GHG emissions reduction. Surabaya City was divided by district level, which has different population sizes and densities, to compare and verify the hypothesis of determining transportation cost using the centroid of each district as the starting point of transported waste to the landfill. The analysis using RA Centroids resulted in similar data, verifying the theory and possibility to be used in a national-scale model. Centroids were a vital element to establish transportation routes, to

project missing landfills, to set up integration between Areas, and to evaluate the cost and GHG emissions reduction. Then the implementation of available MSW facilities was simulated using QGIS in different scenarios to achieve the national goals. Scenario 0 simulates the BAU case for comparison with solely a 3% reduction at TSs. Other scenarios were deploying WBs in Small Areas, MRFs in Medium Areas, 450 t/d capacity incinerators in Big Areas with MRFs handling the uncovered MSW, and 1,000 t/d capacity incinerators in Metropolitan Areas. Scenario 2 and Scenario 3 were like Scenario 1 yet concentrated on the WtE program with different approaches. Scenario 2 with post-integration used the 1,000 t/d capacity incinerator for Metropolitan Areas and take over the nearby Areas if the capacity remained. Scenario 3 with prior integration, on the other hand, utilized both 1,000 and 450 t/d capacity incinerators for Metropolitan Areas and integrate the possible neighboring Areas, with the respective possible transportation distances, to determine the incinerator unit number in advance. All three scenarios were able to pass the targeted landfilled waste reduction with Scenario 3 leading at 64% reduction and the targeted GHG emissions reduction at 0.49%. The performance was compensated with a huge total cost of 1.4 times of BAU due to the OM and investment cost. However, considering the recovery at the source and TWDSs, the tipping cost was decreased while the revenue from recyclables was increased. Thus, the analysis showed that this system resulted in the lowest 19 Mt/y landfilled waste and 14.1 MtCO<sub>2</sub>e/y GHG emissions reduction with a reasonable cost for reduction achievements.

In summary, the national plan of waste management in Indonesia with recycling and energy recovery orientation was designed by considering population size and area integration; and assessed to meet Indonesia's goals by comparing centroid usage as a representation and determinant of missing MSW facilities to the Surabaya Model which has real comprehensive data. This approach addressed the challenge of reducing landfilled waste and GHG emissions, which is common in Southeast Asia and opened new possibilities of implementation possibilities for reproducing the study based on characteristics of environmental parameters in multiple cases with poor MSW facility data.



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## **1. INTRODUCTION**

### **1.1. BACKGROUND OF THE STUDY**

Indonesia ranks fourth in the most populated country at 0.2 billion inhabitants which generate combined municipal solid waste (MSW) at 67.8 Mt/y in 2020 [3] with landfilling orientation MSW management system. Relying on landfills for most of MSW, without any intermediate treatment in between, will deplete the limited capacity and lead to posing threats to both environment and residents. Dealing with this massive amount of MSW produced daily without appropriate management on reducing, reusing, and recycling; and proper treatment could lead to an unwanted environmental condition [9].

The Government acted by introducing different MSW facilities for the past couple of years, targeting different segments of the MSW system. Waste bank (WB) was introduced as a drop point for source-separated recyclables to promote source separation and recyclable recovery at the source segment [6]. At the collection segment, Material recovery facility (MRF) was proposed [7] as an alternative to TWDS, which are mainly transfer stations (TSs), with the organic waste recovery feature to reduce further, while at the treatment segment, incinerator as waste to energy (WtE) was planned in different city/region [5]. In addition, the Government set an MSW reduction target of 30% MSW reduction by 2025 [4] and pledged, back in 2015, to unconditionally reduce the waste sector of GHG emissions reduction at 0.38% of the business-as-usual (BAU) scenario by 2030 [2]. Thus, we proposed the national plan of waste management in Indonesia with recycling and energy recovery orientation with the evaluation of three criteria of landfilled waste reduction analysis and GHG emissions reduction analysis, corresponding to the national targets, and additional cost analysis to visualize the feasibility.

The deployment of MSW facilities will be depending on city/region (Area) class which is categorized based on the number of populations into four classes (small-medium-big-metropolitan) [8] and correspond to each criterion evaluated based on the respective characteristics of the facility and correlation to the attributes of criteria. Transportation of MSW to the landfill site or the incinerator will also be considered as one of the important aspects in the analysis of GHG emissions reduction and cost based on the distance traveled, amount of MSW transported, and the vehicle capacity. However, to analyze them, and to implement any of the MSW facilities themselves, requires detailed geographical information to precisely estimate the locations of the MSW facilities and understand the interaction between in the operation.

National scale research in developing country always dragged by limited, questionable, and undetailed data. Pilot research would be highly beneficial to set the database before executing the full-scale. Throughout the whole of Indonesia, Surabaya City, as the second-largest city in Indonesia, stands out as one of the best cities in the environmental management aspect which has been known and recognized both nationwide and worldwide [9]. Surabaya is, arguably, leading Indonesia in the development of WB, implementing MRFs which recover up to 63.8% of the input [1] and having the largest incinerator nationally, therefore, making it highly a potential city for this pilot research. This city also has the complete datasets required to conduct all necessary criteria, including the geographical information of all available MSW facilities. Therefore, conducting a prior simulation on Surabaya by establishing the Surabaya Model while introducing different MSW facilities in the system, then utilizing the results to expand into the national model will be conducted.

## **1.2. OBJECTIVES OF THE STUDY**

The execution of the Surabaya Model as a prototype provides the fundamental information in the introduction of the MSW facility to be evaluated by set criteria and determination of centroids to

complete the missing data for larger-scale analysis. Having goals of addressing national targets on landfill waste and GHG emissions reduction with reasonable cost, strategic combinations of recyclable recovery approach conducted in WB and MRF; and energy generation approach of WtE is required. Thus, the general objective of this study is to develop a national plan with specific strategies based on recycling and energy recovery to attain the national targets of landfill waste reduction at 30% and the waste sector of GHG emissions reduction at 0.38% in Indonesia.

### 1.3. STUDY OVERVIEW

This study is consisting of 6 chapters which are visualized in Figure 1.1. **Chapter 2:** Current Solid Waste Management in Indonesia, discusses the existing condition of MSW management in Indonesia and specifically in Surabaya based on the literature reviews. The currently available MSW facilities are to be explained in detail as the fundamental idea for the main research. **Chapter 3:** Surabaya Model Using GIS to Estimate Cost and GHG Emissions, Focusing on Replacement of TS to MRF, develops Surabaya Model as prior of nation-wide expansion model analyzing current and newly proposed MSW system, emphasizing on the introduction of TS to MRF replacement. **Chapter 4:** Effectiveness of Waste Bank in Recycling, investigates the performance of WBs in Surabaya and their role in resource recovery. The important attributes for base calculation in the national model are going to be determined here. **Chapter 5:** Scenario Analysis Combining WB, MRF, and Incinerator for National Planning of Waste Management in Indonesia, clarifies the suitability of centroid as a substitute of TS or MRF by executing it on Surabaya Model and comparing the fuel for transportation cost between the centroid and actual MSW system (TS and MRF). Then followed by the establishment of the national plan of waste management in Indonesia using the expanded Surabaya Model to achieve Indonesia's targets of MSW and GHG emissions reduction. Lastly, **Chapter 6:** Conclusion, reviewing the summary of the study in general.

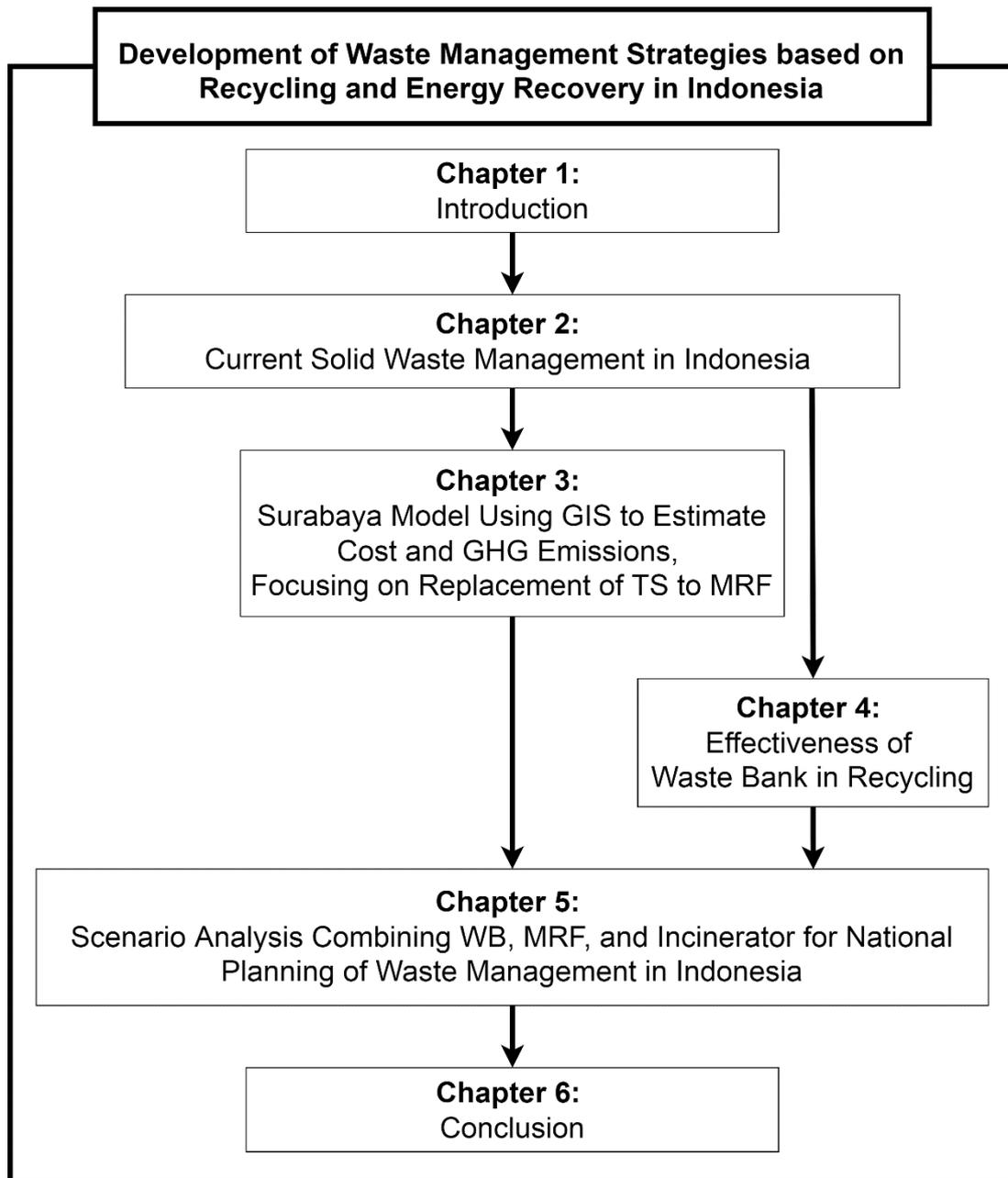


Figure 1.1 Research Structure.

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## **2. CURRENT SOLID WASTE MANAGEMENT IN INDONESIA**

### **2.1. WASTE MANAGEMENT IN INDONESIA**

The government invests trillions of Indonesian Rupiah each year to enhance the environmental condition, but with minimal public engagement in maintaining the best possible environmental state, the benefit will not be realized to its full potential. In contrast, in a rural location, poor competence and a restricted budget are two basic difficulties that require local governments to fight to offer minimal waste management [20], leaving MSW management aside. The visible solid waste management technique to be used is the reduction and handling [12], where solid waste separation is highly suggested and should be prioritized, which is why it is mentioned as the most essential step to do [3].

The Act of the Republic of Indonesia Number 18 [8] mentioned that both national and local governments are tasked to ensure the implementation of good and environmentally sound waste management by developing and increasing public awareness in waste management; conducting research, developing technology for waste reduction and handling; facilitate, develop, and implement efforts reduction, handling, and utilization of waste management; implement waste management and facilitate the provision of waste management infrastructure and facilities; encourage and facilitate the development of benefits from waste processing; facilitate the application of locally developed specific technologies in local communities to reduce and manage waste; and coordinate between government agencies, the community, and the business world so that there is integration in waste management.

The same regulation [8] was also clarifying the obligations and rights of the national authorities to facilitate and develop inter-regional cooperation, partnerships, and networks in waste management; the

provincial authorities to facilitate inter-regional cooperation within one province, partnerships, and networks in waste management; and district/city authorities to organize district/city scale waste management by the norms, standards, procedures, and criteria set by the Government and determine the location of temporary shelters, integrated waste processing sites, and/or final waste processing sites.

The Ministry of Transportation of the Republic of Indonesia [19] classified the demographic into four categories, with Metropolitan Area containing more than one million people, Big Area containing 500 thousand to one million people, Medium Area containing 250 to 500 thousand people, and Small Area containing less than 250 thousand people. According to the Republic of Indonesia's Ministry of Public Works and Housing [16], Metropolitan and Big Areas should have sanitary landfills, while Medium and Small Areas should have regulated landfills. However, this is not all there is to MSW management system planning. Landfilling is a near-end segment of the MSW management chain's treatment segments. To address the problem, the provision of MSW facilities compatible with Area classes in the source and collection segments is critical.

In Indonesia, 0.6-0.7 kg/capita/d of MSW is generated in Small Area and 0.7-0.8 kg/capita/d in Medium Area [21] with 74% biodegradable as the major composition [24], showing the high moisture content in the waste, rendering it to be unsuitable to be incinerated, or at least not without source separation. Thus, landfilling has traditionally been the primary ultimate treatment. Depending on the demographics of the city, several kinds of landfills are being established.

### **2.1.1. Goals on Municipal Solid Waste Management in Indonesia**

Two goals on MSW management in Indonesia were considered in this study, which are the reduction of MSW and reduction of GHG emissions. Both were given the time target to evaluate the achievement at the years 2025 and 2030, respectively for waste reduction and GHG emission reduction.

- **Landfilled waste reduction**

The actual statement of the Government was to have a reduction of residential and non-residential waste at 30% of the waste generation of residential and non-residential waste in the year 2025 [12]. The reduction target per year itself was published [11] and the copy can be seen in Table 2.1. However, Non-residential waste was not specifically considered in this study, therefore, the goal was adapted, so the calculation of waste reduction was at 30% in the unit of landfilled waste reduction.

Table 2.1 Target of Residential and Non-residential Waste Reduction [11].

Indicator	2020	2021	2022	2023	2024	2025
Projection of residential and non-residential waste generation (Mt)	67.8	68.5	69.2	69.9	70.6	70.8
Target of residential and non-residential waste reduction (Mt)	14 (22%)	16.4 (24%)	17.99 (26%)	18.9 (27%)	19.7 (28%)	20.9 (30%)

- **GHG emissions reduction**

The GHG emissions reduction target of Indonesia in 2030 was at 29% [9]. Yet, it was the total of all sectors considered. The waste sector itself is only worth 0.38% of the total reduction targetted. Furthermore, the waste sector is divided into three subsectors, solid waste, domestic liquid waste, and industrial liquid waste, without a detailed distribution share of reduction target. This means that the reduction target for the solid waste sector was less than 0.38%. But still, in this study, only the solid waste subsector of the waste sector was considered for calculation but the value 0.38% was considered as the target achievement or equal to 11 MtCO<sub>2</sub>e.



Two facilities work as a collection point of specifically separated recyclables. Waste bank (WB) for inorganic recyclables and composting site for organic recyclables. WB provides a neat and more customer-friendly environment to store the segregated materials and offers both cashing in and saving options for the value, in comparison to regular waste traders (*loak/pegepul/rombeng*). Composting site, on the other hand, is the collection point and main treatment of separated organic matter from both MRF and source directly, like from parks or any green space areas. The Government provides free compost generated to be utilized by the residents.

The government has already established rules linked to the promotion and implementation of MSW facilities to overcome the MSW issues with WB [16], MRF [18], and the highlight of WtE by campaigning the acceleration of construction of waste processing installations into electrical energy based on environmentally friendly technology in seven cities of Jakarta, Tangerang, Bandung, Semarang, Surakarta, Surabaya, and Makassar [10], and the updates in 2018 added 5 cities of South Tangerang, Bekasi, Denpasar, Palembang, and Manado [13].

Surakarta City and Surabaya City, with their different incineration features, are two instances that should be highlighted. Surakarta, which has a population of about 0.6 million people, has installed a 450 t/d incinerator [23] to address MSW concerns while being environmentally benign. Surabaya, which has a population of around three million people, has a 1,000 t/d incinerator [1] that can treat two-thirds of the MSW.

## **2.2. WASTE MANAGEMENT IN SURABAYA**

Surabaya is Indonesia's second-largest city, situated on the northern coast of the province of East Java. Within a 350.5 km<sup>2</sup> region, the population exceeds three million. The high MSW production from this location is due to a concentrated population in Central and Northern Surabaya (Figure 2.3), which shows

where the primary economic activity is taking place. Surabaya produces roughly 2,913 tons of MSW each day [7]. Organic waste accounts for 72.4% of Surabaya's MSW, with plastic (10.1%), paper (7.3%), and other waste kinds such as glass, metal, rubber, wood, ash, and textile (10.2%) accounting for the remainder [4].

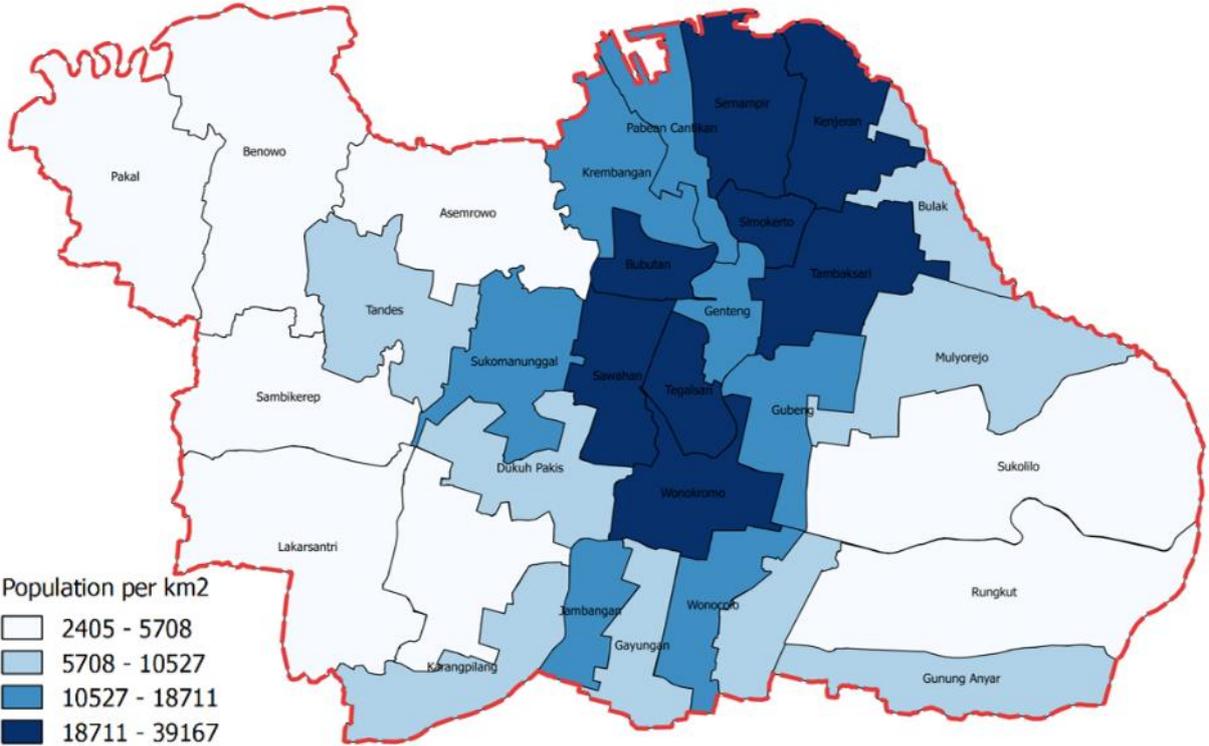


Figure 2.3 Surabaya Population Distribution Map.

**2.2.1. Municipal Solid Waste Flow in Surabaya**

Surabaya's waste generation is separated into two categories: commercial and municipal. MSW produced is assigned to certain facilities depending on the waste's characteristics. However, a significant amount of MSW is publicly burnt and/or illegally discharged ("Unknown" in Figure 2.4). The non-segregated MSW from the source is collected and transported to the TWDSs (TSs or MRFs) for manual separation. Organic waste, on the other hand, is composted, whilst recyclable items are sent to a waste bank or *pengepul*. The waste collector brings the segregated recyclable items from TSs to the *pengepul*

to get additional money. The collected separated recyclable materials from MRFs, as well as those from *pengumpul* and waste banks, will subsequently be transferred to the appropriate recycling facilities or businesses.

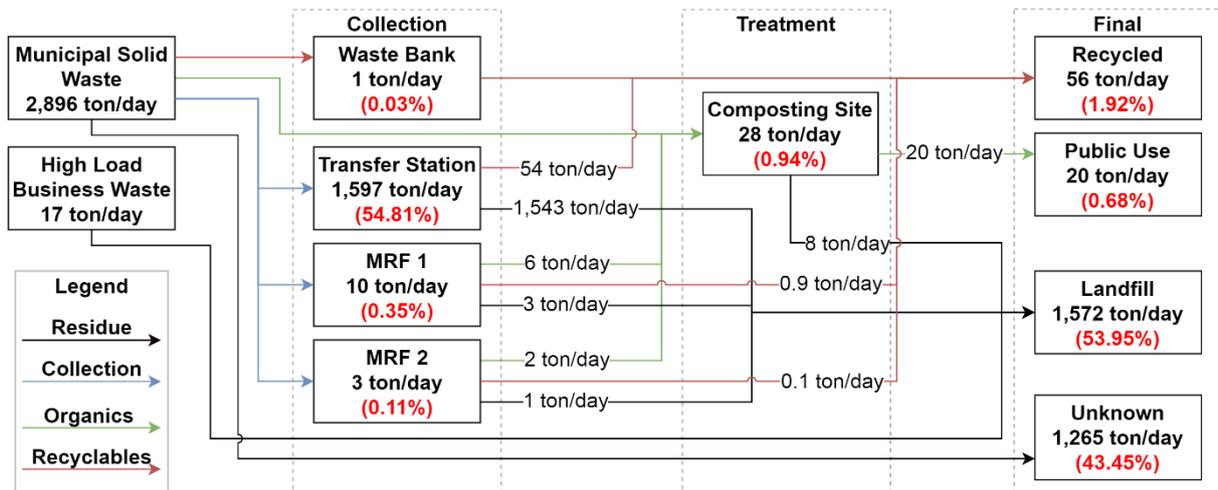


Figure 2.4 Waste Flow in Surabaya.

One probable explanation for the low percentage of source-separated recyclables from the source is that some of them are sold to waste brokers rather than waste banks. Waste brokers, also known as *loak/pengumpul/rombeng* in the local language, are a private informal industry that offers clients the opportunity to exchange their recyclables for cash. However, the lack of trustworthy statistics or publications about the operation makes it impossible to determine the specific recyclables gathered, hence they are labeled as "Unknown" in Figure 2.4 alongside publicly burnt and illegally deposited waste.

Surabaya generates around 1 kg/capita/d of MSW. Source separation was inadequately implemented in both residential and non-residential sectors. The recovery at the source was as much as 1-2 t/d, and the garden waste that was collected went to composting facilities. Approximately 20 tons of organic waste each day, mostly from public parks, is sent directly to composting facilities. The TSs handled 54.8%

(1,597 t/d) of the waste generated, with recyclable items accounting for 3.4% (54 t/d) [26]. The remainder will be handled as waste and disposed of at a landfill. In contrast, two MRFs collected 0.4% (13 t/d) of the produced waste and separated it into three types, organic waste to be composted, recyclable materials, and residue, with rates of 8 tons/day, 1 t/d, and 4 t/d, respectively. Composting facilities, on the other hand, handle 0.9% (28 t/d), both from the source and from MRFs, with a recycling ratio of 72%.

### **2.2.2. Collection and Transportation of MSW in Surabaya**

Surabaya's MSW collection and disposal activities are divided into two tiers: a collection of domestic waste and transportation to temporary waste disposal sites are the responsibility of households, while transportation of MSW from temporary waste disposal sites to the landfill is managed by the city government [3]. Waste from both households and non-households, such as the commercial and educational sectors, is placed in either a permanent or temporary container positioned in front of the household or public institution. A waste collector visits each property to collect waste from residential or non-residential sources within the service region. The collector loads the waste from the source to the capacity limit using a pushcart or a motorcycle-powered cart (Figure 2.5), then returns to the TS to dump it while searching for recyclable goods to be sorted and sold later. The residue is carried to the landfill after the recyclable elements have been recovered at temporary waste disposal facilities.



Figure 2.5 Collection Vehicle in Surabaya: Motorcycle-powered Cart (left) and Pushcart (right).

The transportation of collected waste to the landfill is the duty of the local government; hence, the waste is transported using vehicles from both the government and the participating private enterprises. The frequency of waste transportation varies based on the capacity and waste load of each temporary waste disposal facility. The frequency varies from 6 trips per day to less than 1 trip per day. Most temporary waste disposal facilities (68 units) have their waste delivered to the landfill once per day, 51 units less often, and the others more frequently. According to the present scenario, there are 73 temporary waste disposal sites where collected waste must be stationed overnight and kept exposed, raising risks of airborne, waterborne, or animal-borne illness. Six TSs had the fewest trips per week, with just one journey every week. Businesses or enterprises that create more than 30 m<sup>3</sup> (12 tons) of waste per month are responsible for disposing of their waste to a landfill on their own [6]. As a result, 17 t/d of waste are immediately transported to the landfill by industries and other public entities that create a heavy load of waste (Figure 2.4 in Chapter 2.2.1).

Surabaya's government supplies three kinds of vehicles for various functions. Dump trucks handle incidental waste such as waste from the curbside tree cutting service and river cleaning, whilst arm-roll

and compactor trucks carry MSW from temporary waste disposal facilities (Figure 2.6). Arm-roll trucks are designed with 6, 8, or 14 m<sup>3</sup> containers and operate on a hauled container system. Compactor trucks, on the other hand, employ the stationary container system and have 6 or 10 m<sup>3</sup> capacity with 0.7 m<sup>3</sup> small containers that are semi-automatically loaded into the vehicle.



Figure 2.6 Transportation Vehicles in Surabaya: Arm-roll Truck (left) and Compactor Truck (right).

### 2.2.3. Transfer Station as Temporary Waste Disposal Sites

Surabaya is featured with 197 transfer stations (TSs) as the main temporary waste disposal sites which focus on the coverage of MSW handling service to collect all generated waste from both residential and non-residential sources. TS generally has an average waste load of 2,383 t/y with a recovery ratio of 3.4% or about 81 t/y recyclables recovered from it. The collected waste is unloaded from the cart while manually segregated for valuable recyclables and the rest of the waste is piled inside the container for transportation (Figure 2.7).



Figure 2.7 *Tambak Rejo* Transfer Station in Surabaya.

#### **2.2.4. MRF as Temporary Waste Disposal Sites**

Surabaya has been equipped with two additional MSW facilities which focus on the recovery of recyclables, which are MRF at the collection segment and earlier WB at the source segment. MRFs offer greater benefits, such as knowledge enrichment, raising environmental awareness, and increased job opportunities. However, MRF itself, as a system, needs to be evaluated to understand the effects of selecting it as the substitute TS. In small-scale research where the performance of each MRF is being gauged, the complete analysis on recyclable recovery and cost can be understood. The recovered organic waste will be treated in composting site, therefore, an expanded analysis to understand the details on the composting site would be required. WB, on the other hand, recovers the source-separated recyclables and prevents them to be mixed with different waste. This promises a higher quality in comparison to one from MRF. Even so, the performance and contribution to the system have not been confirmed.

In Indonesia, TSs are the most common TWDSs, but MRFs are only found in a few areas. This is most likely owing to the extensive cost and detailed study required to create such a large-budget facility. The fact that MRF recovers more recyclable materials has no impact on the issue. Instead, waste scavengers and waste collectors in the informal sector play a key role in decreasing waste at the source, transfer stations, and even landfills. The informal sector recycles at a high rate in several developing nations [2]. Apart from being successful, relying on the informal sectors for recyclable recovery causes the system to lose integration, which may result in more missing or unrecorded data for future study.

Since 2013, MRF has been one of the waste treatment facilities in Surabaya, with the next one opening in 2015. MRF's organic recovery for the composting site (CS) has been a significant breakthrough as TWDS alternatives for the average recovery at 63.8% above the TS at 3.4% [26]. MRFs include belt conveyors where the workers perform multi-level separation, resulting in a more specific and higher recovery rate, a shredding machine that prepares the separated organic waste for treatment at the composting site, and a baler to bundle and pile the recovered recyclable materials. The pioneer, Super Depo Sutorejo, which has been operating modern technology for organic and inorganic waste treatment since 2013, receives 10 t/d of MSW from the nearby residential area and recovers an average of 58% of organic materials and 9% of inorganic materials, sending the rest (33%) to the landfill as residue. Pusat Daur Ulang Jambangan, which has been in operation since 2015, receives 3 t/d but recovers the same number of recyclable materials before disposing of 1 t/d of residual to the landfill. Both MRFs were constructed with a capacity of 20 t/d, allowing for some enhancements. The separated inorganic waste will be collected by recycling businesses, while the organic half will be composted at composting facilities.

Surabaya has 24 composting facilities that handle roughly 303 m<sup>3</sup>/d, with a total maximum capacity of 351 m<sup>3</sup>/d [16]. Surabaya's composting facilities handle 75% of the garbage created by the management of cutting roadside trees, 11% of market waste, 11% of park maintenance, 2% of home waste, and 1%

of street sweeping. In addition, MRFs transport their separated organic waste to composting facilities at a pace of up to 8 t/d. Some composting facilities process waste at a rate that exceeds their capacity, while others do not. It is possible to put up to 66 m<sup>3</sup>/d of capacity into operation. Furthermore, Surabaya has adequate green space to meet current demand, accounting for 21.7% of the total area of Surabaya. This region is made up of 1,221 ha of agricultural fields and 1,644 ha of parks [7]. If one ton of compost is required per hectare, the annual demand for compost is projected to be 7,268 tons. Furthermore, all compost generated is free for those in need to take.

### **2.2.5. Landfill Site of Surabaya**

Surabaya's sole landfill, *Benowo Landfill*, is situated in the west section of the city and covers an area of 37.4 ha. The landfill's ultimate cover will be 5–12 m high, and it is expected to be completed in 2030 [14]. Benowo Landfill began its operations in 2011 under the administration of the Surabaya City Government, but in 2012, control was shifted to a private firm. The tipping cost began at 119,000 IDR/t in the first management year and increased yearly with 7% inflation in each prior year for the first nine years and 2% inflation for the next ten years [5]. Food waste accounts for 38.8% of landfilled waste, with the majority coming from houses, restaurants, supermarkets, and traditional markets-garden waste accounts for 21.1%, while plastic waste accounts for 13.3% [25]. Benowo Landfill now contains 7 million tons of landfilled waste. If current MSW management patterns continue, this condition has 13 years until it is set to close owing to exceeding maximum capacity.

## **2.3. SUMMARY**

In general, there is a scarcity of thorough, recorded, and published MSW data on a regional scale that may be investigated further in Indonesia. As a result, Surabaya was chosen as the pilot study to fill in the lacking data for future analysis in this research. In Indonesia, cities and regions are divided into four

categories: small, medium, big, and metropolitan, however, there is no strategic plan for each. As part of the execution of several legislation and directives, the government supports the use of WB, the replacement of TS for MRF, and the acceleration of the WtE program via the use of incinerators. Surakarta City's 450 t/d capacity incinerator and Surabaya City's 1,000 t/d capacity incinerator may be used as a model for implementation in Big and Metropolitan Areas.

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### **3. SURABAYA MODEL USING GIS TO ESTIMATE COST AND GHG EMISSIONS, FOCUSING ON REPLACEMENT OF TS TO MRF**

#### **3.1. INTRODUCTION**

One of the major criteria to be analyzed in developing the national plan of waste management in Indonesia is fuel for transportation. This criterion consists of the attributes of transportation distance from TS or MRF to the landfill, amount of transported waste, and the waste capacity that can be transported of each trip. However, Indonesia is facing a big problem in developing the national plan due to insufficient documented data on these attributes. The scarcity of thorough, recorded, and published MSW data on a regional scale which is required for comprehensive investigation is a major obstacle in developing MSW management strategies in Indonesia. Transportation distance between temporary waste disposal sites (TWDSs) to the landfill is the main issue to be addressed here. This data is unavailable unless directly analyzed from each collection point by the waste transportation truck during the routing to the landfill. The other possibilities are to have the coordinate of TWDSs, as the source, and the landfill, as the goal, along with the road network data then conduct a Geographic Information System (GIS) analysis to calculate the distance.

The prior research in MSW management of Surabaya City provided the complete required data to analyze the fuel for transportation aspect. Here, Surabaya Model is proposed to estimate the transportation cost of all routes of TWDS to landfill and its total cost to ensure the performance and usage of the available data and decide whether the model is possible as the base analysis to develop the national plan of waste management in Indonesia. Surabaya Model will show the city scale analysis with the alteration of TWDSs types and numbers, targeting MSW reduction at 30%.

According to Chapter 2.2 on waste management in Surabaya in the context of its MSW facilities and performance, MRF proved to be a better option in terms of material recovery. One factor to be considered when implementing MRF is that the cost would escalate since MRF utilizes many types of machinery, which will bring the operation and maintenance (OM) cost up in addition to the investment cost. Therefore, a complete upgrade from TS to MRF is not mandatory, yet an adequate distribution of unit numbers is principal. Though MRF appears to be a better option for a temporary waste disposal site, various aspects and criteria should be assessed before making any decision. A sustainable system for MSW management must be environmentally practical, economically affordable, and socially acceptable. Economically affordable means that MSW management systems must operate at acceptable costs to the community, which includes all private citizens, businesses, and government [12]. GHG emissions should also be considered, to investigate the contribution that will be given by implementing a new system in MSW management.

Consequently, to work along with Indonesia's target of MSW reduction, new, realistic, and reasonable strategies by adjusting the unit number of the existing temporary waste disposal sites are necessary to be analyzed. The objective of this chapter is to develop the Surabaya Model, before the nation-wide expansion model, by analyzing the current and newly proposed MSW system, focusing on replacing TS to MRF with 30% landfilled waste reduction as the target.

## **3.2. EVALUATION METHODS**

### **3.2.1. Field Survey of TSs, MRFs, and Landfill Coordinates**

As the required fundamental information to construct the Surabaya Model, coordinate of each concerned facility is needed to be obtained. The field survey was conducted by visiting all facilities and using the geotagging feature in *Garmin GPSMAP 64csx* to obtain coordinates of the locations. The field survey

covered 197 TSs, two MRFs, and *Benowo Landfill* in Surabaya. The collected information was utilized as attributes to develop the base map for the Surabaya Model and can be seen in Table A. 1 in APPENDICES.

### 3.2.2. Development of Base Map of Surabaya Model

The base map of the Surabaya Model is an integration of multiple layers of shapefiles to represent the actual geographical situation of Surabaya City itself. The map was developed using QGIS (Quantum GIS) version 2.18.20 ‘*Las Palmas*’ with its built-in GRASS (Geographic Resources Analysis Support System) GIS. We included various layers obtained from *OpenStreetMap.org*, an open-source detail map provider. The file extracted from the website was in the file extension of “.OSM”, a file type specific to OpenStreetMap file types, which then converted into shapefiles “.SHP” to make it usable in the QGIS. The layers are administrative boundaries, buildings, land uses, and road networks (Figure 3.1).

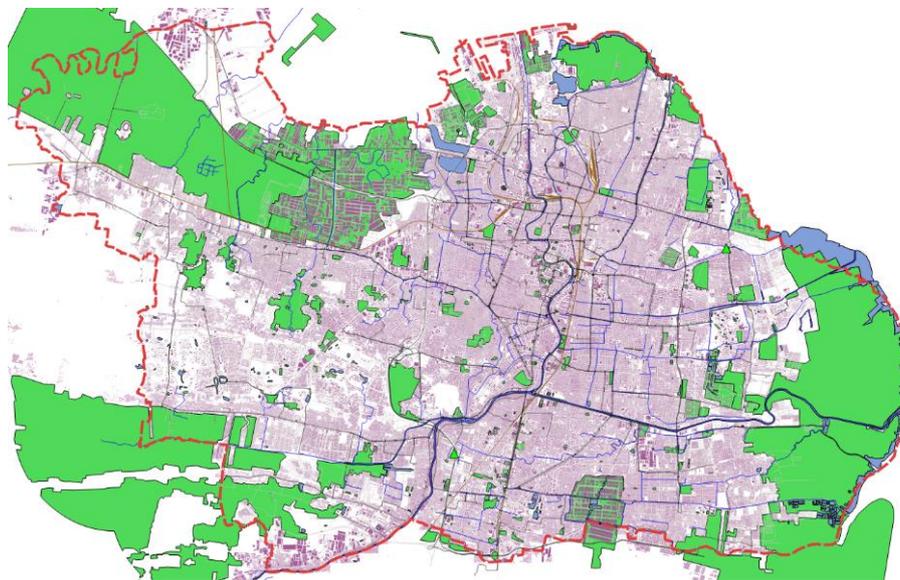


Figure 3.1 Stacked Layers of Surabaya City.

Upon the inspection, the road networks were found to be unusable as it is due to how vertices (corner) of each polygon (road) presented in QGIS were not as in a real situation, rendering some roads

inaccessible for the transportation analysis. There were two possible causes of this problem, there were gaps in the network and the road crosses, but the vertices were not joined (Figure 3.2). This problem can be corrected by adjusting the network vertices carefully, yet it contains loads of network data. The available road networks layer itself contains all levels of roads including small roads which were not used by the waste transportation trucks. Therefore, the selection of related road levels was required before the adjustment of the network vertices to be utilized as the main transportation network in further analysis.

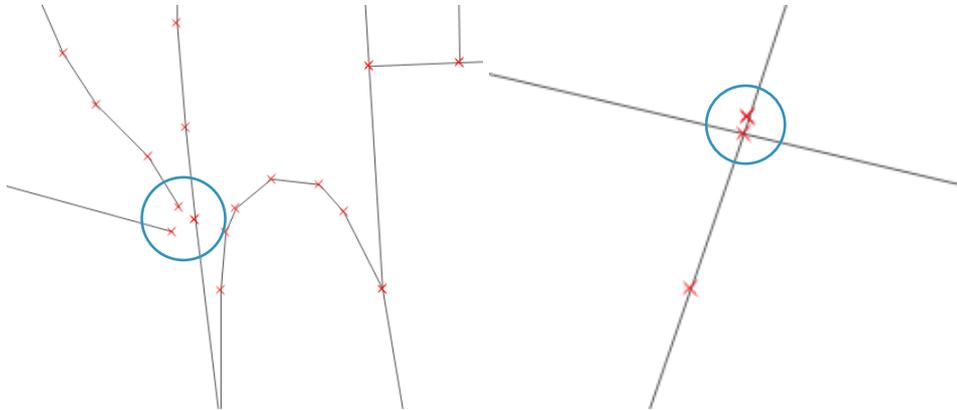


Figure 3.2 Road Network Problems.

**3.2.3. Interview for Main Transportation Network**

To simplify the transportation analysis, the main transportation network is required to be determined beforehand. The in-depth interview was carried out to all waste truck drivers in the dispatch station, questioning the actual route taken from the dispatch station to TS, landfill, other TS, landfill, and until it reaches back to the dispatch station. The interview gave us information regarding main transportation routes which were taken on actual waste transportation from each TS or MRF to the landfill and the transportation frequencies. The actual interview form result can be seen in Figure 3.3.

Nama Supir : Abdul Manaf      Jenis Truk : ARM ROLLER COMPACTOR      Tanggal Survey: 21/09/2015  
 No. Polisi : Bes4 TP      Tipe Truk : Pajak Ryan

No	Waktu	Rute
	06:30	<p>001 - STS - Tomokalisari - Tol Remo - Margomulyo - Tambak Osowalangun</p> <p>TPA - Benowo</p> <p>Tol Demak - Gayung - Gayung Kebonsari</p> <p>Ayani - Mayjend Sungkoro - Karang Barat - Duro Satellite - Osowalangun - Tomokalisari - TPA</p> <p>TPA - Benowo - Pakal -<sup>2</sup> Made - Lekar Santri - Udah Kelon</p> <p>TPA - Tol Remo - Margomulyo - Tanjung Sari - Pool</p>

Supir Truk: (Signature)  
 Surveyor: (Signature)

Figure 3.3 MSW Transportation Route Interview Form.

### 3.2.4. Integrating Results of Field Survey and Interview on Base Map

The base map of the Surabaya Model is finalized by integrating the result of the field survey of TSs, MRFs, and landfill, and interviews for the main transportation network. Doing so, we generated the ready to be utilized base map with all MSW facilities considered plotted in their corresponding coordinates to represent the current situation and the main transportation network with corrected network vertices for transportation route analysis in current and proposed scenarios (Figure 3.4).

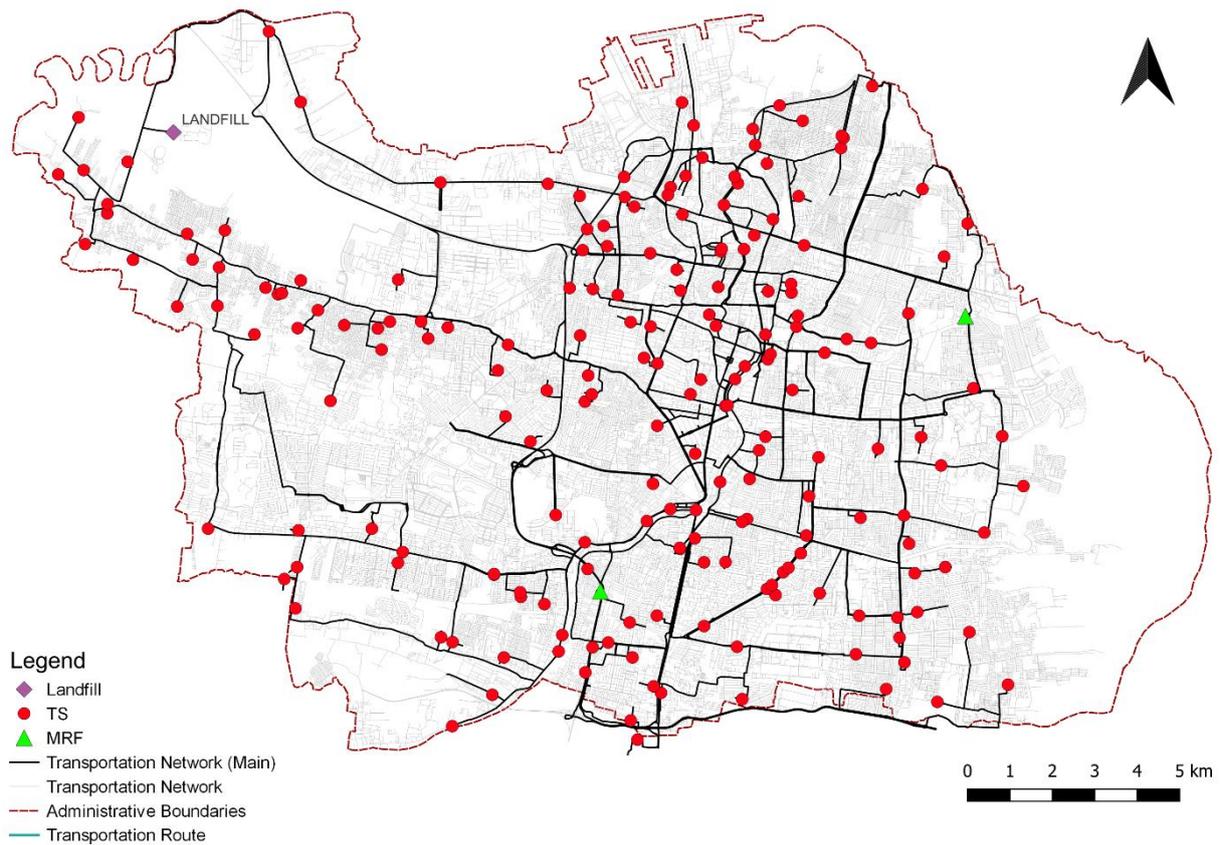


Figure 3.4 Base Map of Surabaya Model.

### 3.2.5. Scenario Setting

Four scenarios were prepared to conduct simulations to clarify the difference in the reduction of landfilled waste, GHG emissions, and overall cost requirement considering the alteration of the TWDS system with the focus on replacement of TS to MRF and the target of 30% landfilled waste reduction.

the scenario setting can be seen in Figure 3.5

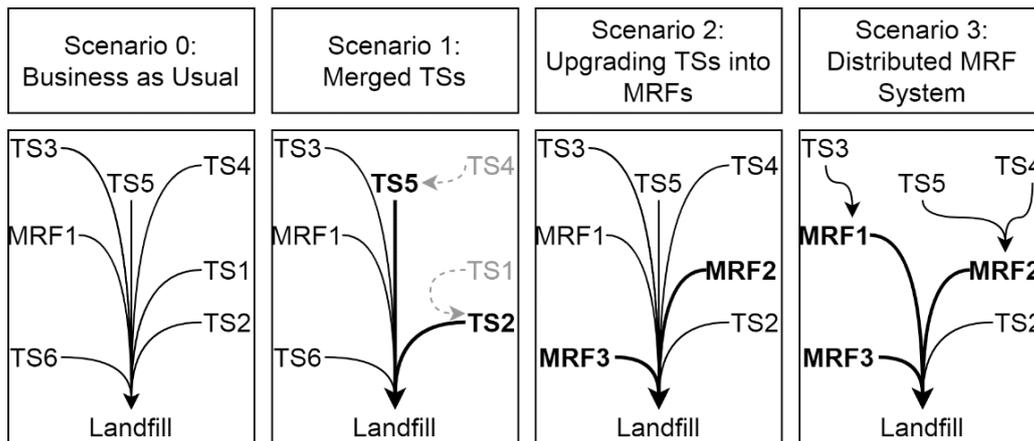


Figure 3.5 Scenario Setting of Surabaya Model.

- **Scenario 0: Business as Usual.** This scenario works as the base scenario to be compared later with other scenarios, visualizing the existing condition of the MSW management in Surabaya.
- **Scenario 1: Merged TSs.** Multiple TSs which are located nearby and have a small capacity are merged into one TS. This scenario was implemented to TSs with a transportation frequency of fewer than once a day and which are located within 1 km from each other. This was due to the reason of maintaining the collection coverage area in a reasonable portion since most of the waste collectors are using a handcart to collect the MSW. In this scenario, the TS located closer to the landfill will be chosen as the merged TSs.
- **Scenario 2: Upgrading TSs to MRFs.** Existing TSs with a high waste load that was pictured in the transportation frequency of 3–6 trips/day will be upgraded into MRFs with the same features as the existing one. There was no change in the transportation route in this scenario.
- **Scenario 3: Distributed MRF System.** As an addition to Scenario 2, after the upgrade of TSs into MRF, the TSs located nearby or those that will pass the MRF on its way to the landfill will undergo a route diversion from directly to the landfill to the MRF instead. In Scenario 2 and Scenario 3, 20 tons/day capacity of MRF was chosen as the standard referring to the capacity of the existing MRFs.

### 3.2.6. Transportation Route Analysis

- **MSW transportation distance from TS or MRF to landfill**

This analysis was established using the information integrated into the base map. The transportation route analysis visualized the transportation route from each TS or MRF to the landfill and its corresponding distance. The analysis to determine the route and distance from each TS or MRF to reach the landfill was done by using the algorithm of “*v.net.distance*” from *GRASS GIS* using the graphical modeler (Figure 3.6). TSs or MRFs are set as the *source* while the landfill was the *goal*, and the adjusted roads network was the *network* in this algorithm. Then the algorithms will compute the shortest distance via the network. The result of distance data was essential for further investigation to determine fuel for transportation based on the number of trips taken.

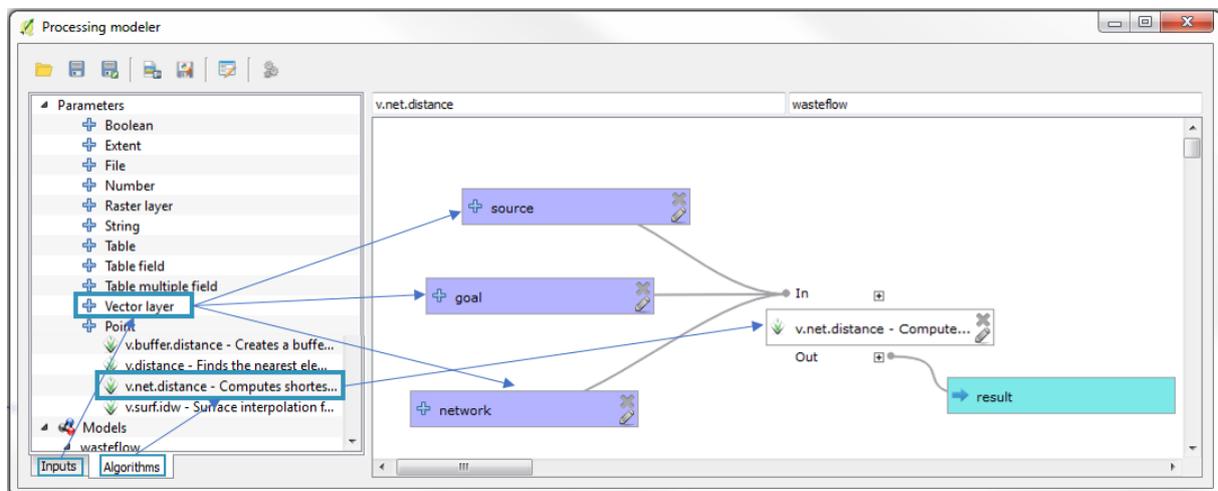


Figure 3.6 Algorithm Model in QGIS for Transportation Route and Distance in Surabaya Model.

- **Fuel for MSW transportation**

The fuel required for MSW transportation in this research was analyzed using the adaptation of prior research by [9] on diesel consumption as a function of distance to treatment plant: a collection of residual household (Figure 3.7).

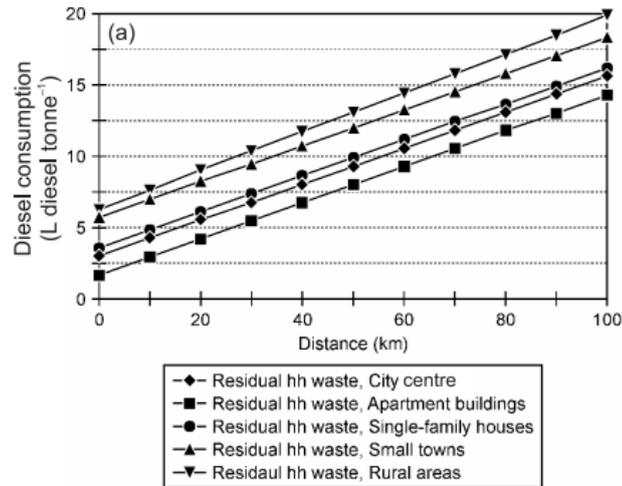


Figure 3.7 Diesel Consumption as a Function of Distance to Treatment Plant: Collection of Residual Household [9].

By reading the graph, we assumed the additional fuel required for each distance (Table 3.1). Due to the maximum distance at 41.7 km based on the transportation distance analysis, only up to 50km distance based on the graph is considered in this analysis. To simplify the calculation of fuel for MSW transportation, the average capacity of the truck has been set to 4 tons for this analysis. The fuel required was then calculated using the distance multiplied by the respective additional fuel per distance and added with the corresponding basic fuel as the lower limit. Fuel per trip can be obtained by multiplying the result by the truck capacity (Table A. 1 in APPENDICES).

Table 3.1 Additional Fuel per Distance Traveled for MSW Transportation in Surabaya Model.

Distance (km)	Basic Fuel (L)	Additional Fuel per Distance (L/km)
0	3.0	-
10	4.5	0.15
20	5.5	0.05
30	6.5	0.03
40	7.5	0.03
50	9.0	0.03

The modification of the MSW transportation routing system in Scenario 3 alters the transportation distance highly. Some TSs transported to the MRFs were considered discharging all their waste to the corresponding MRFs for further recovery, therefore the distance traveled from TSs might be lower compared to the original one to the landfill and the total distance traveled from MRFs will be higher due to the additional waste load from nearby TSs.

- **MSW transportation frequency**

The frequency of MSW transportation from temporary waste disposal sites to the landfill in each scenario was needed for the fuel cost analysis and as an indicator of the amount of landfilled waste. The transportation frequencies were obtained from the interview explained in Chapter 3.2.3. However, in Scenario 1-3, especially in altered TSs or MRFs, the transportation frequencies needed were based on the residue after reduction at the temporary waste disposal site of the corresponding system in each scenario. The comparison between the residue and the truck's capacity revealed the new transportation frequency.

### **3.2.7. Landfilled Waste Reduction Analysis**

This simulation was based on Scenario 0, where the capacity and transportation frequency of temporary waste disposal sites were appraised. Subsequently, referring to the scenario setting, the simulations in Scenario 1 to Scenario 3 were conducted under the respective constraint where 30% landfilled waste reduction was attained and under their specific preferences. The utilization of recyclable materials was considered corresponding to the specific amplification of recovered recyclable materials from each scenario. In this study, the market of inorganic recyclable materials was assumed to be enough; however, there will be a shortage of composting site capacity. For that, additional composting sites were added accordingly. An assumption of implementation of the same existing composting site with the most significant capacity was used to perform the analysis.

In both Scenario 2 and Scenario 3, the trial-and-error method was executed to get the expected result at 30% landfilled waste reduction. The new MRFs were assumed to have 20 tons/day capacity, and a recovery ratio of 78.4% for organic waste and 34.4% for inorganic waste, based on the average of both available MRFs. In Scenario 2, all TSs in the criteria were used, yet the result was still under 30%—extra upgraded TSs were added to get the optimal result closest to target. On the other hand, Scenario 3 required more analysis beforehand. Groups of TSs (and the existing MRFs) were made to fulfill the new MRF’s capacity. High load TSs were prioritized to be MRFs, and if there were remaining capacity, then nearby TSs joined as a group to transfer the residue to the MRF for further recovery.

- **Recovery rate**

The landfilled waste analysis was conducted by simulating the alteration of the temporary waste disposal site number. In this research, the alteration was assumed not to give any changes in the amount of waste generated and collected; and the recovery ratio of recyclable materials (Table 3.2) from MSW at TSs [17] and MRFs were expected to be the same while the recovery ratio of the new MRF proposed will be based on the average available MRFs [6].

Table 3.2 Recover Ratio of MSW Facilities in Surabaya Model.

MSW Facility	Recovery Ratio (%)		
	Organic	Inorganic	Total
TS [17]	-	3.4	3.4
MRF 1 [6]	58.2	9.3	67.5
MRF 2 [6]	55.4	4.8	60.1
New MRF	56.8	7.0	63.8

- **MSW Composition**

The MSW composition of household waste was adjusted based on prior research on Surabaya household MSW composition [4] so that the categorization of compositions was aligned with

landfilled waste composition [16]. The organic waste was split into food waste and garden waste based on the proportion of their share in landfill waste composition. Hazardous waste is considered as others in the original household waste composition while others in the adjusted household waste are the combination of wood and ash categories from the original household waste composition.

Table 3.3 Composition of Household, Landfill, and Adjusted Household Waste in Surabaya Model.

<b>Composition</b>	<b>Household Waste (%) [4]</b>	<b>Composition</b>	<b>Landfill Waste (%) [16]</b>	<b>Adjusted Household Waste (%)</b>
Organic	72.4	Food	38.8	46.9
Plastic	10.1	Garden	21.1	25.5
Paper	7.3	Plastic	13.3	10.1
Glass	1.7	Paper	4.2	7.3
Metal	1.4	Glass	0.8	1.7
Textile	2.7	Metal	0.3	1.4
Leather/Rubber	0.5	Textile	3.8	2.7
Wood	2.4	Leather/Rubber	1.0	0.5
Ash	1.5	Hazardous	0.2	0.1
Others	0.1	Others	16.6	3.9

- **Mass balance**

The mass balance was divided into five segments at most, depending on the scenario. The segments are TSs, MRF 1, MRF 2, New MRFs, and total. Each of the segments was separated into three parts, which are input, recovered, and residue with respective MSW compositions. These classifications were conducted as the preliminary arrangements for GHG emissions analysis.

The calculation was started and traced back based on the available data of total MRFs waste input at 10.1 and 3.1 t/d for MRF 1 and MRF 2 accordingly. The analysis was conducted at the annual level by assuming there are 365 days in a year. Multiplying the total input of MRFs by corresponding total recovery ratio in Table 3.2 gave the total recovered in MRFs, and multiplying it by adjusted

household waste composition in Table 3.3 gave the waste input amount for each component type in MRFs. With known each waste input amount, multiplying it by the organic and inorganic recovery ratio in Table 3.2 gave the recovered amount for each component type in MRFs. Then both total and each composition types of residues can be obtained by subtraction of known data.

The mass balance for TSs took a longer analysis by calculating the total waste input of TSs first. By having data on truck capacity (in m<sup>3</sup>) and transportation frequency, multiplying it with the density at 389.6 kg/m<sup>3</sup> [1] resulted in the residue amount (Table A. 1 in APPENDICES). The recovered amount was calculated using Eq. 3.1 and adding with the residue showed the total amount of TSs input. With the known total recovered amount, we generated the recovered amount of each composition by multiplying it by corresponding composition type and dividing them by the sum of all recovered compositions (plastic, paper, glass, and metal (20.5%)).

$$TS\ Recovered = Recovery\ Rate\ of\ TS \times TS\ Residue / (1 - Recovery\ Rate\ of\ TS)$$

Eq. 3.1.

The total residue of all segments assumed as landfilled residue and with landfill composition in Table 3.3, each landfilled residue amount by composition can be obtained. This result was used to trace back each TSs residue by composition type by subtracting it with both residue data in MRFs. The mass balance was completed by adding both recovered and residue of TSs by composition type to fulfill the input TS by composition type.

Scenario 1 has no difference in the MSW facility type and transportation system therefore there were no changes in the mass balance compared to Scenario 0. Scenario 2 upgraded TSs into new MRFs therefore the new MRFs data are according to the corresponding TSs which were upgraded. Scenario 3, on the other hand, modifies most of the balance due to MSW transportation system

alteration. TSs were grouped into TSs to landfill, TSs to MRF 1, TSs to MRF 2, and TSs to New MRFs; to determine the total input MSW for each group. The composition of input MSW in TSs to landfill and TSs to New MRFs group were considered the same as original TSs for they were based on TSs. The other groups were having their input MSW composition changed into the average MSW composition of both TSs and the respective MRF. The rest of the mass balance calculation was conducted with the corresponding recovery ratio in Table 3.2.

- **Landfill lifetime**

Referring to the result shown by [11], the *Benowo Landfill* reached 7,183,027 tons of landfilled MSW in 2017 with average annual disposal at 478,868 t/y. The landfill was stated to be closed due to fully maximized capacity in 2030, giving 13 years left for the operation. Then, implementing the average annual disposal for the blank years, a total capacity of the landfill could be assumed. The extension of landfill lifetime analysis was conducted using the reduction of waste in each condition and the assumption that if the reduction state is being kept throughout the upcoming years, the time required to fill the site could be obtained.

### **3.2.8. GHG Emissions Analysis**

The GHG emissions analysis was done by utilizing the GHG Calculator for Solid Waste ver. II-2013 model, from the Institute for Global Environmental Strategies (<https://iges.or.jp/en/pub/ghg-calculator-solid-waste-ver-ii-2013>), which is an adaptation of the 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories with adjustments to be focused on the Asia-Pacific region. The availability of country and climate feature options gives the user a more accurate parameter to be used in the analysis. The country and its climate zone selection available at the beginning of the model gave an exact parameter for the study case. In this study, “Indonesia” and “moist and wet tropical” were selected as country and climate zone, respectively. Other than that, the amount

of waste, fuel consumption, the composition of waste, energy consumption, and compost production are the essential parameters to execute the simulation. Three activities are measured in the analysis, transportation, landfilling of mix MSW, and composting. The calculator will run itself after we inputted the required attributes and will generate the summary of GHG emissions from respective activities (Figure 3.8). However, since the results were in kgCO<sub>2</sub>e/t of corresponding loads of attribute (waste/mix-waste/organic-waste), it was necessary to modify it into annual GHG emissions in tCO<sub>2</sub>e/y by using Eq. 3.2. Attribute *waste* represents total waste transported, *mix-waste* represents total waste landfilled, while *organic waste* represents total composted food and garden waste.

**Summary of GHG emissions from your municipality**

Activity	Direct GHG Emissions	Indirect GHG Savings	Net GHG Emissions	Unit
Transportation	13.15	0.00	13.15	kg of CO <sub>2</sub> -eq/tonne of waste
Landfilling of mix MSW	844.69	0.00	844.69	kg of CO <sub>2</sub> -eq/tonne of mix waste
Composting	177.52	1164.87	-987.34	kg of CO <sub>2</sub> -eq/tonne of organic waste
Anaerobic digestion	0.00	0.00	0.00	kg of CO <sub>2</sub> -eq/tonne of organic waste
Mechanical Biological Treatment (MBT)	0.00	0.00	0.00	kg of CO <sub>2</sub> -eq/tonne of waste
Recycling	0.00	0.00	0.00	kg of CO <sub>2</sub> -eq/tonne of mixed recyclables
Incineration	0.00	0.00	0.00	kg of CO <sub>2</sub> -eq/tonne of incinerated waste
Open burning	0.00	0.00	0.00	kg of CO <sub>2</sub> -eq/tonne of open burned waste
<b>GHG emission from whole system</b>	<b>843.57</b>	<b>24.92</b>	<b>818.65</b>	<b>kg of CO<sub>2</sub>-eq/tonne of collected waste</b>

Figure 3.8 Example of Summary Results from GHG Calculator in Surabaya Model.

$$Annual\ GHG\ Emissions = Direct\ GHG\ Emissions \times Attribute\ Load \times \frac{12}{1,000}$$

Eq. 3.2.

In the model, the values of global warming potential for CH<sub>4</sub> and N<sub>2</sub>O are based on the IPCC Second Assessment Report (SAR) at 21 kg-carbon dioxides (CO<sub>2</sub>)/kgCH<sub>4</sub> and 310 kgCO<sub>2</sub>/kgN<sub>2</sub>O. However, the value was updated in the IPCC Third Assessment Report, 2001 (AR3), IPCC Fourth Assessment Report, 2007 (AR4), and the IPCC Fifth Assessment Report, 2014 (AR5). The most recent values are at 28 kg-CO<sub>2</sub>e/kgCH<sub>4</sub> and 265 kgCO<sub>2</sub>e/kgN<sub>2</sub>O [8]. However, in this research, the values from the SAR were used.

The model will generate direct GHG emissions for every activity evaluated. However, the value will be in kgCO<sub>2</sub>e/t-handled-waste. The result of GHG emissions from landfilling of mix MSW analysis will be in kgCO<sub>2</sub>e/t mix waste, composting activity in kgCO<sub>2</sub>e/t composted waste, and transportation activity in a combination of both (kgCO<sub>2</sub>e/t total waste) for each is transported using the same vehicle. Then, the result of GHG emissions for every activity (in the unit of tCO<sub>2</sub>e/y) can be obtained by multiplying the direct GHG emissions and the amount of waste handled.

- **Transportation activity**

One of the essential points in the calculation of GHG emissions from transportation is the total amount of fossil fuel consumption. Since all waste transportation trucks in Surabaya are assumed to be diesel-fueled, the calculation for natural gas-fueled trucks is ignored. Diesel consumptions were calculated based on the distance traveled from each TS or MRF to the landfill site in Chapter 3.3.1. The total amount of waste transported in each scenario was required in this analysis, which was acquired from the landfilled waste analysis in Chapter 3.3.2. The GHG emissions from transportation activity then calculated using the following equation:

$$Emission_r = \frac{Fuel}{Waste} \times Energy \times EF$$

Eq. 3.3.

Where:

Fuel : Total amount of fossil fuel consumption (L)

Waste : Total amount of waste transported (t)

Energy : Energy content of the fossil fuel (Diesel: 36.42 MJ/L)

EF : CO<sub>2</sub> emission factor of the fuel (Diesel: 0.074 kgCO<sub>2</sub>/MJ)

- **Landfilling of mix MSW activity**

In the analysis of mixed waste landfilling, total residue transported to the landfill (Chapter 3.2.2), the total amount of diesel fuel used for the operation of machinery at the landfill, and the composition of mixed waste landfilling were considered [16]. Both the total landfilled waste and its composition were obtained from the landfilled waste analysis in Chapter 3.2.2, while landfill operation fuel usage in every scenario was assumed based on the study of [15] on diesel consumption during the operation process of a landfill site at 1.38 L/t-waste. Methane (CH<sub>4</sub>) emitted from landfilling of each ton of waste was analyzed by simulating CH<sub>4</sub> emissions generated per year on waste landfilled per year.

The emissions from operation activity are assessed by the fossil fuel used per organic waste disposed of, then multiplied by both energy content and emission factor of the diesel. Afterward, these two parameters were calculated together with the global warming potential of CH<sub>4</sub> to get the emissions from mix MSW landfilling. The GHG emissions from landfilling of mixed MSW activity were then calculated using the following equation:

$$Emission_L = E_{CH_4} \times GWP_{CH_4} + E_O$$

Eq. 3.4

Where:

$E_{CH_4}$  : CH<sub>4</sub> emission per ton waste (kgCH<sub>4</sub>/t waste)

$GWP_{CH_4}$  : Global warming potential of CH<sub>4</sub> (21 kgCO<sub>2</sub>/kgCH<sub>4</sub>)

$E_O$  : Emission from operation activity (kgCO<sub>2</sub>)

- **Composting activity**

The calculation of GHG emissions from composting activity required more precise data on food waste and garden waste composted for the input which was provided by prior analysis of mass

balance and its composition in Chapter 3.3.2. Fuel used for operational activities and the total compost produced were determined based on the number of composting sites in the respective scenario. Fuel used for operational activities was stated in Table 3.5 in Chapter 3.2.9 while total compost produced was assumed to be at 5 t/month for total food waste composted at 150 t/month and garden waste composted at 82 t/month in Scenario 0. The other scenarios were using direct comparison based on the amount of composting material. For compost demand in Surabaya estimated to be over the compost generated, 100% usage was assumed.

CH<sub>4</sub> emissions during organic waste degradation in this study were set at 0.4 kgCH<sub>4</sub>/t as the average value given by [5] as well as the nitrous oxide (N<sub>2</sub>O) emissions at 0.3 kgCH<sub>4</sub>/t. Both the emissions from the degradation and the operation are examined by considering the total waste composted and the total fuel consumption during the operation. The GHG emissions from composting activity were then calculated using the following equation:

$$Emission_c = \left( \frac{Fuel}{Waste} \times Energy \times EF \right) + (E_{CH_4} \times GWP_{CH_4} + E_{N_2O} \times GWP_{N_2O})$$

Eq. 3.5.

Where:

Fuel : Total amount of fossil fuel consumption (L)

Waste : Total amount of waste composted (t)

Energy : Energy content of the fossil fuel (Diesel: 36.42 MJ/L)

EF : CO<sub>2</sub> emission factor of the fuel (Diesel: 0.074 kgCO<sub>2</sub>/MJ)

E<sub>CH<sub>4</sub></sub> : Emissions of CH<sub>4</sub> during organic waste degradation (kgCH<sub>4</sub>/t waste)

GWP<sub>CH<sub>4</sub></sub> : Global warming potential of CH<sub>4</sub> (21 kgCO<sub>2</sub>/kgCH<sub>4</sub>)

E<sub>N<sub>2</sub>O</sub> : Emissions of N<sub>2</sub>O during waste degradation (kgN<sub>2</sub>O/t waste)

GWP<sub>N<sub>2</sub>O</sub> : Global warming potential of N<sub>2</sub>O (310 kgCO<sub>2</sub>/kgN<sub>2</sub>O)

### 3.2.9. Cost Analysis

Total cost would be the main comparison between each scenario and Scenario 0. The annual total cost comprises the investment cost, operation and maintenance (OM) costs, fuel for transportation cost, tipping for landfilling cost, and the subtraction of recyclable revenue from the selling of recovered materials (Eq. 3.6).

$$Total\ Cost = I_C + OM_C + F_{TC} + T_C - R_R$$

Eq. 3.6.

Where:

$I_C$  : Annual investment cost (IDR/y)

$OM_C$ : Annual operation and maintenance cost (IDR/y)

$F_{TC}$  : Fuel for transportation cost (IDR/y)

$T_C$  : Tipping for landfilling cost (IDR/y)

$R_R$  : Revenue from the sales of recyclables (IDR/y)

- **Investment cost**

The investment cost of both building and equipment is considered by the lifetime of these aspects as well (Eq. 3.7). In this study, building lifetime ( $B_L$ ) was assumed to be 20 years while equipment lifetime ( $E_L$ ) was assumed to be 10 years. However, since there will not be any improvement in either the MRF or composting site unit in Scenario 0 and Scenario 1, the investment cost will only consider the existing units for the calculation. The details on investment cost can be seen in Table 3.4.

$$I_C = \frac{B_C}{B_L} + \sum_{i=1}^n (EQ_{C_i} \times \frac{B_L}{E_{L_i}})$$

Eq. 3.7.

Where:

$I_C$  : Annual investment cost (IDR/y)

$B_C$  : Building cost (IDR)

$B_L$  : Building lifetime (y)

$EQ_{C_i}$  : Cost of equipment i (IDR)

$EQ_{L_i}$  : Lifetime of equipment i (y)

Table 3.4 Details on Investment Cost (in million IDR) in Surabaya Model.

Details	Cost	Unit	Cost	Depreciation Time (y)	Depreciation Cost (million IDR/y)
<b>MRF</b>					
Building	480.0	1	480.0	20	24.0
Shredder	22.8	2	45.7	10	4.6
Conveyor Belt (54m)	693.0	2	1,386.0	10	138.6
Baler	65.0	2	130.0	10	13.0
<b>Total</b>	<b>1,260.8</b>		<b>2,041.7</b>		<b>180.2</b>
<b>Composting Site</b>					
Composting Area	960.0	1	960.0	20	48.0
Screen Plant	271.0	2	542.0	10	54.2
Shredder	22.8	2	45.7	10	4.6
<b>Total</b>	<b>1,253.8</b>		<b>1,547.7</b>		<b>106.8</b>

\*1 USD = 14,800 IDR (based on 2020 estimate)

- **OM cost**

OM cost was calculated based on the guidelines provided by [12] considering salary of the workers, maintenance cost of equipment, fuel for machinery, and electricity required which is shown in Eq. 3.8. Due to insufficiently precise data, especially in TSSs, OM cost was analyzed by focusing on the

existing and additional MRFs and composting sites. Similarly, analysis of OM cost in Scenario 0 and Scenario 1 will only cover the existing MRFs and composting sites. Specifically, for the new MRFs in Scenario 2 and Scenario 3, there was no alteration to the existing workers, for they are assumed to keep working on the collection, yet the waste separation workers and those who work inside the MRF building were considered and calculated in the OM cost. The maintenance ratio for machinery was estimated at 5% of the investment cost [1]. The details on OM cost can be seen in Table 3.5.

$$OM_C = (S \times N \times W) + \left( \sum_{i=1}^n (M \times EQ_{C_i}) \times W \right) + \left( F_C \times \sum_{i=1}^n FN_i \times EQ_{W_i} \right) + \left( EL_C \times \sum_{i=1}^n (P_i \times EQ_{W_i}) \right)$$

Eq. 3.8.

Where:

$OM_C$  : Annual operation and maintenance cost (IDR/y)

$S$  : Salary (IDR/person/y)

$N$  : Number of workers (person)

$W$  : Working period (y)

$M$  : Maintenance ratio (5%/y)

$EQ_{C_i}$  : Cost of equipment  $i$  (IDR)

$F_C$  : Fuel cost (5,150 IDR/L)

$FN_i$  : Fuel needed for equipment  $i$  (L/y)

$EQ_{W_i}$  : Working period of equipment  $i$  (y)

$EL_C$  : Electricity cost (1,343 IDR/kWh)

$P_i$  : Electric power of equipment  $i$  (kW)

Table 3.5 Details on Operation and Maintenance Cost in Surabaya Model.

Details	Cost	Unit
<b>MRF</b>		
Monthly Salary	3,500,000	IDR/month/person
Number of Workers	13	person
Working Period	240	month/20 y
<b>Salary</b>	<b>10,920,000,000</b>	<b>IDR/20 y</b>
Machinery Maintenance Ratio	5	%/y
Shredder Maintenance	2,282,500	IDR/y
Conveyor Belt (54m) Maintenance	69,300,000	IDR/y
Baler Maintenance	6,500,000	IDR/y
<b>Maintenance Cost</b>	<b>1,561,650,000</b>	<b>IDR/20 y</b>
Fuel Price	5,150	IDR/L
Fuel Needed for Machinerics	5.7	L/d
Working Days	7,300	d/20 y
<b>Fuel Cost</b>	<b>214,291,500</b>	<b>IDR/20 y</b>
Electricity Price	1,343	IDR/kwh
Water Pump Power	0.15	kw/h
Water Pump Working Time	2	h/d
Water Pump Working Days	7,300	d/20 y
<b>Water Pump Operational Cost</b>	<b>2,941,126</b>	<b>IDR/20 y</b>
Lamp Power	0.2	kw/h
Lamp Working Time	8	h/d
Lamp Working Days	7,300	d/20 y
<b>Lamp Operational Cost</b>	<b>15,686,006</b>	<b>IDR/20 y</b>
Computer Power	0.5	kw/h
Computer Working Time	8	h/d
Computer Working Days	7,300	d/20 y
<b>Computer Operational Cost</b>	<b>39,215,016</b>	<b>IDR/20 y</b>
<b>Total OM cost</b>	<b>12,753,783,649</b>	<b>IDR/20 y</b>
	<b>637,689,182</b>	<b>IDR/y</b>
<b>Composting Site</b>		
Monthly Salary	3,500,000	IDR/month/person
Number of Workers	7	person
Working Period	240	month
<b>Salary</b>	<b>5,880,000,000</b>	<b>IDR/20 y</b>

<b>Details</b>	<b>Cost</b>	<b>Unit</b>
Machinery Maintenance Ratio	5	%/y
Screen Plant Maintenance	27,100,000	IDR/y
Shredder Maintenance	2,282,500	IDR/y
<b>Maintenance Cost</b>	<b>587,650,000</b>	<b>IDR/20 y</b>
Fuel Price	5,150	IDR/L
Fuel Needed for Machinery	1.5	L/d
Working Days	7,300	d/20 y
<b>Fuel Cost</b>	<b>56,392,500</b>	<b>IDR/20 y</b>
Electricity Price	1,343	IDR/kwh
Water Pump Power	0.15	kw/h
Water Pump Working Time	2	h/d
Water Pump Working Days	7,300	d/20 y
<b>Water Pump Operational Cost</b>	<b>2,941,126</b>	<b>IDR/20 y</b>
Lamp Power	0.2	kw/h
Lamp Working Time	8	h/d
Lamp Working Days	7,300	d/20 y
<b>Lamp Operational Cost</b>	<b>15,686,006</b>	<b>IDR/20 y</b>
<b>Total OM cost</b>	<b>6,542,669,633</b>	<b>IDR/20 y</b>
	<b>327,133,482</b>	<b>IDR/y</b>

\*1 USD = 14,800 IDR (based on 2020 estimate)

- **Fuel for transportation cost**

Transportation cost is a calculation of fuel costs required in the transportation frequency of waste trucks. The current trucks and drivers were assumed to not be affected by the alteration of MSW facilities and will continue to work as it is since one driver (and the truck) was not assigned to one specific TS or MRF only. Instead, the modification in MSW facility number and MSW system directly affects the fuel required for transportation based on the distance and reduction in the corresponding MSW facilities.

Determination of fuel for transportation cost per trip was a continuation of fuel for MSW transportation analysis started in Chapter 3.2.6. The obtained fuel per trip was then valued by the

fuel price at 5,150 IDR/L prices for diesel fuel [1] with the assumption of no price fluctuation over the years. Transportation costs in all scenarios were calculated based on the multiplication of fuel for transportation cost per trip by the respective transportation frequency. The complete database for fuel for transportation cost in the form of cost/trip can be found in Table A. 1 in APPENDICES.

- **Tipping for landfilling cost**

The tipping for landfilling cost was determined at 155,985 IDR/t, based on the actual tipping cost in 2018 [9], to be used in the complete analysis and the annual inflation assumed to be ignored. This will be calculated based on the landfilled waste analysis on the amount of waste landfilled calculated by the landfilled waste analysis in Chapter 3.3.2.

- **Recyclable revenue**

The calculation for recyclable revenue was based on the amount of each component of recovered recyclables from landfilled waste analysis in Chapter 3.3.2 and the price list of recyclables from Surabaya Central Waste Bank. The recyclables then were grouped into plastic, paper, glass, and metal as to how recovered materials were classified in the waste composition. The total amount of recovered recyclables of each recyclable composition was then specified based on the price list of recovered recyclables in Surabaya Central Waste Bank (Table 3.6) and valued accordingly to obtain total recyclable revenue. In the calculation of revenue, the item proportion in each group was used to elaborate on the composition of recovered materials; therefore, the precise value in each scenario could be acquired. Direct cash in value was assumed for all items to show the least possible revenue.

Table 3.6 Details on Price List of Recovered Recyclables Surabaya Central Waste Bank.

	<b>Item</b>	<b>Percentage (%)</b>	<b>Value (IDR/t)</b>
	Clear Plastic	3.8	1,000,000
	Plastic Bag	3.2	300,000
	Thin Screen-Printed Plastic	2.5	300,000
	Multi-layer Packaging	3.4	250,000
	Thick Screen-Printed Plastic	1.7	250,000
	Colored Thick Plastic Glass	1.1	5,500,000
	Plastic Glass (Clean)	3.1	5,500,000
	Plastic Glass (Dirty)	2.4	3,500,000
	Clear PET (Clean)	18.3	3,300,000
	Clear PET (Dirty)	3.1	2,300,000
	Blueish PET (Clean)	6.6	2,300,000
	Blueish PET (Dirty)	0.2	1,300,000
<b>Plastic</b>	Green/Dark Blue PET (Clean)	1.0	1,500,000
	Green/Dark Blue PET (Dirty)	0.2	1,000,000
	Mix Plastic Lid	3.8	3,300,000
	Mixed Tub	23.8	2,000,000
	Polypropylene	5.8	2,000,000
	Black Bucket	1.1	1,000,000
	Hard Plastic	11.5	200,000
	Plastic Strap	0.4	500,000
	CD	0.3	3,300,000
	Hose	0.0	200,000
	PVC Pipe	0.4	400,000
	Plastic Sack (25kg)	2.0	200,000
	Plastic Sack (50kg)	0.3	500,000
	Plastic Sack (100kg)	0.1	1,000,000
	Cardboard (Good Condition)	27.9	1,300,000
	Cardboard (Bad Condition)	8.1	1,000,000
	Newspaper	3.8	2,500,000
<b>Paper</b>	HVS Paper	14.0	2,200,000
	Recycled Paper	12.6	1,000,000
	Paper Sack	0.7	1,300,000
	Duplex Paper	32.9	400,000
<b>Glass</b>	Syrup Bottle	61.4	100,000

	<b>Item</b>	<b>Percentage (%)</b>	<b>Value (IDR/t)</b>
	Sauce Bottle	8.1	400,000
	Gasoline Bottle	0.9	1,000,000
	Beer Bottle	5.6	600,000
	Colored Glass Bottle/Shard	8.1	50,000
	Clear Glass Bottle/Shard	15.9	150,000
	Copper	0.1	40,000,000
	Brass	0.1	20,000,000
	Bronze	0.4	6,500,000
	Aluminum Plate	0.7	9,500,000
	Aluminum Elbow	0.5	9,500,000
	Aluminum Skillet	1.3	9,500,000
<b>Metal</b>	Aluminum Pot	2.6	8,500,000
	Aluminum Can	0.4	7,500,000
	Thick Iron	17.4	2,200,000
	Thin Iron	34.1	1,500,000
	Nail/Bicycle	0.6	1,000,000
	Can	36.3	1,000,000
	Zinc	5.6	500,000

\*1 USD = 14,800 IDR (based on 2020 estimate)

### 3.3. RESULTS AND DISCUSSION

#### 3.3.1. Transportation Route, Total Distance, and Fuel Saving

The collective result on MSW transportation distance from TS or MRF to landfill, fuel for MSW transportation, and MSW transportation frequency can be seen in Table 3.7. Both transportation frequency and distance were shown as total in each scenario, while fuel for MSW transportation was presented as the reduction of fuel required in comparison to BAU (Scenario 0). The complete results of each aspect on every temporary waste disposal site (TWDS) can be seen in Table A. 1 in APPENDICES.

Table 3.7 Details on Transportation Route Analysis Result.

Details	SC 0	SC 1	SC 2	SC 3
Transportation Frequency (times/y)	96,540	96,415	68,173	94,596
Fuel saving (L/y)	0	2,757	645,126	209,161
Total Distance (km/y)	2,114,328	2,111,448	1,469,179	1,745,639

The existing transportation route, depicted in Figure 3.9, gives the basic situation (**Scenario 0**) before any changes were simulated. **Scenario 1** (Figure 3.10) gave slight improvements in terms of optimizing the transportation frequency (125 times fewer transportation frequency per year) and shortening the distance (2,880 km/y), which lowered the fuel usage by 2,757 L/y. Hypothetically, Scenario 1 was supposed to increase the waste transportation frequency, but the analysis result shows the opposite. Reduced transportation frequency was noted since the merged TSs have different sizes of waste containers, and a larger container was chosen for further analysis.

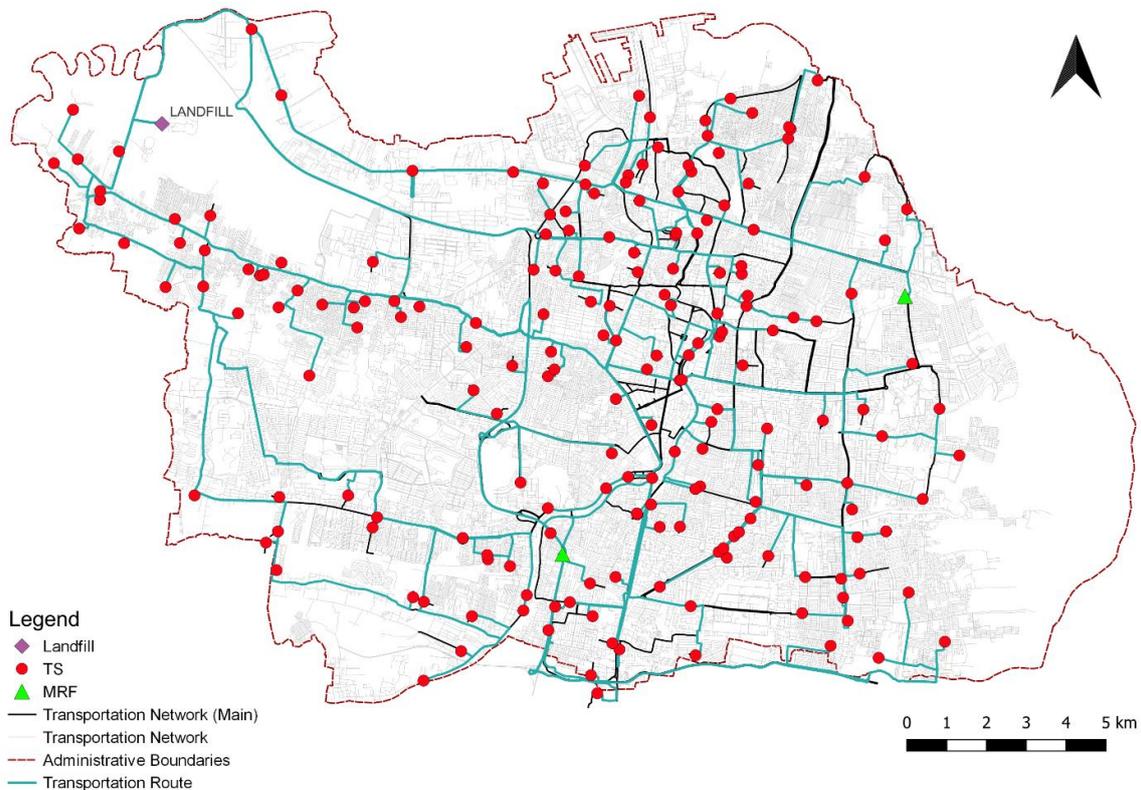


Figure 3.9 Existing Condition (Scenario 0) of MSW Management in Surabaya Model.

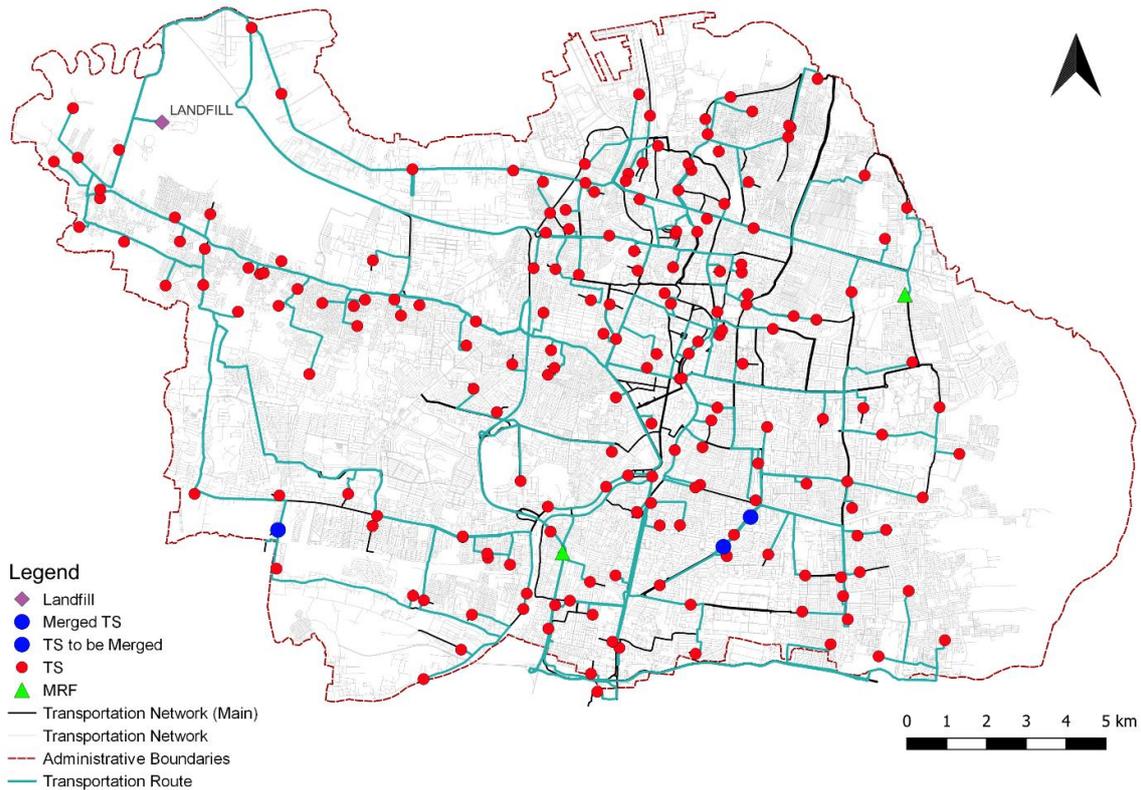


Figure 3.10 Transportation Route of MSW System in Scenario 1 in Surabaya Model.

Merging the TSs and optimizing waste transportation also prevents overnight stationed waste at the temporary waste disposal sites, therefore lessening the risk of any waste-derived diseases. The restraint on the waste collection coverage area limited the possibility of having more merged TSs. Numbers of TSs seemed to be in the required distance, yet in existence, they were separated by the river or drainage with no short access to reach the other location easily.

**Scenario 2** (Figure 3.11) reduced transportation distance by 645,150 km/year (= 2,114,328 km/y–1,469,179 km/y) as an outcome of the higher recyclable waste recovery ratio in MRFs. Less landfilled waste decreased the waste transportation frequency by 28,367 times and saved 645,126 L/year worth of fuel supply.

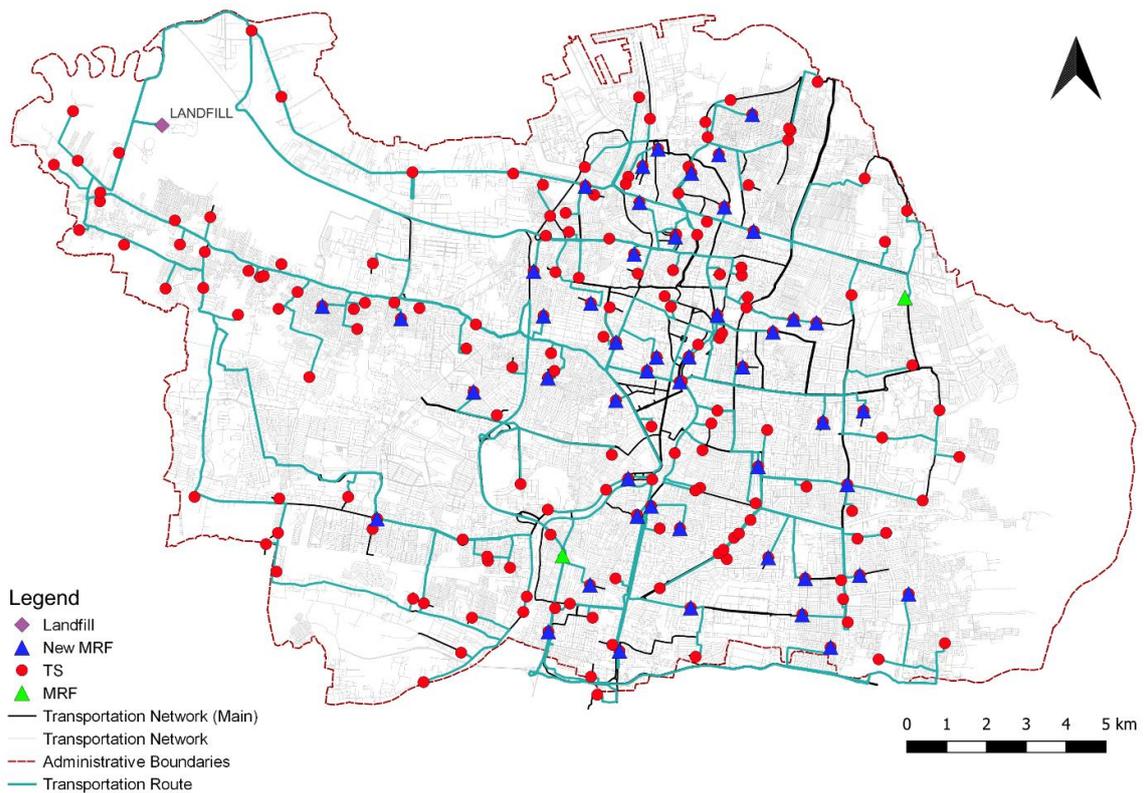


Figure 3.11 Transportation Route of MSW System in Scenario 2 in Surabaya Model.

In comparison to Scenario 2, **Scenario 3** needed 1.4 times more transportation frequency, and the total distance traveled was 1.2 times greater because of accommodating the transportation of waste from several TSs to the MRFs. The requisite transportation from TS to MRF and then to landfill caused the inevitably higher needs of fuel and total transportation frequency. The remarkable results from the alteration of the temporary waste disposal site type in Scenario 3 are visualized in Figure 3.12.

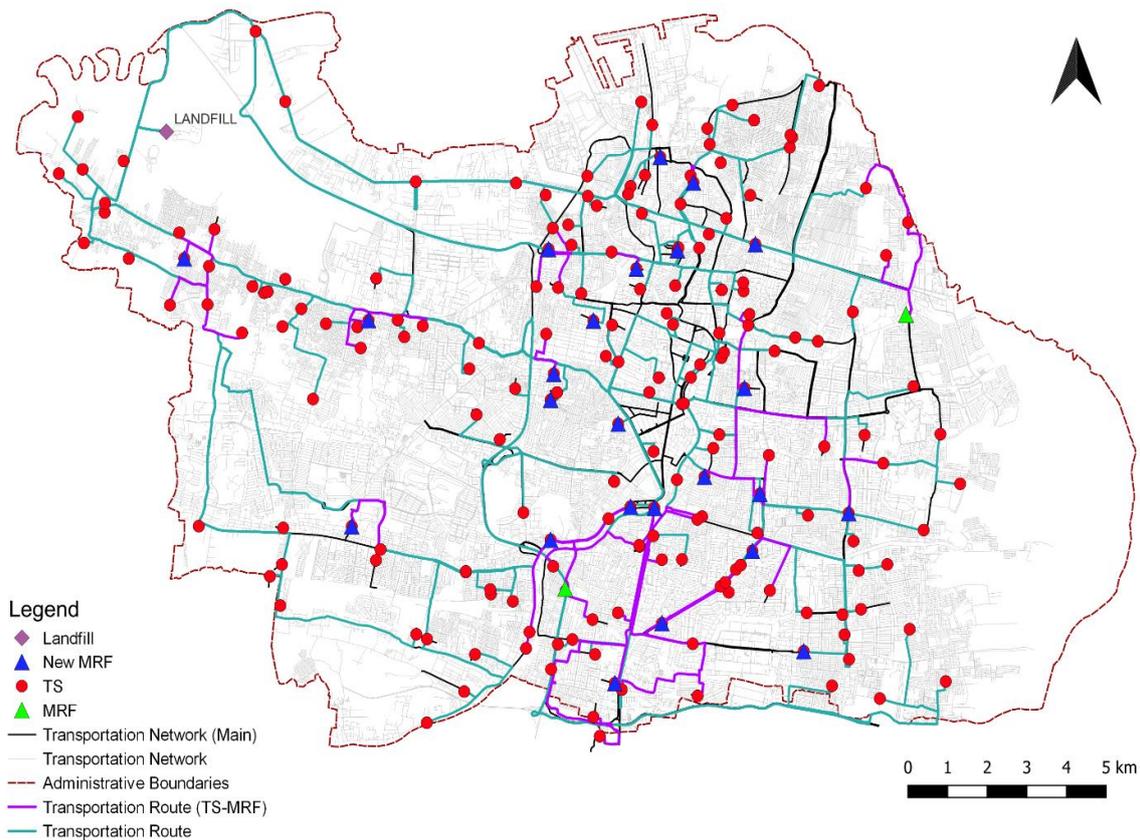


Figure 3.12 Transportation Route of MSW System in Scenario 3 in Surabaya Model.

### 3.3.2. Landfilled Waste

The alteration of TS, MRF, and composting site numbers were calculated considering the constraints and achievement of the target of landfilled waste reduction at 30% using mass balance considering actual data on MRFs, each recovery rate, and compositions in different segments. The complete mass balance analysis in each scenario including the input, recovered, and residue to be transported to the landfill could be seen from Table A. 2 to Table A. 15 in APPENDICES. The summary result of the landfilled waste analysis is shown in Table 3.8.

Table 3.8 Summary of Landfilled Waste Analysis Result in Surabaya Model.

Details	SC 0	SC 1	SC 2	SC 3
TS (unit)	197	194	149	173
MRF (unit)	2	2	50	26
Composting Site (unit)	24	24	44	44
MSW Reduction (t/y)	19,111	19,111	140,746	141,964
MSW Landfilled (t/y)	455,126	455,126	333,491	332,273
Landfill Lifetime (y)	13	13	19	19

**Scenario 0: Business as Usual**, deals with 455,126 t/y of MSW with two units of MRFs and 197 units of TSs which recover 19,111 t/y of recyclable materials (4%). Currently, there are 24 composting sites with some unused capacity, creating an opportunity for the other scenarios to make the best out of it. The waste flow of Scenario 0 can be seen in Figure 3.13.

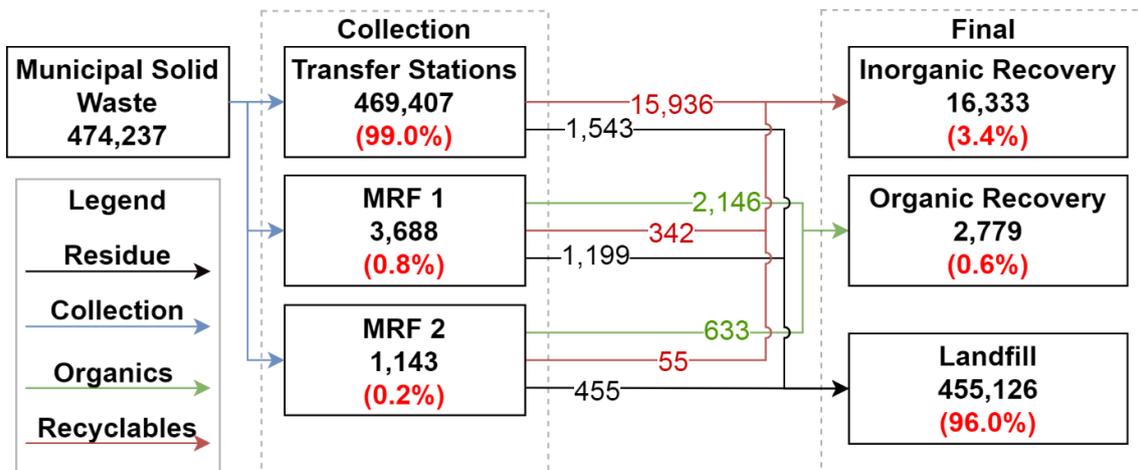


Figure 3.13 Waste Flow in Scenario 0 and Scenario 1 (in t/y) in Surabaya Model.

**Scenario 1: Merged TSs**, has only six units that fulfilled the constraints and no further enhancement could be added. Therefore, six TSs with the transportation frequency of once every 2–7 days were merged into three TSs. TSs with a closer location to the landfill was chosen as the merging locations. The final number of TWDSs will be at 194 units of TSs and the number of MRF stays the same. The result shows no change in waste composition in any stage or improvement of MSW reduction because

of the identical system between the merged units, yet optimum transportation frequency was achieved. Figure 3.13 also represents the waste flow in Scenario 1. Combining the TSs will prevent the waste from being stationed for too long nearby the residential area, which will be a threat of airborne, animal-borne, and/or waterborne disease. With the absence of MSW, the odor and cleanliness quality will be improved accordingly.

The waste flow of **Scenario 2: Upgrading TSs to MRFs** is shown in Figure 3.14. Scenario 2 upgraded 17 TSs and improved the MSW reduction to 20% with high loads. For this reason, 20 additional TSs with 2 trips/day were needed to push the landfilled waste reduction up to 30%. A total of 50 MRFs show a surge of MSW recovery to 7.4 times more. Food and garden waste composed 81.6% of the recovered material and it diverted the amount of landfilled organic waste into composting treatment facilities. For this reason, 20 additional units of the composting site are needed. The major changes in the recovery of organic materials modified the composition balance to have a less organic portion (Table 3.9) in comparison to the existing landfilled waste composition [16]. The remaining 18.4% is the shares of plastic, paper, glass, and metal, which ended up in the recycling industries. Referring to the existing state of the MRFs, the development of 48 new MRFs will bring this to the attention of the public. The sites will be an excellent educational resource, for example, for school field trips. At the same time, job opportunities will become available, helping to save the scavengers from the harsh work they used to do. Having a roofed building will give comfort for the workers and prevention from further generations of leachate.

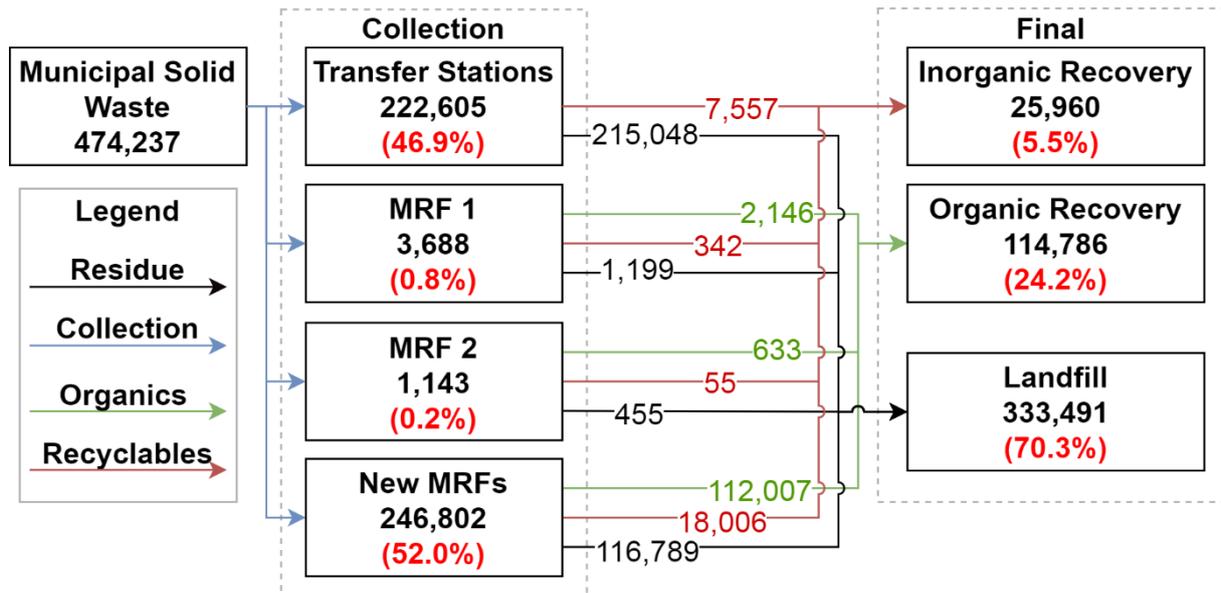


Figure 3.14 Waste Flow in Scenario 2 (in t/y) in Surabaya Model.

Table 3.9 Composition of Recovered (R) and Landfilled (L) Waste in Surabaya Model.

Composition	SC 0 and SC 1		SC 2		SC 3	
	R (%)	L (%) [16]	R (%)	L (%)	R (%)	L (%)
Food Waste	9.4	38.8	52.8	31.2	52.9	31.1
Garden Waste	5.1	21.1	28.7	16.9	28.8	16.9
Plastic	42.1	13.3	11.5	15.7	11.5	15.7
Paper	30.3	4.2	5.1	5.3	5.1	5.3
Glass	7.1	0.8	1.1	1.0	1.1	1.0
Metal	5.9	0.3	0.7	0.4	0.7	0.4
Textile	0.0	3.8	0.0	5.2	0.0	5.2
Leather/Rubber	0.0	1.0	0.0	1.3	0.0	1.3
Hazardous Waste	0.0	0.2	0.0	0.3	0.0	0.3
Others	0.0	16.6	0.0	22.6	0.0	22.6

**Scenario 3: Distributed MRF System**, on the other hand, was able to fully reach the target of landfilled waste reduction with fewer MRFs (Table 3.8) by recovering following the boosted reduction coverage of the waste from nearby TSs. TSs located near the MRF will change the transportation route to that MRF instead of directly to the landfill, also to TSs which will pass the MRF on its original way to the landfill. The MRFs' capacity of 20 t/d will be maximized before the rest of the unhandled MSW is

disposed of to landfill. A total of 42 TSs transported their collected waste to 26 MRFs (Route 1 in Figure 3.12), while the rest of the 131 TSs transported the waste directly to the landfill. Scenario 3 recovered recyclables similarly to Scenario 2 due to the same reduction target (Figure 3.15); therefore, resulting in the same number of new composting sites needed. Similar landfilled waste composition and unit of composting sites needed was achieved due to the previously assumed recovery ratio of the MRF despite its unit number difference. Fewer job opportunities will be provided in comparison to Scenario 2 for different numbers of facility units. Nonetheless, other benefits will be equally presented.

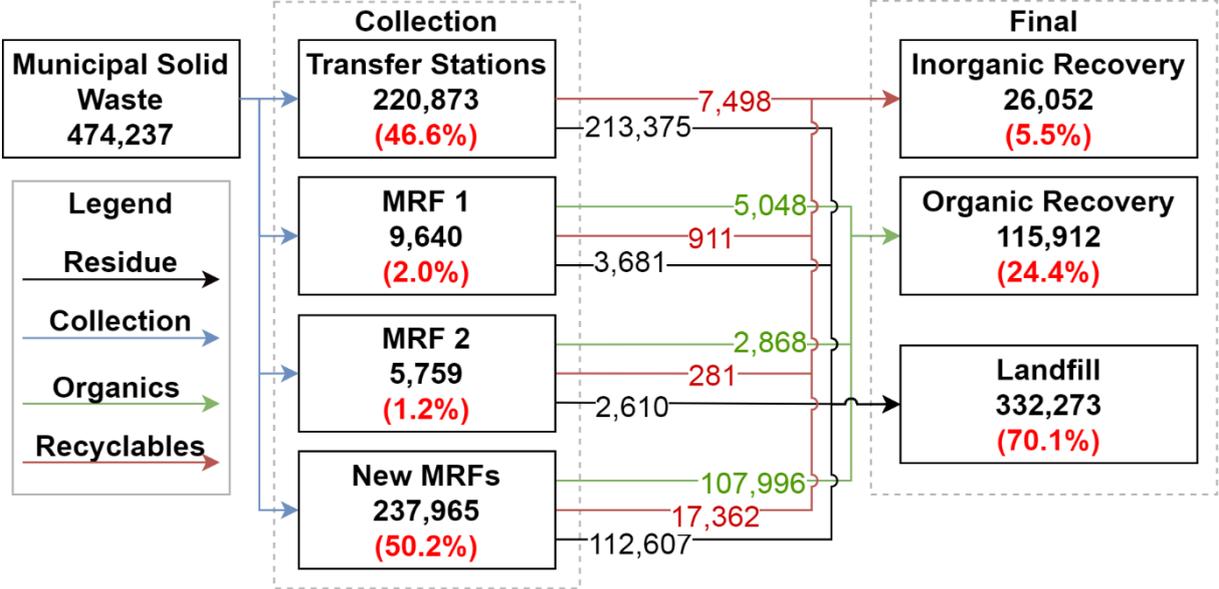


Figure 3.15 Waste Flow in Scenario 3 (in t/y) in Surabaya Model.

Landfilled waste reduction leads to a prolonged landfill lifetime. Scenario 1 did not give any changes in this aspect; meanwhile, both Scenario 2 and Scenario 3, with 30% landfilled waste reduction, extended the possible lifetime of the landfill by six years.

Having more MRFs in the city should offer greater benefits, such as knowledge enrichment, raising environmental awareness, and increased job opportunities. Since the new MRFs will be constructed at the location and as an upgrade/replacement of the existing TSs, there will not be any land-use issue.

Also, the TSs and MRFs are located at “public facilities” in Surabaya spatial planning 2014–2034.

**3.3.3. GHG Emissions**

Three MSW-related activities were analyzed in GHG emissions using the GHG calculator and the summary can be seen in Figure A. 1 to Figure A. 4 in APPENDICES. The results were then recalculated to obtain annual GHG emissions (Table 3.10). Between those three activities, landfilling of mix MSW dominated the share. The present situation in **Scenario 0** generated GHG emissions at 329,932 tCO<sub>2</sub>e/y. An indistinguishable drop of GHG emissions arose in **Scenario 1** due to a small improvement in waste transportation. GHG emissions from waste transportation activity in **Scenario 2** was decreased by 30%, while in Scenario 3, it was only 10% in comparison to the present condition. The reached target of landfilled waste reduction in both Scenario 2 and **Scenario 3** brought down the GHG emissions from landfilling of mix MSW by 36%. In contrast, the surge of composting activity increased GHG emissions by an average of 39 times as much.

Table 3.10 Details on GHG Emissions Analysis in Surabaya Model.

Activity (tCO <sub>2</sub> e/y)	SC 0	SC 1	SC 2	SC 3
Transportation	5,838	5,834	5,464	7,077
Landfilling of Mix MSW	323,567	323,567	207,742	207,096
Composting	527	527	20,381	20,580
<b>Total GHG Emission</b>	<b>329,932</b>	<b>329,929</b>	<b>233,590</b>	<b>234,756</b>
<b>GHG Emission Reduction</b>	<b>0</b>	<b>4</b>	<b>96,343</b>	<b>95,176</b>

Averagely, GHG emissions from transportation contribute to 2%, while landfilling of mix MSW at 94% of all GHG emissions activity was considered in the analysis. In Scenario 0 and Scenario 1, the GHG emissions generated from the activity of composting were lower than the ones from transportation due to the small quantity of recovered food and garden waste. On the other hand, a significant recovery in

Scenario 2 and Scenario 3 increased the share of GHG emissions from composting activity to 9%. In general, both Scenario 2 and Scenario 3 decrease the GHG emissions by 29% from BAU (Scenario 0).

The reduction of GHG emissions at 1.05 gigaton (Gt)CO<sub>2</sub>e/y by Indonesia’s effort was targeted to be reached in 2020 and followed by the updated target of 1.18 GtCO<sub>2</sub>e/y in 2030 (Government of the Republic of Indonesia, 2015). Looking at the result, strategic changes in the transportation system of MSW in Surabaya alone led to the GHG emissions reduction from the initial state (Scenario 0) at a promising level in both Scenario 2 and Scenario 3. This proposal could be one of the feasible strategies to accomplish the GHG emissions reduction goal.

**3.3.4. Cost**

The total cost analysis shown in Table 3.11 gave the general difference between scenarios. The result was presented in annual cost and the negative values in the revenue and subtotal rows represent income obtained from the selling of recyclable materials.

Table 3.11 Details on Cost Analysis of Surabaya Model (in billion IDR/y).

<b>Details</b>	<b>SC 0</b>	<b>SC 1</b>	<b>SC 2</b>	<b>SC 3</b>
Investment	3	3	14	9
Operation and Maintenance (OM)	9	9	46	31
Fuel for Transportation	11	11	8	10
Tipping for landfilling	71	71	52	52
Revenue Recyclables	-20	-20	-43	-43
<b>Total Cost</b>	<b>74</b>	<b>74</b>	<b>77</b>	<b>59</b>

\*1 USD = 14,800 IDR (based on 2020 estimate)

The existing condition put the basis of comparison between scenarios at 74 billion IDR/year for the total cost (Table 3.11). An identical outcome in the cost analysis was shown for **Scenario 0** and **Scenario 1**.

The investment cost and OM cost in both Scenario 0 and Scenario 1 are the calculation for two MRFs and 24 composting sites (Table 3.8). The improvement made in Scenario 1, resulted in slightly lower transportation costs at 14.2 million IDR/y fewer than Scenario 0.

The massive development of 48 new MRFs in **Scenario 2**, the newly implemented system with 24 new distributed MRFs in **Scenario 3**, and the additional 20 composting sites needed in both scenarios demand 4.7 and 3.2 times as much of the initial investment cost, respectively. The OM cost followed consequently at 5 and 3.4 times, respectively, compared to Scenario 0. Even so, since the recovery of recyclable materials was enhanced in Scenario 2 and Scenario 3, 2.2 times more revenue was obtained in both scenarios. Furthermore, with less waste needed to be transported to the landfill in Scenario 2 and Scenario 3, the tipping cost dropped consequently by 27%. Tipping cost has the largest share of all cost analysis details, proving the importance of preventing landfilling, even from an economic perspective. The change in the routing system in Scenario 3 has a drawback in terms of transportation cost because of the additional transportation of waste from TSs to the MRFs. However, with a 30% reduction of landfilled waste, Scenario 3 ended up with 10% less transportation cost than Scenario 0. On the other hand, Scenario 2 reduced the transportation cost further to 27% less. Overall, the total cost of Scenario 2 ended up at 103% of Scenario 0, while Scenario 3 was 79% of Scenario 0.

### **3.4. SUMMARY**

Surabaya Model with the introduction of MRF as the main MSW facility to recover the recyclables was successfully generated and it was deemed possible to be expanded to a national scale. The distributed MRF system (Scenario 3) is proven as a realistic and reasonable solution to reduce landfilled waste by 30% and help reduce GHG emissions at a promising level.

Scenario 3 offers a scheme with 2.2 times more revenue, 27% less tipping cost, and 10% less transportation cost than the present condition. It offered a better overall cost with the integration of TWDSs yet at the same time, it impacted the fuel for transportation cost. The sensitivity of transportation cost shows that TWDSs and landfill coordinates are essentials to broaden the Surabaya Model to the national scale.

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## **4. EFFECTIVENESS OF WASTE BANK IN RECYCLING**

### **4.1. INTRODUCTION**

The waste bank is a collaborative waste management method that encourages the public to participate in sorting waste and collecting recyclables to increase its economic worth. People can earn money by selling specific recyclable inorganic waste. The main targets of waste banks are to implement the 3R concept among the communities, to create comprehensive and integrated MSW management, to increase community awareness [3].

Waste banks rooted back to 1997 in Thailand where the “garbage for egg” project was initiated [2]. As the name implied, the recovery of recyclables was started by exchanging them with eggs. However, adjusting to the high interest of public participation, payments are given by the waste bank in the form of cash or credit [4]. Through the development, a similar system is then being adopted in different parts of the world. Indonesia is one of them and Surabaya City, arguably, is home to the first waste bank in Indonesia which started in 2006. So far, it is reported that there are 5,031 waste banks in Indonesia [5].

Participation of the community is critical in achieving the MSW management target [7]. Therefore, the Government set the roles on the waste bank for both authorities and communities. The Minister to give technical guidance, to build and integrate waste banks with the implementation of extended producer responsibilities (EPR), to monitor, evaluate, and develop international collaboration in the operation. The local government is responsible to increase the number of waste banks, giving technical guidance and training, monitoring and evaluating the operation, and aiding in marketing the result of 3R activities. While the communities are given the responsibility to separate and collect the recyclables to the waste

bank, and to increase the number of waste banks [3].

Waste banks in Surabaya back in 2010 were recorded at 15 units but the number climbed to 180 units in 2013 with more than 10,000 customers [6] and rocketed to 371 units in 2017 with over 13,000 customers [1]. Waste banks in Surabaya were able to reduce the waste up to 7.14 t/week [6] or approximately 0.04% of generated waste. According to a preliminary estimate of the waste bank's development in Surabaya, if all households engage in the waste bank program, MSW reduction would increase to 8.17%, saving 42 million IDR on the tipping fee necessary to dump the waste.

The waste bank as a concept is well-known across the world for its ability to encourage source separation and resource recovery through a community-based effort. However, the exact impact of the recycling system to waste reduction is yet unknown. Accordingly, the goal of this chapter is to investigate the performance of WBs in Surabaya and their role in resource recovery.

## **4.2. EVALUATION METHODS**

### **4.2.1. Collection of Recovered Recyclables Loads Data**

An interview was conducted with the authority of Surabaya Central Waste Bank (SCWB) to acquire detailed information on the amount of each recovered recyclable. The interview was conducted during the ongoing global pandemic so some data cannot be used for its anomaly. The monthly report of the amount of each recovered recyclable for January-July 2020 was obtained. However, the operation on March-May was terminated in response to the overwhelming health situation so only four months were considered in this research. The secured data were classified and analyzed to generate both numbers of individual and collective customers and numbers of recovered recyclable load.

The recovered recyclable load data were classified into composition categories based on the adjusted composition in Table 3.3 for the recyclable materials. The data received were already divided between individual and collective (unit waste bank) customers. However, some types of recyclables were not quantified in weight but unit. Therefore, an assumption was made on its weight to standardize the measurement and totalize the load of monthly recovered recyclables. The average value of all four months was then taken as a general WB load amount (Table A. 16).

**4.2.2. Detail Information on Unit WBs and NGOs**

The Authority of SCWB also provided the contact of authorities of unit WBs and Non-Governmental Organizations (NGOs) of *Wehasta Foundation* and *Lohjinawi Foundation* to advance to more detailed analysis. Online phone interviews were conducted as a resort to the ongoing global pandemic. The objective of this interview is to obtain detailed performance of waste banks in Surabaya per unit scale. The interview was conducted with each contact person of the unit waste banks, NGOs, and other concerned parties. The interview comprises of:

- Identity
- Address
- Starting year
- Scope of operation
- Storage capacity
- Operation frequency
- Collection vehicle
- Selling frequency
- Number of workers
- Number of customers
- Initial cost
- Operating cost
- Sponsor
- Price lists
- Recap of collected recyclables
- Number of Unit WB
- Number of Sectoral WB

**4.2.3. Number of Individual and collective (unit waste bank) customers of WBs**

All data of both individual and unit WB customers of SCWB from four months were combined and classified to remove duplicate data to draw unique identities which represent customers. However, possibly due to manual data entry during the recap, similar identities which might originate from the same customer were found (Figure 4.1). Due to many cases, it was unable to clarify each case to the Surabaya Central Waste Bank and assumptions were made on the customers' number. Each number of customers here was presumed to represent each household.

164	CHINTYA	129	PIN PIN
165	CHINTYA DEWI	130	PIN PIN 07
166	Chistina Lucia Martini	131	PIN PIN 7
167	CHRISTINA	191	SDN MEDOKAN SEMAMPIR 1
168	CHRISTINA LUCIA MARTINI	192	SDN MEDOKAN SEMAMPIR I

Figure 4.1 Individual (left) and Collective (right) Customers with Similar Identities.

Both NGOs did not give the precise number of individual and collective customers. Yet, according to the authority of *Wehasta*, there are roughly 10 customers in each sectoral WBs. Using this information and the provided number of Sectoral WBs from each NGO, we estimated the number of their customers.

**4.2.4. Recovered Recyclables Loads of WBs under NGOs Supervision**

The phone interviews did not provide the detailed information recovered recyclables load based for WBs (unit and sectoral) under NGOs supervision. The only data received were recovered plastic (based on type) recyclables from Sectoral WBs under *Wehasta*. Therefore, in calculating recovered recyclables loads from WBs under both NGOs supervisions assumptions were made.

Recovered plastic data from the same time range as the one used for recovered recyclable load analysis in Chapter 4.2.1 were taken and classified based on the types to boost the assumption accuracy. The average total load from each month was generated to be compared to the share of the composition of recovered recyclables in SCWB. By doing so, the monthly load of recovered recyclables from Sectoral WBs under *Wehasta* can be generated. On the other hand, since *Lohjinawi* did not provide the detailed load on any recovered recyclables, determining the recovered recyclable load of WBs under *Lohjinawi* was completely based on the comparison to the recovered recyclable load of WBs under SCWB in Chapter 4.2.1 and the number of customers in Chapter 4.2.3.

#### **4.2.5. Recyclables Value in each Ton Recovered**

The information on typical revenue which can be obtained in each ton recovered was needed as the base recyclable revenue analysis in further investigation with the introduction of WB in the system. The classified items in Chapter 4.2.1 were then valued based on respective prices in the latest price list from Surabaya Central Waste Bank (October 2020). The share of each item based on the total of respective composition type was calculated to understand the weight and value of each item in one ton of the corresponding composition type. The calculation was repeated to obtain a share on each item in the total recyclables recovered to get the share and value (Table A. 16 in APPENDICES).

### **4.3. RESULTS AND DISCUSSION**

#### **4.3.1. Fundamental Information on Waste Banks in Surabaya**

The waste bank is a community-based project without the government's intervention in the development or operation and can both start and stop at the community's will. The main purpose is to educate about the needs and benefits of source segregation, which is what makes waste banks different from a common

informal waste collection point called a waste trader or *pengepul*. The waste bank operates in Surabaya since 2006 and developed to about 755 units in 2020 along with annual environmental management competitions like *Merdeka dari Sampah*, *Surabaya Green and Clean*, and *Surabaya Smart City*. Started as corporate social responsibility (CSR) of Unilever PLC, which in operation were collaborating with *Wehasta*, a local NGO, and the Government of Surabaya. In the competition, they included waste reduction as one of the evaluating criteria, yet a common *pengepul* was not providing details on collected recyclables, therefore, waste banks were established to quantify the waste reduction in the village.

The typical waste flow of waste banks can be seen in Figure 4.2. Depending on the location, customers (representing household) can bring their separated recyclables to either Unit WB, Surabaya Central Waste Bank (SCWB) (Figure A. 5 in APPENDICES), or Sectoral WB. The collected recyclables in Unit WBs then being collected as collective customers to SCWB or Sectoral WBs as intermediates between unit WBs and endpoints where collected recyclables are sold to. Collectively, the recyclables then are prepared to be sent or collected by recyclers depending on their deal on the recyclable amount.

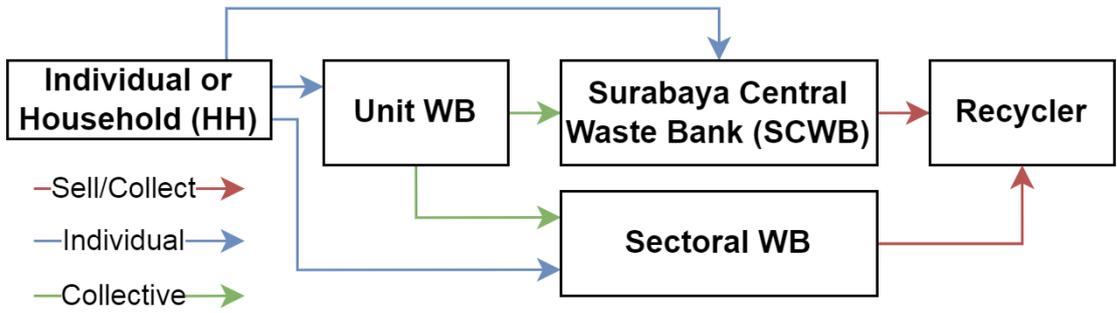


Figure 4.2 Typical Flow of Waste Banks in Surabaya.

**4.3.2. Detail Information on Unit and Sectoral Waste Banks**

In general, the unit waste bank could be established with no initial cost or sponsor since the required inventories are either lent by anyone from the community or invested by the community’s monthly

contribution fee. Strong commitment and environmental consciousness throughout the community are required more to establish a waste bank. The operating cost is mainly subtracted 10% from the income or depends on the community's initial agreement for inventories and refreshments during the operation. The workers, instead, are considered as volunteer workers or merely obtaining a small allowance from the operating cost. The number of workers is varied at 3-22 (averaged at 7 workers) and dominated by men. The customer of the waste bank will have a bank book, just as in a regular (money) bank, and will be able to withdraw money after it has been built up. They can also get fundamental food ingredients or everyday necessities as a substitute for money. In some situations, recyclables can be utilized as payment for education or medical insurance.

The storage capacity of a waste bank is highly affecting the operation and selling frequency. Those with no storage capacity tend to operate once a month to collect recyclables from the community and sell them or be taken by Surabaya Central Waste Bank afterward on the same day. Only a small share of waste banks has a handcart to support gathering recyclables from the community. The operational scale of each unit waste bank ranges to serve community groups of 6-250 customers, which represents the household, and in total, the waste bank in Surabaya serves an estimated 35,068 households. The customers, who are majority mid-to-low-income residents, were largely motivated out of financial reason to get additional income or following the community's decision.

Plastic dominates the recyclable composition in the waste bank (Table 4.1). It shows that Surabaya is a metropolis with a consumptive lifestyle, shown by the high use of disposable plastic food containers, followed by the paper which mainly originated from offices, schools, and others. Considering the recovery of those recyclables are performed at the source, waste banks promise a higher recyclables quality since they are not mixed or contaminated with other waste. This can improve the recycling system and, especially, might be a key to plastic waste reduction.

Table 4.1 Recovered Recyclables Loads in SCWB and *Wehasta's* Sectoral WBs.

Type	Recovered Recyclables Load (t/m)					Composition (%)	<i>Wehasta's</i> Sectoral WBs
	January	February	June	July	Average		
Plastic	23.6	24.5	5.1	10.5	15.9	53	34.4
Paper	2.1	1.7	10.3	22.4	9.1	31	19.7
Glass	0.3	0.3	0.5	1.1	0.5	7	4.3
Metal	1.7	2.0	1.4	2.9	2.0	7	4.6
Other	0.8	0.9	2.3	4.6	2.1	2	1.1
<b>Total</b>	<b>28.4</b>	<b>29.4</b>	<b>19.5</b>	<b>41.5</b>		<b>100</b>	<b>64.5</b>

Unit waste banks in Surabaya are mostly supervised by any of the three parties, SCWB, *Wehasta*, or *Lohjinawi*. Not like SCWB which took both roles of supervisor and collector, *Wehasta* and *Lohjinawi* only supervise the operation of unit waste banks and establish 11 and five sectoral waste banks (Table 4.2), respectively, as a place to gather recyclables from unit waste banks before selling them. In the operation, 20 units of the waste bank under *Wehasta's* supervision are covered by SCWB for collection for the location is closer than any sectoral waste bank. Approximately, there are 10 individual customers in each sectoral waste bank, an average of 45 customers in each unit waste bank, and 933 individual customers were assumed in SCWB. The current operation is estimated to only cover 0.16% (3.5 tons/day) of the generated waste or 4% of the total household in Surabaya which the flow is shown in Figure 4.3.

Table 4.2 Detail on Number of Facility, Customer, and Recovered Recyclables of WBs in Surabaya.

Supervisor	Number		Customer		Recovery (t/m)		
	Sectoral	Collective	Individual	Total	Individual	Collective	Total
SCWB	0	235	933	11,508	8	22	30
<i>Wehasta</i>	11	400	110	18,110	17	47	64
<i>Lohjinawi</i>	5	120	50	5,450	0.4	11	12
<b>Total</b>			<b>1,093</b>	<b>35,068</b>	<b>26</b>	<b>81</b>	<b>106</b>

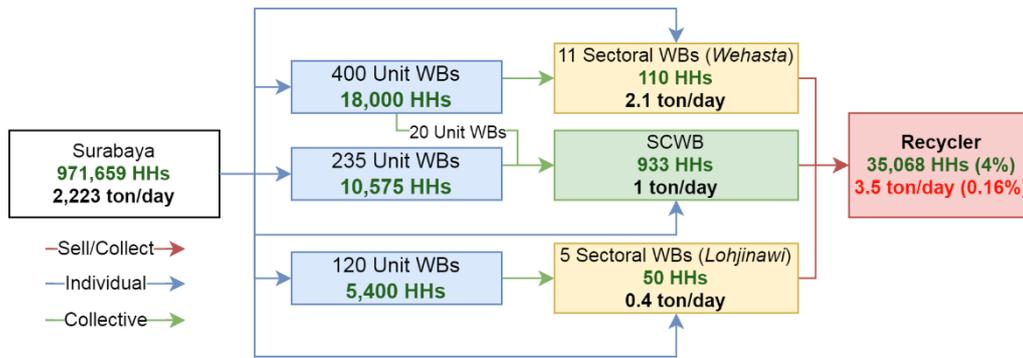


Figure 4.3 Flow of Customer and Recovered Recyclable Load of WBs in Surabaya.

While waste pickers only take the high-value recyclables (e.g., metals, PET bottles, plastic cups), waste banks tried to cover the rest of low-value recyclables (e.g., plastic bags, packaging, films) and sell straight to industries to get a better price. The customer can exchange up to 60 types of recyclables for some cash (25–42,000 IDR/kg or unit). The offered value for recyclables could vary between WBs but usually, Unit WB sets a little bit higher price since they are most likely reselling their collected recyclables to the Sectoral WBs or SCWB. They can either directly cash in or deposit the value as in a regular bank. Since generally the deposited recyclables are in a small amount, waste banks encourage the costumers to save the value by offering 3–100% more value to be obtained compared to cashing in. Averagely, the revenue obtained from waste bank collection is at 3,369 IDR/t recovered recyclables (Table A. 16). This figure may be used to calculate the recyclable revenue earned of additional WBs in a later study.

#### 4.4. SUMMARY

Waste banks in Surabaya contribute a minor amount of MSW reduction of 3.5 t/d of recyclables or only as much as 0.16% of total waste generated. Surabaya is equipped with 755-unit WBs and was able to collaborate with 4% of total households in Surabaya as customers. Still, it provides better recyclable quality for recycling systems which covers up to 60 types of recyclable items. Waste banks in general have a small impact yet were considered important to be included in the system. The information on the

unit number, recovery rate, recyclable items, and prices was necessary as base calculations in further analysis.

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## **5. SCENARIO ANALYSIS COMBINING WB, MRF, AND INCINERATOR FOR NATIONAL PLANNING OF WASTE MANAGEMENT IN INDONESIA**

### **5.1 INTRODUCTION**

In Indonesia, MSW treatment is still mostly based on landfills. However, most of the landfill is in a state of land scarcity and has a finite capacity to manage future waste. A robust strategy to handle this problem is required, but it must be adaptable enough to be applied in every Area throughout Indonesia. The government has made a step forward in this regard by enacting several rules that may be assigned to various classes of Area.

Because Small Areas are believed to be mostly comprised of middle-to-low-income individuals, WB may be used to both collect more recyclables at the source by encouraging source separation and benefit the community via additional income from selling recovered recyclables and 3R programs as studied in Chapter 4. The government has already established a rule linked to the promotion and implementation of WB for this purpose [14]. For Medium and Big Areas with more complicated waste yet limited budgets, MRF was introduced to aid in recyclable recovery at the collection segment, resulting in less MSW to be landfilled. The guidelines on MRF were published and several Areas have already been implemented via collaboration with international stakeholders [15] While for the Metropolitan Area the Government has pushed the implementation of WtE by releasing the acceleration of incinerator as WtE project [7]. This can solve both issues of landfilled waste and GHG emissions at the same time.

Implementing mentioned MSW facilities, a national plan for waste management in Indonesia was proposed. However, due to a limited database on the types and location of both collection and treatment

MSW facilities, a prior study of the Surabaya Model with the introduction of MRF in Chapter 3 was utilized as the base of simulation. With Surabaya Model having a complete set of databases to evaluate all criteria (landfilled waste reduction, GHG emissions reduction, and cost), Surabaya Model was also applied as a prototype to determine the substitute of limited data on MSW facilities in Indonesia using centroid with final goals to evaluate all criteria. There was no implementation of centroid as the replacement of temporary waste disposal sites (TS or MRF) or to determine the missing MSW facilities in a prior study, therefore the reliability is vital to be confirmed beforehand.

The GHG emission target itself splits into 5 sectors of energy, waste, IPPU, agriculture, and forestry and other land use (FOLU). The waste sector accounts for 0.38% of the total GHG emissions in BAU and is further subdivided into three sub-sectors of solid waste, liquid waste, and industrial liquid waste. In this study, we will just look at solid waste, however, we will use 0.38% as a goal to cut the GHG emission from the waste sector along with the landfilled waste reduction target at 30% [6]. Therefore, the objectives of this study are to clarify the compatibility of centroids as the representative TS or MRF and to develop a national plan of waste management in Indonesia using the expanded Surabaya Model to address national targets on landfilled waste and GHG emissions reduction.

## **5.2 EVALUATION METHODS**

### **5.2.1. Confirmation of Centroid Usage in Surabaya and Determination of Centroid in Indonesia**

- **Methods of generating centroid**

Covering the shortage of data on temporary waste disposal sites (TS or MRF) in the city/region (Area) level in Indonesia, centroid was proposed as the substitute. Along with the determination of centroid location for each Area, confirmation of its performance in representing real locations of MSW facilities was conducted. For that, the centroid will be implemented in Surabaya and

compared to the result of analysis in Surabaya Model by district level to increase the accuracy (Chapter 3.3.4).

Determination of centroid location was performed using QGIS 3.20.1 ‘Odense’ using the “Vector geometry: Centroid” algorithm (Figure 5.1). The selection of area(s) to be analyzed was required to operate this algorithm. Two types of area based on the land use were proposed in this analysis, the administrative boundaries (AB) and residential and/or working area (RA) which were visualized by building layers.

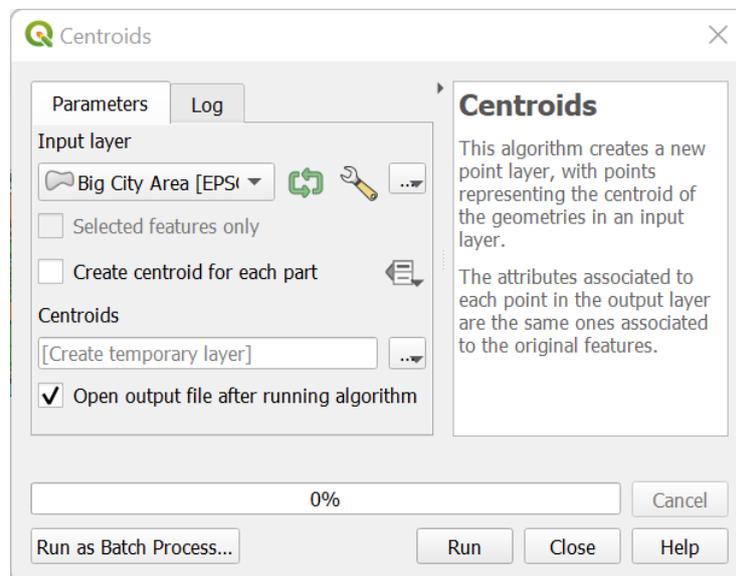


Figure 5.1 “Vector geometry: Centroid” Algorithm in QGIS.

The raw spatial data of the building layer was on a national scale and in a separated feature for each building, thus it needed to be separated for each Area and merged into a respective Area unit. Then, using the “Vector overlay: Clip” algorithm to the building, with the administrative boundaries as the overlay layer, the separated layers for each Area were obtained. Next, the “Vector geometry: Dissolve” algorithm was used to unify all features in one building layer. After having a *single unit* of building for each Area, the “Vector geometry: Centroid” algorithm was used to generate the centroid.

- **Validation of centroid coordinate by manual calculation**

To validate the coordinate of the centroid generated by both methods, a manual calculation was performed. Using the same algorithm, a centroid was generated for each feature in the building layer before it was dissolved. For the calculation, the area and coordinates of each building were needed so “Geometry: function \$area” in Field Calculator and “SAGA: Points – Add Coordinates to Points” were used to get the required information. Then the data were calculated using Eq. 5.1.

$$C_x = \frac{\sum_i^n C_{x,i} A_i}{\sum_i^n A_i}, C_y = \frac{\sum_i^n C_{y,i} A_i}{\sum_i^n A_i}$$

Eq. 5.1.

Where:

$C_x$  : X centroid coordinate

$C_y$  : Y centroid coordinate

$A_i$  : Area of shape i

$C_{x,i}$  : X centroid coordinate of shape i

$C_{y,i}$  : Y centroid coordinate of shape i

- **Confirming reliability of centroid in evaluating fuel for transportation cost**

Both results of the centroid from administrative boundaries and building layer were then compared with Surabaya Model (Chapter 3.3.4) in terms of the fuel for transportation cost. Using the same base map and methods fuel for transportation, and transportation frequency of Surabaya Model in Chapter 3.2.6. The difference here is that in centroid analysis, the “v.net.distance” algorithm as in Chapter 3.2.6 was not used, and instead of using the “Vector analysis: Shortest path (layer to point)” algorithm which will be explained further in Chapter 5.2.2. The better result between the two centroid methods was chosen as the method to generate centroid in all Areas in Indonesia.

## 5.2.2. Generating Transportation Route

The transportation route between centroids, as the representation of TS or MRF, and landfills were processed automatically using QGIS with some prior computation. Firstly, generated points (centroids and landfills) should connect to the available road network so that the algorithm can create a route between them. The nearby road networks were selected then using the “SAGA: Points – Convert Lines to Points” algorithm the selected lines were converted to points (Figure 5.2) so that with “Vector analysis: Distance to the nearest hub (line to hub)” algorithm a link can be generated (Figure 5.3). “Vector general: Merge vector layers” then used to combine the road network layer with the newly generated connection line layer (Figure 5.4).

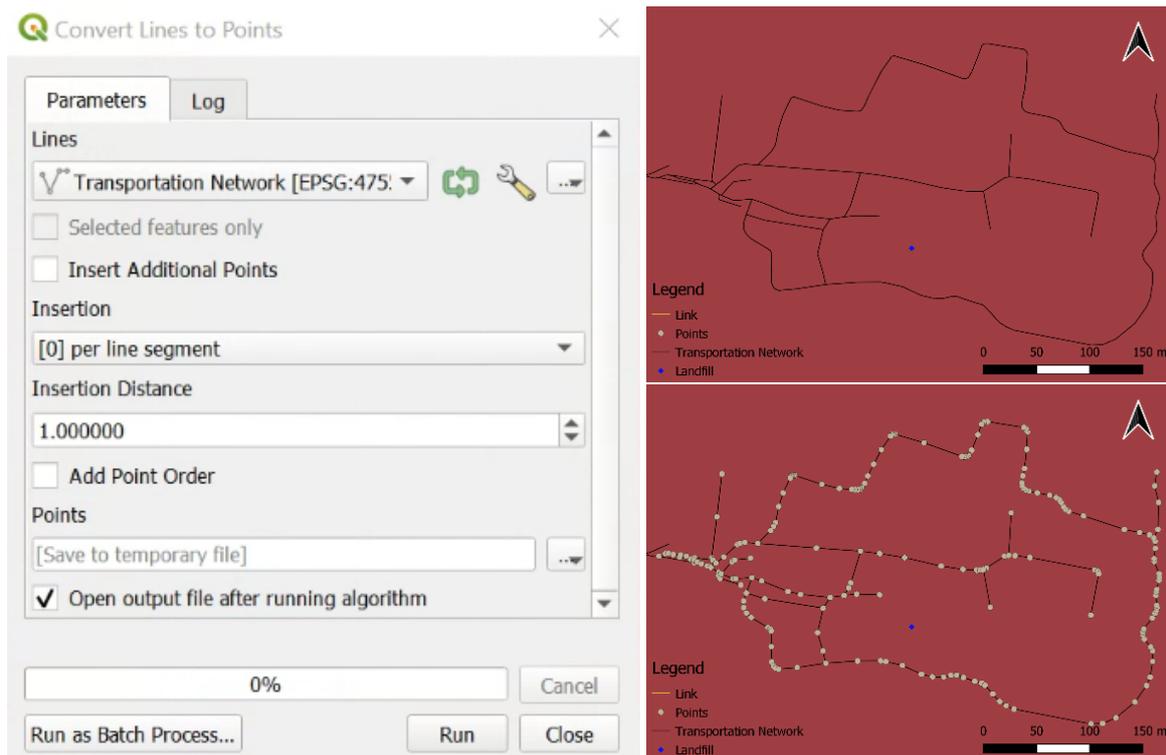


Figure 5.2 Converting Nearby Transportation Network to Points in QGIS.

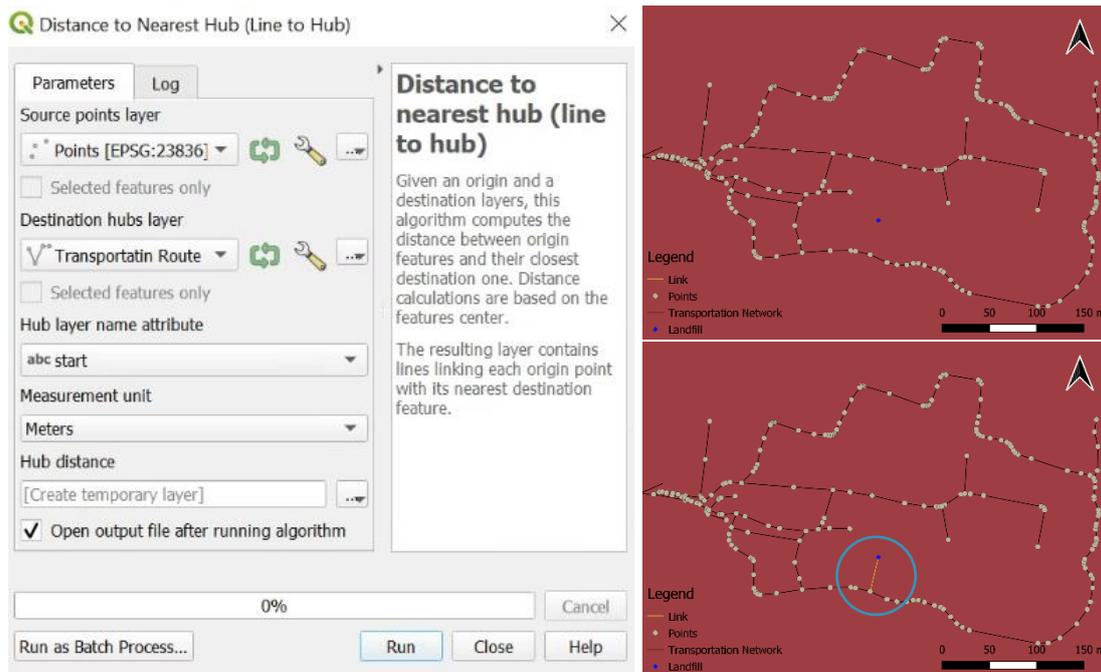


Figure 5.3 Generating Link from Centroid or Landfill to Road Network in QGIS.

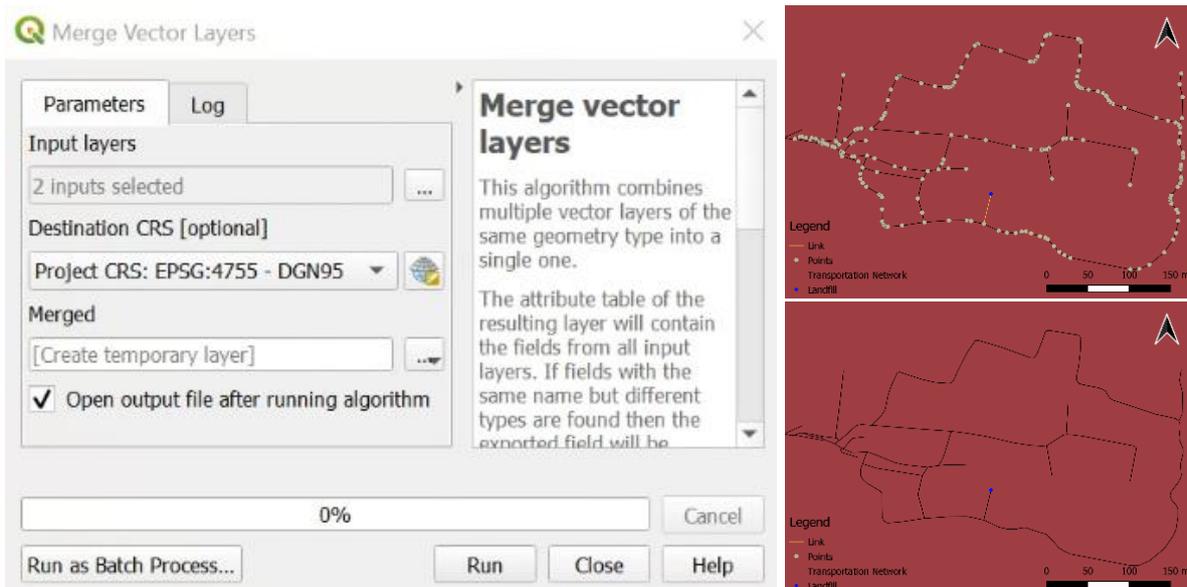


Figure 5.4 Merging Link with Road Network in QGIS.

Then with the ready-to-use road network, the “Vector analysis: Shortest path (layer to point)” algorithm was used, with centroid as layer source and landfill as the point, to generate the route (Figure 5.5). The “v.net.distance” algorithm as in Chapter 3.2.6 was not used since this algorithm requires an adjusted road network to overcome the road network problem as shown in Figure 3.2. It was neither possible to

conduct an interview to determine the main transportation route (as in Chapter 3.2.3) nor to manually fix the road problem. On the other hand, “Vector analysis: Shortest path (layer to point)” could ignore the vertices problem in the transportation network and provide transportation routes directly. However, different from the “v.net.distance” algorithm, it did not provide distance information. Therefore, the “Vector geometry: Add geometry attributes” algorithm was used to complete it (Figure 5.6.

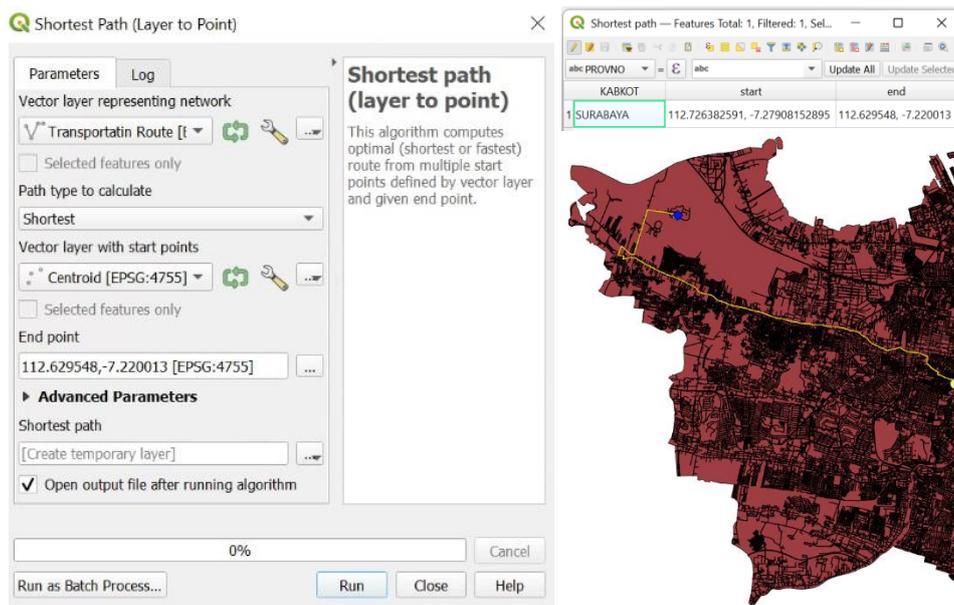


Figure 5.5 Generating Transportation Route in QGIS.

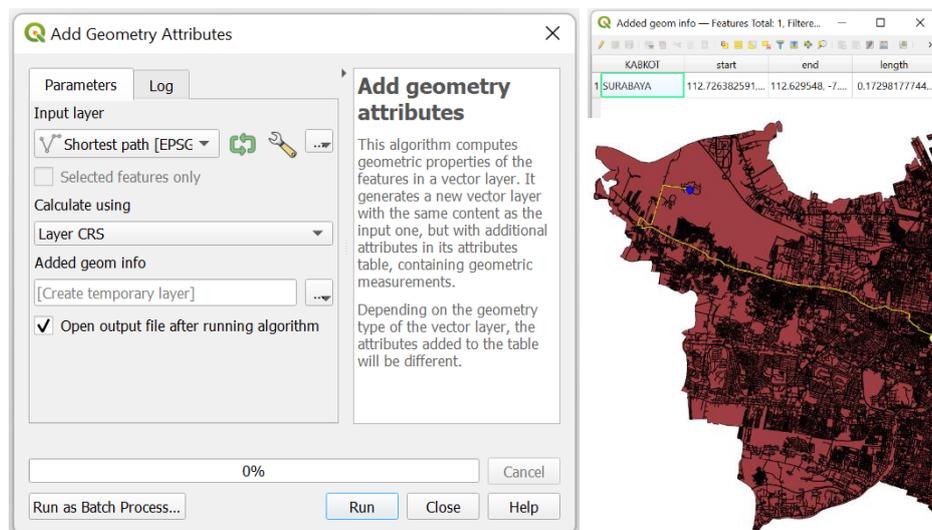


Figure 5.6 Generating Transportation Distance in QGIS.

**5.2.3. Building Base Map of National Plan of Waste Management in Indonesia**

The development of a base map for the analysis of the national plan of waste management in Indonesia was using the same method as Chapter 3.2.2. The required attributes for this base map were administrative boundaries of all cities/regions in Indonesia, buildings, road networks, and each population data. Population data of each Area was needed to classify the Area based on population by the Government [16], shown in Table 5.1 and visualized in Figure 5.7.

Table 5.1 City/Region (Area) Classification by Population.

<b>Classification</b>	<b>Low</b>	<b>High</b>	<b>Color Code</b>
Small City	-	250,000	Light Blue
Medium City	250,000	500,000	Green
Big City	500,000	1,000,000	Orange
Metropolitan City	1,000,000	-	Dark Red

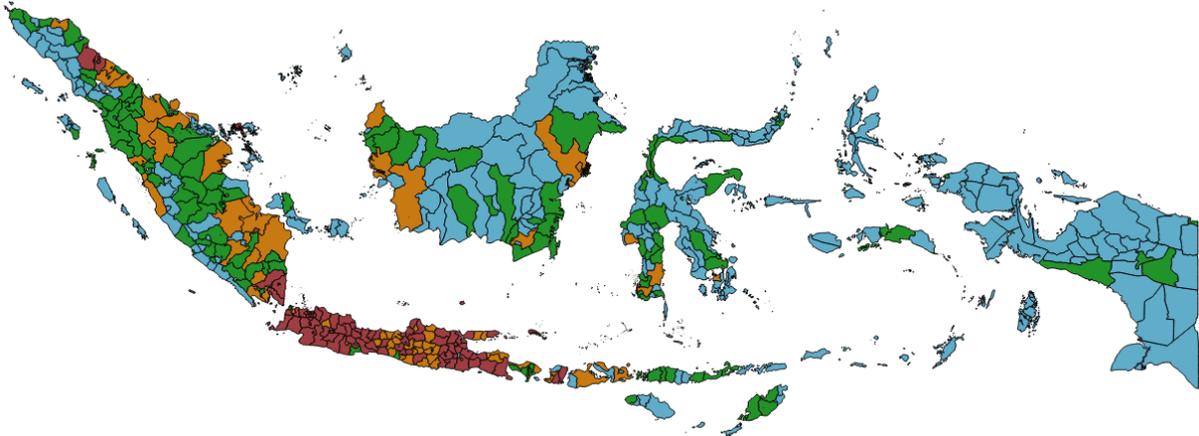


Figure 5.7 Area Classification on Base Map.

**5.2.4. Mining and Predicting Landfill Coordinate in Indonesia**

The spatial data of all landfills in Indonesia were provided by the Government of Indonesia through the website of the Ministry of Environment and Forestry of the Republic of Indonesia [10]. The extraction

of coordinates was done manually, then they were plotted in the base map (Figure 5.7) in QGIS as landfill layer. Based on the extraction, some Areas were known to have more than one landfill while some others did not have any. This might be due to the mix of old data containing no longer operating landfills and due to unrecognized/unreported landfills. In this study, for those who have more than one, one of the landfills will be selected as a representative or by latest information regarding the respective Area.

To complete the missing data for those Areas without landfills, random points were generated on the boundaries. The boundaries were based on the average transportation distance (based on Chapter 0) for respective Area classification from Area with available landfill data. Buffer area (Figure 5.8) was made using the “Vector geometry: Buffer” algorithm with the respective average distance from the available data.

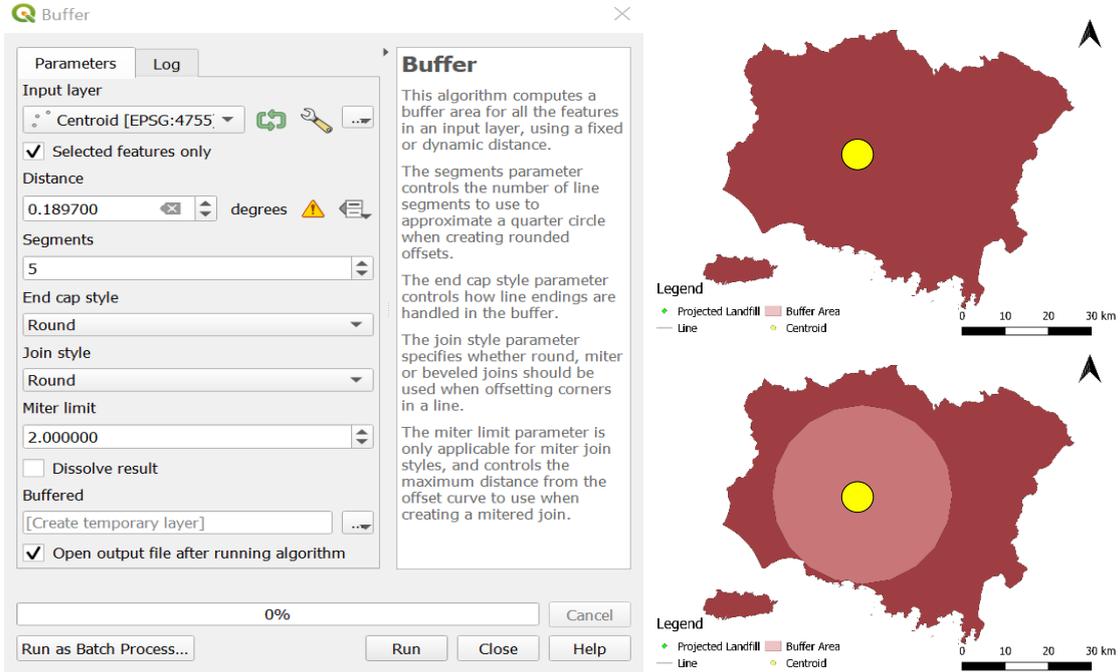


Figure 5.8 Generating Buffer Area in QGIS.

The buffer area then is clipped by the “Vector overlay: Clip” algorithm with the administrative boundaries as the overlay layer so that the buffered area will be limited to the corresponding administrative boundaries. Then the clipped buffer area is changed into lines using the “Vector geometry: Polygons to lines” algorithm and the projected landfill is going to be randomly placed along those lines with the “Vector creation: Random points on lines” algorithm (Figure 5.9). Prediction of landfill location was limited to the line of buffer area to represent the average distance and the location should be nearby the road network, meaning it cannot be unrealistically stranded in inaccessible locations.

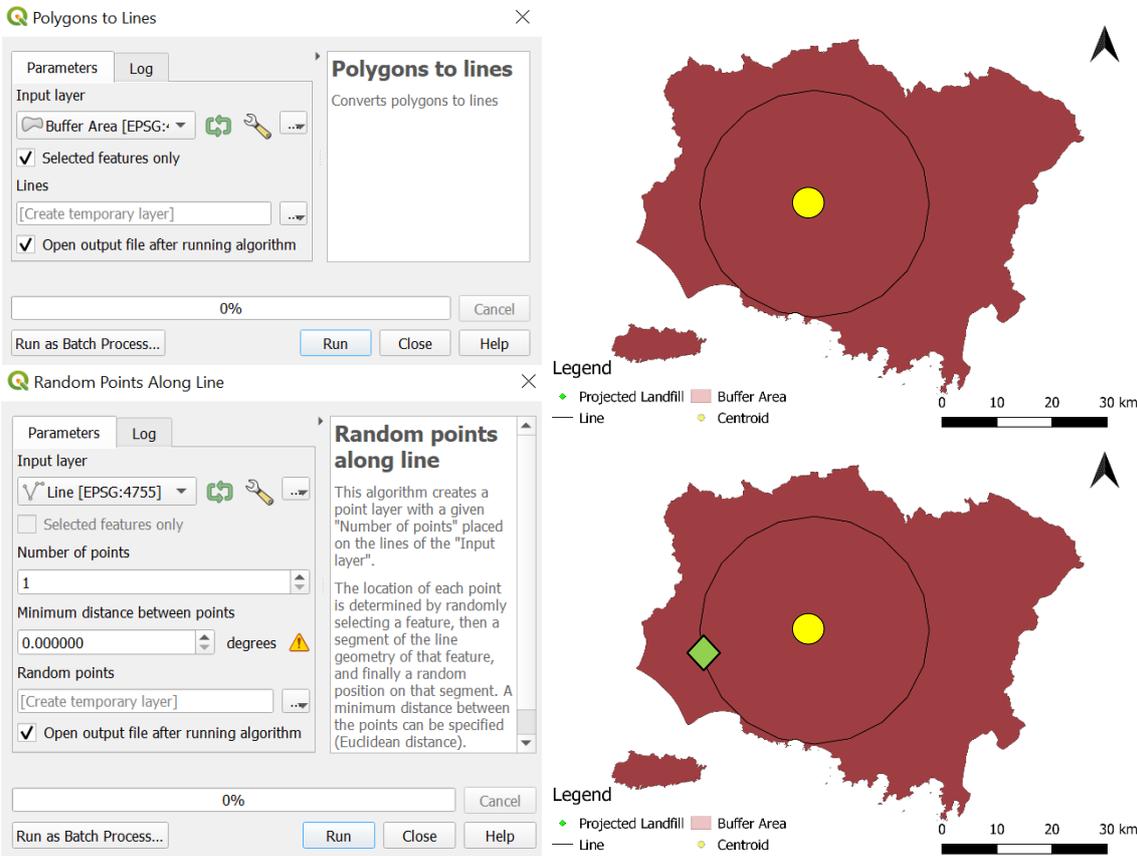


Figure 5.9 Converting Buffer Area to Line and Predicting Landfill Location in QGIS.

**5.2.5. Scenario Setting**

The availability of various approach in MSW treatment and facilities give more space for improvement in the whole MSW management. The waste bank might not be a good system to rely on solely, especially

in big Areas but might be a good solution for Small Areas with residents needing an additional income. On the other hand, MRF shows a promising recovery rate which could be implemented safely in many levels, while incinerator is reassuring of waste reduction but call for high expenses in both investment and operation. The combination of two or more of those MSW facilities are most likely desired but a sustainable and economically affordable system for MSW management in each class should be carefully planned. Four scenarios (Figure 5.10) were arranged to run the model to know the changes happening between them, especially in terms of landfill waste reduction, GHG emissions reduction, and the cost required.

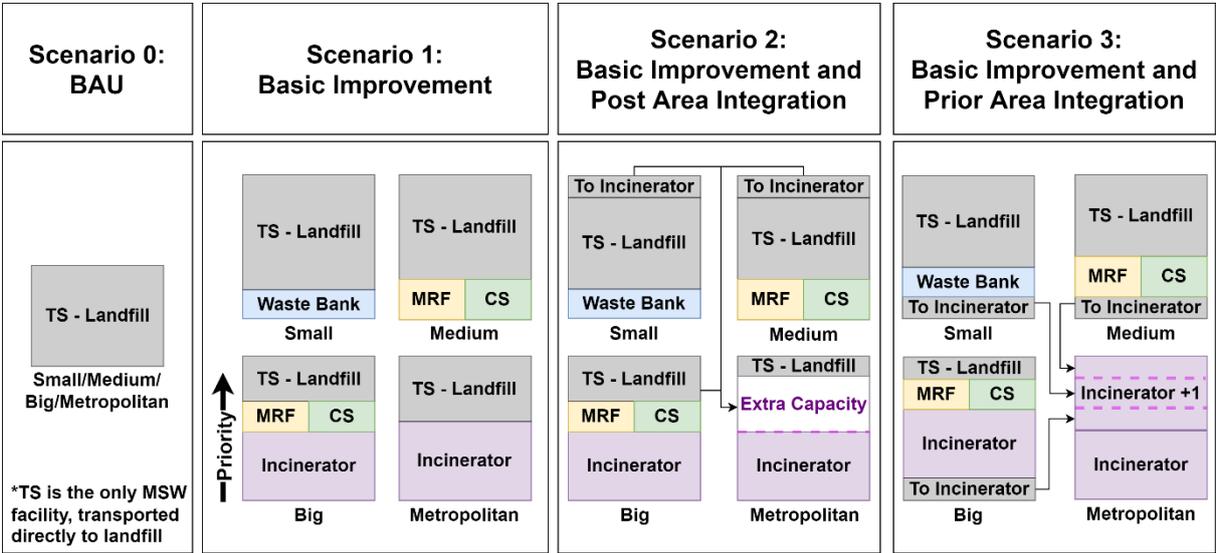


Figure 5.10 Scenario Setting of National Plan of Waste Management in Indonesia.

- Scenario 0: Business as Usual.** This scenario works as the baseline, depicting a state where no implementation of new facilities in the system. In this control scenario, to give an equal start for every Area, it was assumed that only TS was implemented nationally, neglecting currently available MSW facilities.
- Scenario 1: Basic Improvement.** In this scenario, all Areas were equipped with TS as the base as in Scenario 0 then MSW facilities were introduced according to the priority (bottom to top). Each Area class was analyzed differently with a particular implementation of MSW facilities.

Small Areas utilized waste banks to recover recyclables before collection. Medium Areas implemented MRF in the system as a replacement of TS with a limitation of a unit number to the point where 30% of its input was achieved. The Big Areas were the most complicated with 450 t/d capacity of the incinerator [19] as top priority and MRF to follow the remaining. Metropolitan Areas, on the other hand, only used the 1,000 t/d capacity incinerator [1].

- **Scenario 2: Basic Improvement and Post Area Integration.** Scenario 2 was built based on Scenario 1 and focuses on the utilization of unused incinerator capacity in Metropolitan Areas by integrating the nearby Areas with it. The integration was limited to the incinerator within the average transportation distance (Chapter 0) of the transferring centroid.
- **Scenario 3: Basic Improvement and Prior Area Integration.** As an alternative to Scenario 2, this scenario was also based on Scenario 1 but uses both 450 t/d and 1,000 t/d capacity incinerators in metropolitan cities/regions instead. Also, in this scenario, the integration of cities/regions is determined beforehand, as a priority, before the Recyclable Recovery-Oriented MSW facilities. This scenario considers the respective possible transportation distance, to appoint the required incinerator number.

#### **5.2.6. Constructing the Model of National Plan of Waste Management in Indonesia**

The model was established based on information provided by the Surabaya Model (Chapter 3). This model was carried out separately into TSs in all Areas, WBs in Small Areas, MRFs in Big and Medium Areas, incinerators in Big Areas, incinerators in Metropolitan Areas; incinerators and the integration in Scenario 2; and incinerators and the integration in Scenario 3.

- **TSs in National Model (Scenario 0)**

Determination of TSs started with classification of all Area by the population, based on Table 5.1 in Chapter and followed with the generation of transportation distance (based on Chapter 5.2.2)

between the centroids (based on Chapter 5.2.1) and landfills (based on Chapter 5.2.4). At the same time, MSW generation and landfilled waste were calculated based on the generation and landfill ratio at 0.35 t/cap/y and 55% generated waste, respectively [4]. With the known TS recovery ratio Table 3.2 in Chapter 3.2.7 and landfilled amount, the TS input and recovered recyclables amount can be traced back. Then, the number of TS required in each Area was calculated by rounding up the value given from the amount of waste landfilled divided by average TS input where the value of average TS input was obtained from the landfilled waste analysis of the Surabaya Model in Chapter 3.2.7 and can be seen in Table A. 2 in APPENDICES. The landfilled waste amount was also necessary to determine the trip frequency by dividing the landfilled waste by average truck capacity (Chapter 3.2.6).

- **WBs in Small Areas in National Model**

The calculation of WBs was relatively simple since there were no changes in the current TS number. The analysis was based on the previous analysis on WB in Chapter 4. The recovered recyclables can be obtained by multiplying MSW generation and the recovery ratio of WB at 0.16% which was the result of Chapter 4. With the reduction happening at the source, the MSW load to be collected to TS will be changed accordingly.

- **MRFs in Medium and Big Areas in National Model**

MRFs were implemented in both Medium and Big Areas as a resort to absorb potential recyclables with relatively affordable MSW facilities. The main difference of application in both Area was that in Medium Area the MRF was an upgrade of the current TS as in Scenario 2 of the Surabaya Model (Chapter 3.2.5) while in Big Area, MRF was chosen as the temporary waste disposal site to handle all waste other than those which were transferred to the incinerators. However, most of the analysis for MRFs in the National Model was the same. Additional attributes were needed since Big Areas were having incinerators as well.

Generally, the determination of the numbers of MRF to be included in each Area was based on the national target on MSW reduction at 30% [6]. In Medium Area, the number of TS was set as close to 30% MSW reduction as possible. In contrast, Big Areas upgraded all non-transferring-to-incinerators TSs into MRFs. The number of TSs changed to MRFs decided was used to have the original input load and compared to the average capacity of MRF then the required unit number of MRF can be known. The recovery ratio of MRF was based on the New MRF ratio used in Table 3.2 in Chapter 3.2.7 to calculate the recovery of MRFs which will be totaled with the recovery from TSs, and incinerators in Big Areas, to have total recyclables recovered. The total residue was calculated with the same method as total recyclables recovered. Then with this value, the total landfilled waste reduction ratio can be known by comparing it to the original landfilled waste amount. Residue values from TSs, incinerators, and MRFs were also used to investigate the transportation trip frequency required to transfer the waste to the landfill, or incinerators in Big Areas, by comparing to the truck capacity. The total trip will be considering the trip of TSs to landfill and MRFs to landfill, plus TSs to incinerators in case of Big Areas.

Since MRF recover both inorganic and organic materials, composting sites were needed to manage the recovered organic ones to be composted. The number of the composting sites was decided based on the roundup of a load of organic materials and the average capacity of the composting site at 3,614 t/y [10]. Transportation of organic materials recovered from MRFs to composting sites was assumed to be neglected since there was not enough information on this issue.

- **Incinerators in Big and Metropolitan Areas in National Model**

Both analyses of the incinerator in Big and Metropolitan Areas were using the same method. However, 450 t/d capacity of the incinerator was chosen [19] for Big Areas, while 1,000 t/d for Metropolitan Areas [1] as mentioned in the scenario setting (Chapter 5.2.5). The waste load itself will be recalculated to adjust the load of input incinerators per day since incinerators are considered

to only work in 280 days annually for maintenance (Eq. 5.2) [2].

$$C = W_L \times \frac{365}{280} \times A_{OR}$$

Eq. 5.2.

Where:

C : Incinerator intake capacity for 280 day/year operation (t/d)

$W_L$  : Original waste load (t/d)

$A_{OR}$  : Adjusted operating ratio (96%)

Then by comparing the adjusted load by incinerator capacity, we obtained the number of incinerators needed by rounding up the number in case the adjusted number is less than the incinerator and rounding down otherwise. The number of TSs transferring their residue to incinerators was decided by the total incinerators' capacity. All TSs transferred their residue when the capacity of the total incinerator was higher or rounded down to the suitable amount of TSs number. The rest of the non-transferring to incinerators will be merged into MRFs for Big Areas while in Metropolitan Areas it directly disposed to landfill. Next, having the precise number of TSs transferring, the precise amount of waste transferred can be obtained as well. This load was then separated beforehand to recover both metal and glass material as recovery at 1% (Table A. 2 in APPENDICES) and the rest is considered incinerated. The incineration residue as ash and non-combustible here was assumed to be 20% of the incinerated load [11]. Along with landfilled waste from the TSs, ash generated was considered as total landfilled waste and by comparing to the original load the recovery ratio can be found. There was no difference in transportation frequency from TSs since the incinerator was placed in the landfill area and likewise, no transportation was required for landfilling incinerator residue.

- **Integration to Incinerators in Metropolitan Areas Scenario 2 and Scenario 3 of National Model**

Integration of Areas nearby Metropolitan Areas was only conducted in Scenario 2 and Scenario 3 and only to incinerators in Metropolitan Areas. The difference was that in Scenario 2, the idea is to fulfill the capacity if any extra capacity, while Scenario 3 took the approach of prior planning to maximize the possible integration and decided the required unit later. Scenario 3 also introduce both 450 and 1,000 t/d incinerator to increase the precision of handling waste load with the required incinerator number.

Defining the remaining capacity of the incinerator in Scenario 2 was carried out using a comparison of the original waste load and incinerator unit which was determined using the same way as in other scenarios. The result of remaining capacity means extra capacity if positive and over capacity if negative. Scenario 3 determine the required combination of both incinerator capacity by maximizing the number of 1,000 t/d capacity using the usual way to cover the load and the rest of the load, if any, was covered by rounding up using the 450 t/d capacity incinerator.

As for the integration, it was conducted under multiple limitations. The transferring Area can only transfer to any incinerator (landfill point in Chapter 5.2.4) within the corresponding average transportation range (buffer area in Chapter 5.2.4), Area with higher classification will be prioritized to transfer the waste, and transferring will be stopped once maximum capacity of the incinerators reached or all possibly transferred waste was transferred. In Scenario 2, Areas other than Metropolitan Areas implement their respective MSW facilities first, then the rest, if any, was used in this integration analysis. Conversely, Scenario 3 prioritizes the integration first before any implementation of MSW facility in any Area. Transferring Areas has additional or adjustment calculations for fuel for a transportation cost analysis for its new routes. An example of integration can be seen in Figure 5.11. Only the transportation range of *Kota Probolinggo* of Small Area with 166 t/d MSW load intersects with an incinerator in *Kab. Probolinggo* of Metropolitan Area with 789

t/d MSW load, which means there was 211 t/d remaining capacity of 1,000 t/d capacity incinerator, therefore all the MSW load in *Kota Probolinggo* was transferred and stopped there even if maximum capacity was not reached.

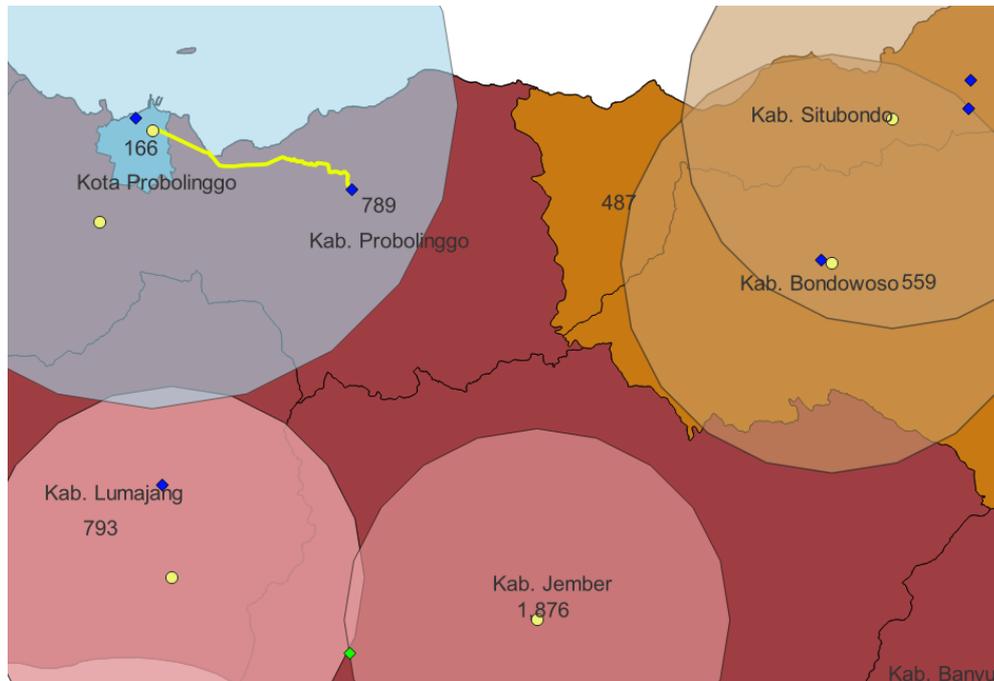


Figure 5.11 Example of Integration between Areas in National Model.

### 5.2.7. Landfilled Waste Reduction Analysis

The landfilled waste reduction analysis was done by simulating the changing of MSW facilities introduced in terms of type and unit number. The adjustment done in this study was anticipated not to produce any changes in the amount of waste generated and the unit number of TSs. The whole scenario will be compared to Scenario 0 (BAU) and the introduction of MSW facilities will be implemented to the respective Area classes. In this analysis, the market of inorganic recyclable materials was anticipated to be ample; nonetheless, there would be a scarcity of composting site capacity. For such, extra composting sites were established correspondingly.

Based on the detailed method given to construct the model of the National Plan on Waste Management in Indonesia in Chapter 5.2.6, both landfilled waste reduction and landfill load can be calculated. Scenario 0 as the base calculation only introduce TS, therefore, the analysis was conducted solely on the recovery and residue of TSs in all levels of Areas. The other scenarios calculate more specifically since different combination MSW facilities were implemented in each Area. Small Areas with WB and TS consider reduction from both facilities while the total landfill load was only from TS since WB was considered to only receive separated recyclables and not generate residue. Medium Areas with MRF as replacement of TS calculate both recovery and residue from the total of both facilities. Composting sites that treated the recovered organic materials were also assumed to not generate residue in the process. Implementation of incineration systems in Big and Metropolitan Areas took a different approach in the calculation. While other facilities recover the recyclable from the waste, incinerators reduce the waste itself into nothingness, leaving ashes as the output. For this, landfilled waste load from incinerator calculated by comparing with incinerator residue and residue from directly landfilled TSs in Metropolitan Areas and additional MRF residue in Big Areas. The landfilled waste reduction itself considers the difference between the amount incinerated and residue it generated, plus recyclables recovery from the corresponding MSW facilities introduced.

### **5.2.8. GHG Emissions Reduction Analysis**

The analysis of GHG emissions reduction in the National Plan of Waste Management in Indonesia was using the same tools as in Chapter 3.2.8, which was *GHG Calculator for Solid Waste ver. II-2013* from Institute for Global Environmental Strategies (IGES) (<https://iges.or.jp/en/pub/ghg-calculator-solid-waste-ver-ii-2013>). However, with the introduction of the incinerator as an MSW facility in the system (Figure 5.10), the activity incineration was added to the calculation. The analysis will track four activities in total: transportation, mix MSW landfilling, composting, and incineration activities. Likewise, since the results were in kgCO<sub>2</sub>e/t of corresponding loads of attribute, in incineration activity

was waste incinerated, it was required to change it into annual GHG emissions in tCO<sub>2</sub>e/y by using Eq. 3.2. in Chapter 3.2.8. The total GHG emissions reduction was then compared to the BAU in Scenario 0 to see whether any of the scenarios fulfill the targeted GHG emissions reduction at 0.38% or 11 MtCO<sub>2</sub>e in 2030 [5].

- **Transportation activity**

GHG emission analysis from transportation activity in the National Model considered different attributes depending on the MSW facilities introduced in the Scenario. While Scenario 0 only has TS, the other three scenarios introduce all types of MSW facilities. A load of waste transported and fuel consumed for transporting waste from TSs to landfill, MRFs to landfill, and TSs to the incinerator, including those transferring from one Area to another by integration, were considered in this analysis. The calculation was using the same formula of Eq. 3.3. in Chapter 3.2.8.

- **Landfilling of mix MSW activity**

The GHG emission generated from landfilling mix MSW considered total waste landfilled, which the value was generated from landfilled waste reduction analysis in Chapter 5.2.7, total fuel for machinery in a landfill site, which is an adaptation from earlier research by [20], and composition of landfilled waste. Landfilled waste composition of TS was mentioned in prior research [21], from MRF was the average composition of residue from MRF 1 and MRF 2 based on mass balance analysis in Chapter 3.2.7 and the value can be seen in Table A. 3 and Table A. 4 in APPENDICES, while the one from the incinerator was from an earlier study [3]. The complete base residue composition for each MSW facility can be seen in Table 5.2.

Table 5.2 Residue Composition from MSW Facilities in National Model.

<b>Composition</b>	<b>TS (%) [21]</b>	<b>MRF (%)</b>	<b>Incinerator (%) [3]</b>
Food	38.8	28.0	0.0
Garden	21.1	15.2	0.0
Plastic	13.3	18.2	0.0
Paper	4.1	13.1	0.0
Glass	3.8	7.5	48.0
Metal	1.0	1.3	18.3
Textile	0.8	3.1	0.0
Leather/Rubber	0.3	2.5	0.0
Hazardous	0.2	0.3	0.0
Others	16.6	10.8	33.7

Residue from respective MSW facility was quantified based on corresponding composition type then sum up the total value and again classify its composition share based on the total landfilled waste. The GHG emission calculation itself used the same formula of Eq. 3.4 in Chapter 3.2.8.

- **Composting activity**

The analysis of GHG emission from composting activity accounts for both food and garden waste composted based on recovery from the MRF. The fuel for machinery in the composting site which was also included here was referred to in Table 3.5 in Chapter 3.2.7. The other two attributes of total compost produced and percentage of compost utilized were assumed, compared to the compost generated in Surabaya Model in Chapter 3.2.8, and the total GHG emission from composting activity was calculated using Eq. 3.5. in Chapter 3.2.8.

- **Incineration activity**

Incineration activity is a new criterion to calculate total GHG emissions in this research. There were six attributes to be included in the analysis. Total waste incinerated containing both incinerators in Big and Metropolitan Areas. Each ton of waste incinerated required 0.23 L of diesel for the operation

[11] and had the same composition as the composition of landfilled waste [21]. The other three attributes were correlated to electricity generation. The total amount of electricity produced can be calculated with the fundamental information from literature studies, mentioning that 1,000 t/d incinerator capacity generates 19.7 MW [1] and 450 t/d incinerator capacity generates 10 MW [19]. This can be translated into 473,958 kWh/d and 240,000 kWh/d or 134,081 kWh/y and 150,878 kWh/y, with 280 working days a year and 1% recovery before incineration in consideration. 10% of generated electricity was assumed [8] to be used onsite for operational activity.

GHG emissions from incineration consider both emissions from the operation and the combustion. However, The incomplete combustion that might happen during the process is being neglected in this research, therefore we can assume that the combustion efficiencies are at nearly 100% or the value of oxidation factor at 1. The following formula (Eq. 5.3) explains the quantification of GHG emissions from the utilization of fossil fuel and grid electricity for plant operation.

$$Emission_i = (FC \times NCV_{FF} \times EF_{CO_2}) + (EC \times EF_{el}) + \left( \sum_i (SW_i \times dmi \times CF_i \times FCF_i \times OF_i) \times \frac{44}{12} \right)$$

Eq. 5.3.

Where:

FC : Fuel consumption for on-site activities (mass or volume/ton of combustibles)

NCV<sub>FF</sub> : Net calorific value of the fossil fuel consumed (MJ/unit mass or volume)

EF<sub>CO<sub>2</sub></sub> : Emission factor of CO<sub>2</sub> by combustion of fossil fuel (kgCO<sub>2</sub>/MJ)

EC : Electricity consumption for on-site activities (MWh/t combustibles)

EF<sub>el</sub> : Emission factor of country grid electricity production (kgCO<sub>2</sub>e/MWh)

SW<sub>i</sub> : Total amount of solid waste of type i (wet weight) incinerated (kg/t waste)

dmi : Dry matter content in the waste (partially wet weight) incinerated

- CF<sub>i</sub> : Fraction of carbon in the dry matter (total carbon content), (fraction; 0.0-1.0)
- FCF<sub>i</sub> : Fraction of fossil carbon in the total carbon, (fraction; 0.0-1.0)
- OF<sub>i</sub> : Oxidation factor, (fraction; 0.0 – 100%)
- 44/12 : Conversion factor from C to CO<sub>2</sub>
- i : Type of fossil-based waste incinerated such as textiles, rubber and leather, plastics

Again, the estimates of global warming potential for CH<sub>4</sub> and N<sub>2</sub>O in the model are based on the IPCC Second Assessment Report (SAR) at 21 kg carbon dioxide (CO<sub>2</sub>)/kgCH<sub>4</sub> and 310 kg CO<sub>2</sub>/kgN<sub>2</sub>O, respectively were used in this analysis [7].

### 5.2.9. Cost Analysis

The cost analysis in this chapter was considered more attribute compared to the cost analysis in Surabaya Model (Chapter 3.2.9) because the incinerator was introduced as one of the MSW facilities in this National Model. The annual total cost comprises of investment cost, operation and maintenance (OM) costs, fuel for transportation cost, tipping for landfilling cost; and the subtraction of recyclable revenue from the selling recovered materials, revenue from the selling generated electricity, and revenue from the incentive of WtE (waste to energy) operation (Eq. 5.4).

$$Total\ Cost = I_C + OM_C + F_{TC} + T_C - R_R - R_E - R_I$$

Eq. 5.4.

Where:

I<sub>C</sub> : Annual investment cost (IDR/y)

OM<sub>C</sub>: Annual operation and maintenance cost (IDR/y)

F<sub>TC</sub> : Fuel for transportation cost (IDR/y)

T<sub>C</sub> : Tipping for landfilling cost (IDR/y)

$R_R$  : Revenue from the sales of recyclables (IDR/y)

$R_E$  : Revenue from the sales of electricity (IDR/y)

$R_I$  : Revenue from the incentives of WtE operation (IDR/y)

- **Investment cost**

Investment cost analysis was using Eq. 3.7 in Chapter 3.2.9 by considering additional information on investment of incinerator. The investment in the incinerator was estimated using Eq. 5.5 by [1]. The details on the investment cost of the incinerator in this analysis can be seen in Table 5.3.

$$\text{Investment Cost of Incinerator} = \left( \frac{\text{Incinerator Capacity} * \frac{365d}{y}}{150,000t/y} \right)^{0.6} \times 35.2 \text{ million USD}$$

Eq. 5.5

Table 5.3 Details on Investment Cost of Incinerator (in billion IDR) in National Model.

Details	Cost	Depreciation Time (y)	Depreciation Cost (billion IDR/y)
Building	0.5	20	0.02
450 t/d Capacity Incinerator	551.3	25	27.6
1,000 t/d Capacity Incinerator	890.1	25	35.6

\*1 USD = 14,800 IDR (based on 2020 estimate)

- **OM cost**

OM cost for MRF and composting site was explained earlier in Chapter 3.2.9 and detailed in Table 3.5. The OM for TS will be considered here as the base situation in Scenario 0. The OM of TS will be similar to MRF, but without the maintenance cost for machinery, fuel cost, and operational cost for the computer. The determination of OM cost of the incinerator was adapted to [17] for employee number in each incinerator (Table 5.4) and [1] for incinerator OM calculation.

Table 5.4 Details on Employee Number in each Incinerator Capacity in National Model.

<b>Employees</b>	<b>1,000 t/d Capacity</b>	<b>450 t/d Capacity</b>
Director	1	1
Deputy Director	1	1
Operation Management	32	25
Maintenance Inspection	4	4
Platform	13	13
Reception/Weighing Personnel	12	12
Clerk	1	1
<b>Total</b>	<b>64</b>	<b>57</b>

Table 5.5 Details on OM Cost (in billion IDR/y) of each Incinerator in National Model.

<b>Component</b>	<b>Specific Value</b>		<b>OM Cost (1,000 t/d)</b>	<b>%</b>	<b>OM Cost (450 t/d)</b>	<b>%</b>
Pretreatment Cost	100,059	IDR/t waste				
Employee Salaries		IDR/month				
Maintenance Costs	2%	fixed capital	30.26	19	18.74	17
Plant Supplies	15%	maintenance cost	4.54	3	2.81	3
Royalties and Patent	1%	sales				
Utilities	100%	maintenance cost	30.26	19	18.74	17
<b>Direct Operational Cost</b>			<b>71.59</b>	<b>44</b>	<b>46.13</b>	<b>41</b>
Payroll Overhead	15%	salary	0.98	1	0.87	1
Laboratory	10%	salary	0.65	0	0.58	1
Plant Overhead	50%	salary	3.26	2	2.91	3
<b>Indirect Operational Cost</b>			<b>4.89</b>	<b>3</b>	<b>4.37</b>	<b>4</b>
Depreciation	capital-salvage value/plant lifetime		54.47	34	42.17	38
Property Tax	1%	fixed capital	15.13	9	9.37	8
Insurance	1%	fixed capital	15.13	9	9.37	8
<b>Fixed Operational Cost</b>			<b>84.74</b>	<b>53</b>	<b>60.92</b>	<b>55</b>
<b>Operational Cost</b>			<b>161.21</b>	<b>100</b>	<b>111.41</b>	<b>100</b>

\*1 USD = 14,800 IDR (based on 2020 estimate)

The pretreatment cost, employee salaries, and royalties and patents were left blank since it requires prior calculation on waste treated in the incinerator, total number of employees (Table 5.4), and both revenue from electricity production and recyclable selling, respectively.

- **Fuel for transportation cost**

In this analysis, the changes in MSW facility and transportation system were considered to not affect the number of trucks and drivers as in the Surabaya Model in Chapter 3.2.9. The difference is that in National Model, the transportation range increased and integration between Areas was proposed as well. Consequently, a higher distance range for analysis was needed for transportation routing analysis, and Table 3.1 was developed into Table 5.6. Transportation of MSW above 100 km was considered ineffective therefore the calculation was limited to 100 km distance.

Table 5.6 Additional Fuel per Distance Traveled for MSW Transportation in National Model.

Distance (km)	Basic Fuel (L)	Additional Fuel per Distance (L/km)
0	3	0.15
10	4.5	0.10
20	5.5	0.15
30	7	0.10
40	8	0.15
50	9.5	0.10
60	10.5	0.15
70	12	0.10
80	13	0.15
90	14.5	0.10
100	15.5	-

Fuel for transportation cost here will consider the transportation from TSs to landfill, MRFs to landfill, and TSs to the incinerator, including those transferring from one Area to another by integration.

- **Tipping for landfilling cost**

Tipping costs will only be used to divert landfilling from TS or MRF because the incinerator will be considered a government-owned facility that operates and was managed by the Government itself. The tipping cost itself was set at 191,088 IDR/t landfilled waste based on the actual tipping cost of *Benowo Landfill* in Surabaya in the fiscal year of 2021 [10].

- **Recyclable revenue**

The revenue from selling recyclables was calculated based on the analysis and the price list in Chapter 4.2.5, shown in Table A. 16 in APPENDICES. Different from analysis in WB, the recovered recyclables considered here were different in each MSW facility depending on the composition of recovered materials. TS and MRF recovered plastic, paper, glass, and metal, while incinerators only recover glass and metal. The composition of recovery in each facility was based on earlier analysis on mass balance in Chapter 3.2.7. Recyclables' composition of TS can be seen in Table A. 2 in APPENDICES. The composition of recovered materials from MRF was the average of MRF 1 and MRF 2 in the Surabaya Model, shown in Table A. 3 and Table A. 4 in APPENDICES. The incinerator received the residue from TS or MRF therefore it calculated recyclables from the residue of those MSW facilities, instead of the recovered composition. The summary of recyclable composition for recyclable revenue can be seen in Table 5.7. This composition value was then calculated for the revenue in each ton as in Chapter 4.2.5.

Table 5.7 Recovered Recyclable Composition for Selling from MSW Facilities in National Model.

<b>Composition</b>	<b>TS (%)</b>	<b>MRF (%)</b>	<b>Incinerator (%)</b>
Food	0.0	0.0	0.0
Garden	0.0	0.0	0.0
Plastic	49.3	5.4	0.0
Paper	35.5	3.8	0.0
Glass	8.3	0.9	0.8
Metal	6.9	0.7	0.3
Textile	0.0	0.0	0.0
Leather/Rubber	0.0	0.0	0.0
Hazardous	0.0	0.0	0.0
Others	0.0	0.0	0.0

- **Electricity revenue**

The revenue from electricity generated was a new attribute to be considered in analyzing cost as the criterion of the research. The Government offered to buy the generated electricity from the WtE facility at 13.35 cents USD/kWh [7] or in this analysis was equal to 1,976 IDR/kWh (1 USD = 14,800 IDR, based on 2020 estimate). The amount of electricity generation itself was mentioned in Chapter 5.2.8 at 134,081 kWh/y and 150,878 kWh/y for 1,000 t/d capacity incinerator and 450 t/d capacity incinerator, respectively.

- **Incentive revenue**

In addition to electricity revenue, the Government of Indonesia also promised a subsidy to help waste treatment service for the acceleration of the WtE program at a maximum of 500,000 IDR/t waste [7]. This part of the analysis used the maximum possible incentive and multiplied it by the amount of waste handled by the incinerator.

#### **5.2.10. Cost-Benefit Analysis**

The cost-benefit analysis will be conducted to give a direct comparison between the cost required per achievement in each scenario. For landfilled waste reduction analysis, the cost required for every ton reduced will be generated while for GHG emissions reduction analysis, it will be the cost required for every ton CO<sub>2</sub> equivalent reduced. Also, in the GHG emissions reduction analysis, since the reduction is by compared to the BAU scenario in 2030 (Scenario 0), there will be no cost-benefit analysis shown in Scenario 0.

### **5.3 RESULTS AND DISCUSSION**

#### **5.3.1. Confirmation of Centroid Usage in Surabaya Model and Centroid Generation**

As a solution to overcome the problem of the inability to conduct the complete analysis of cost and GHG emissions criteria due to missing the location of MSW facilities in Indonesia, a different approach to representing those MSW facilities using centroid was chosen. Centroid is a central point of an area, in this case, a city/region (Area), which can be generated using an algorithm in QGIS. Centroid is a vital element to determine the MSW facility locations, establish transportation routes to any treatment facilities, set up possible integration between Areas, and further evaluate both cost and GHG emissions reduction.

Surabaya City, on the other hand, was evaluated in prior Chapter 3 and resulted in a complete database of all coordinates of TSS, MRFs, and landfill in Surabaya. This fundamental information was used to validate the adoption of centroid as a replacement of TS or MRF by comparing the result generated by the centroid and the original result. To increase the reliability, district-level analysis of centroid was conducted, and the administrative boundaries of each district were chosen as the representation of the

Area. The example of generated Administrative Boundary (AB) Centroid can be seen in Figure 5.12.

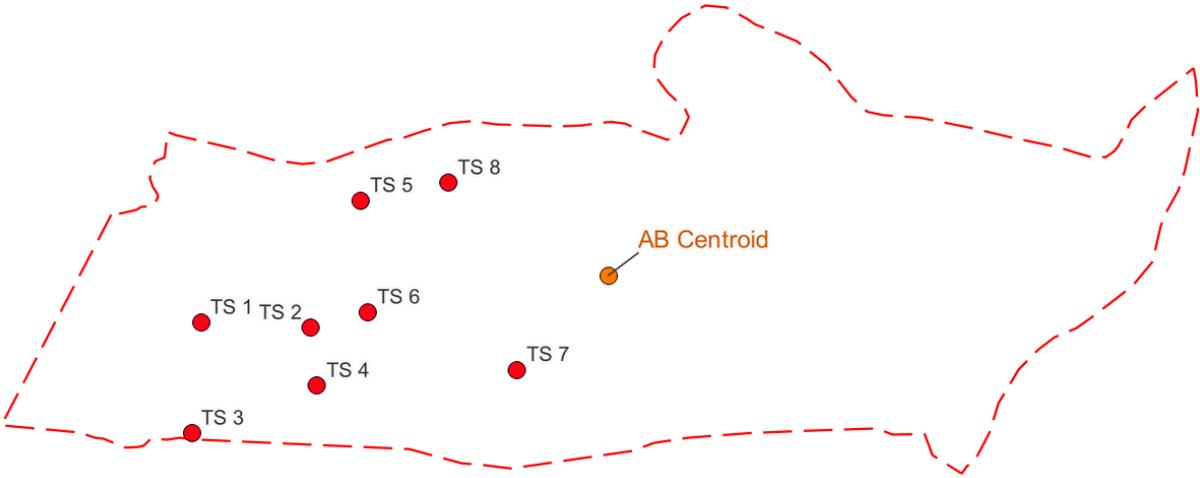


Figure 5.12 Administrative Boundary (AB) Centroid of *Rungkut District*, Surabaya.

The generated centroids then calculated for its fuel for transportation cost to transfer their MSW to the landfill using the same method as the distance, transportation frequency, and fuel for transportation in Chapter 3.2.6 and compared to the original results of fuel for transportation cost by temporary waste disposal sites (TWDSs) of TSs and MRFs in Chapter 3.3.4. The detail of the comparison can be seen in Table A. 17 in APPENDICES and displayed in Figure 5.13.

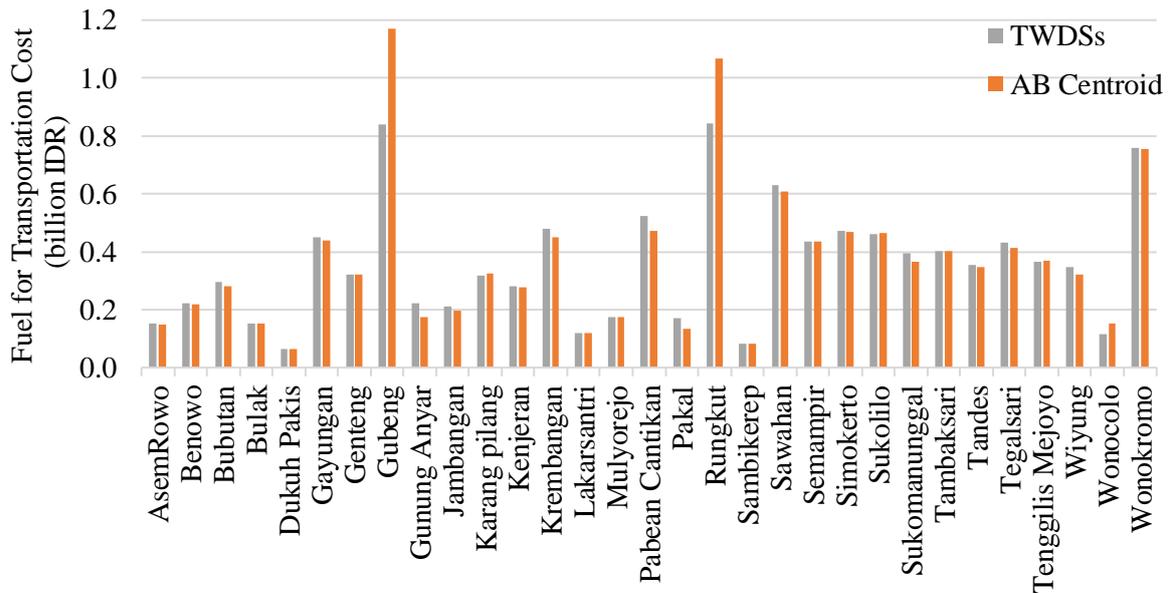


Figure 5.13 Comparison of Fuel for Transportation Cost Between TWDSs and AB Centroid.

AB Centroid generated close enough result to the actual condition of fuel for transportation with TWDSs. However, the result showed a clear anomaly in at least two districts in which AB Centroids generate higher costs. The possible reason might be that majority of the TWDSs were way closer to the landfill in comparison to how close the centroid is to the landfill itself. One other reason was that the administrative boundaries failed to visualize the distribution of TWDSs since it neglects the land use of the area, while commonly TWDSs was located nearby the residential area.

Thus, we proceeded to the next candidate of Residential and/or Working Area (RA) Centroid. This method took into account the land use and only considered the residential and/or working area represented by the building layer in the base map (Figure 3.4 in Chapter 3.2.2). The example of generated Administrative Boundary (AB) Centroid can be seen in Figure 5.14.

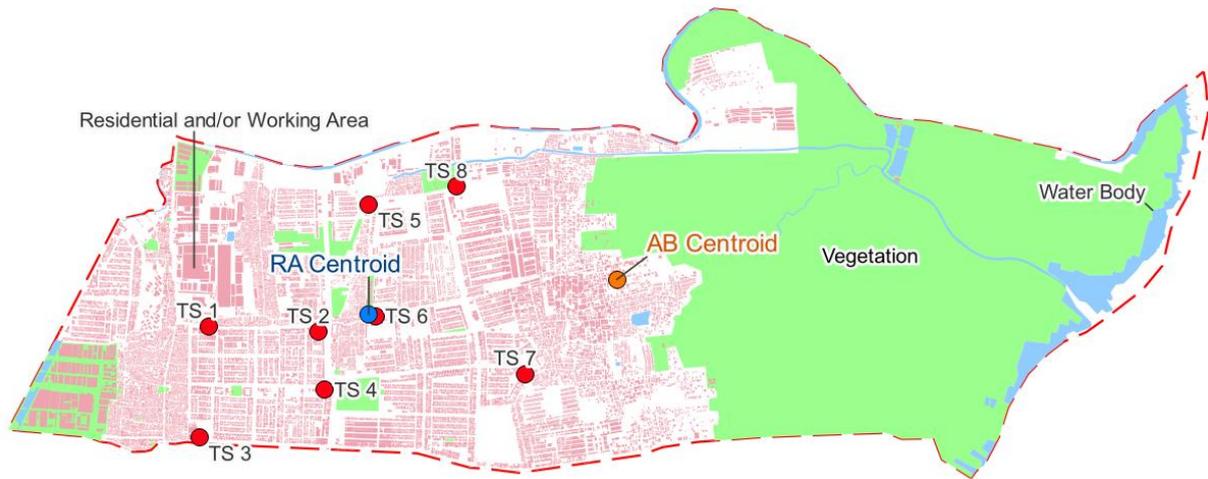


Figure 5.14 Residential and/or Working Area (RA) Centroid and Land Use of *Rungkut District*, Surabaya.

The generated Figure 5.14 shows a possibly more promising result in comparison of fuel for transportation cost. The clarification of the centroid coordinate needed to be confirmed as well comparing the coordinate of both centroids and by manual calculation (Table 5.8). RA Centroid resulted in a similar x, y coordinate to the manual calculation. Then the evaluation of fuel for transportation cost comparison between TWDSs and both centroid methods was conducted, and the result was visualized in Figure 5.15.

Table 5.8 Comparison of Centroid Analysis Result.

Method	X Coordinate	Y Coordinate
Manual Calculation	231353.2	690431.6
RA Centroid	231351.5	690430.4
AB Centroid	233385.6	690717.5

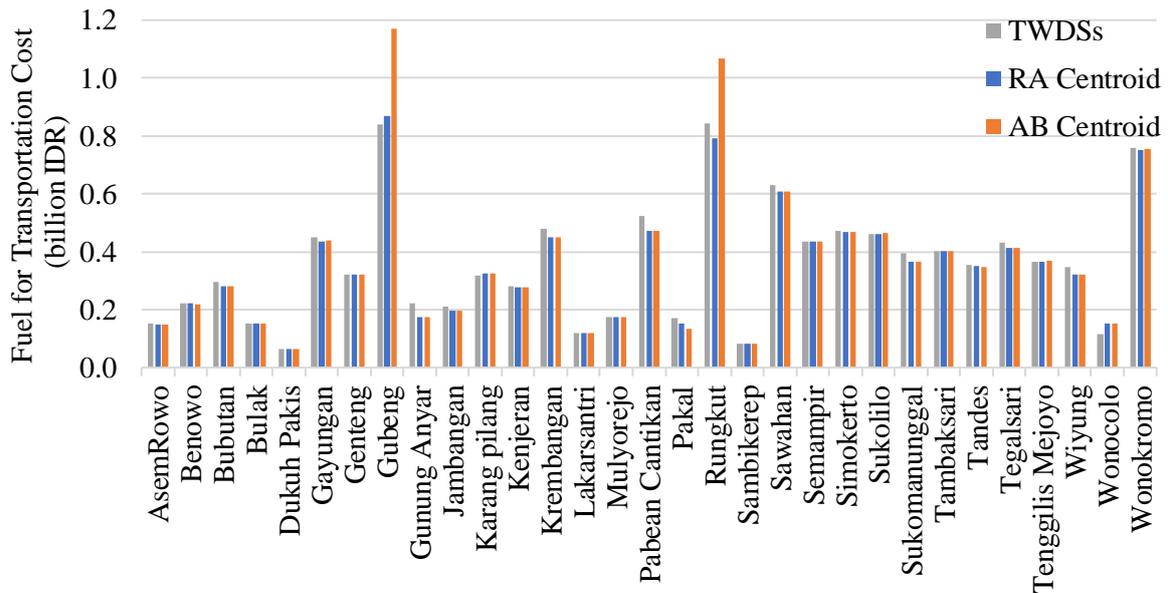


Figure 5.15 Comparison of Fuel for Transportation Cost Between TWDSs and Both Centroid Methods.

RA Centroids provided better results, especially in the two districts which were having a big difference in fuel for transportation cost in AB Centroid Result. We can realize that the major reason why RA Centroid delivered a superior result was that AB Centroid also consider the non-residential area, such as vegetation or water body. This demonstrates that RA Centroid was a superior alternative with 98% compatibility data to be adopted in National Model to generate centroid in all Areas in Indonesia (Figure A. 6). The entire comparison of yearly transportation expenses in each district can be seen in Table A. 17 in APPENDICES.

### 5.3.2. Mapping Landfill Locations

Using the produced centroid (Figure A. 6 in APPENDICES) and extracted landfill data provided by the Government [10], the transportation route of the Area with available landfill data was constructed using the method mentioned in Chapter 5.2.4 to obtain the average transportation distance (Table 5.9). It can be noted that the average distance is growing less the higher the Area class is. This phenomenon likely

owing to the concentrated activity surrounding Metropolitan Area in contrast to the more scattered one in Small Area. More than half of the Areas was lacking landfill data, thus a random landfill location was predicted using the average distance (Table 5.9.) for the corresponding Area using the method mentioned in Chapter 5.2.4. The result was displayed in Figure A. 7 in APPENDICES. With all components secured, the implementation of new MSW facilities in each scenario can be executed and evaluated.

Table 5.9 Availability of Landfill Data and Average Distance of Area Class.

Details	Small	Medium	Big	Metropolitan	Total
Area Class with Landfill Data	89	63	52	46	<b>250</b>
Area Class without Landfill Data	148	61	22	33	<b>264</b>
Average Distance (km)	30.08	26.31	20.76	18.97	

### 5.3.3. Landfilled Waste Reduction and Transportation

After the completion of landfill location data for each Area in Chapter 5.3.2, the modeling of scenarios (Figure 5.10) can be executed. The number of MSW facilities deployed was based on the condition and guidelines given in Chapter 5.2.6 with the main target of landfilled waste reduction at 30% nationally [6]. Table 5.10 gives the comparison of landfilled waste reduction evaluation results in each scenario.

**Scenario 0: BAU**, deals with 53 Mt/y of initial MSW with 21,556 units of TSs which can only decrease 3 percent of the MSW produced and must send the balance of the waste to the landfill. The load of 51 Mt/y of landfilled MSW needed more than 13 million trips with 296 million liters of gasoline per year for transportation. This is regarded as a starting line for the other cases to make changes. The distribution of all TSs in Scenario 0 can be seen in Figure A. 8 in APPENDICES.

Table 5.10 Details on Landfilled Waste Reduction Analysis Result in National Model.

Details	SC 0	SC 1	SC 2	SC 3
<b>Facility (unit)</b>				
WB	-	11,636	11,636	11,636
TS	21,556	19,105	19,105	18,143
MRF	-	817	817	629
Incinerator	-	174	174	190
<b>Waste (Mt/y)</b>				
Landfill Waste	51	21	20	19
Waste Reduction	2	32	33	34
Waste Reduction (%)	3	61	62	64
<b>Transportation (ML/y)</b>				
Transportation Frequency (million trip/y)	14	13	13	15
Fuel for transportation	296	274	276	324
Fuel-saving	-	22	20	-28
Transferring Areas	-	-	40	53
Receiving Areas	-	-	32	34

In **Scenario 1: Basic Improvement**, this scenario picturized the situation where each Area implemented a different combination of MSW facilities with WB, MRF, and incinerator. In general, Scenario 1 was able to cut the MSW up to 61%, effectively completing the goal of landfilled waste reduction at 30% [6]. The reduction in TSs (Figure A. 9 in APPENDICES) was happening after the initial recovery in 11,636 units of WB in Small Areas (Figure A. 10 in APPENDICES), but most of the recovery is done by 817 units of MRF in Medium and Big Areas (Figure A. 11 in APPENDICES). The recovery in Small Areas with WBs was lowering the MSW to be handled in the TWDSs, in this instance TSs, and coupled with the recovery in TSs they offer the least percentage of landfilled waste reduction at 0.5%. To be accurate, incorporating this number of WBs in the Small Areas only delivered a 0.1% share of the overall decrease. MRFs presented a contrasting viewpoint here, in Medium Areas 578 units were deployed and were able to recover 5%, however in Big Areas, because they were the second priority of MSW facility design after the preceding incineration plan, only 2% were recovered from MRFs. Yet, the deployed 74

units of 450 t/d capacity of incineration and prior reduction by TSs were able to drive the landfilled waste reduction up to 16%. The greatest recovery share was provided by Metropolitan Area with 100 units of 1,000 t/d capacity incinerator (Figure A. 12 in APPENDICES) that pushed the landfilled waste reduction to 39%. However, in terms of waste transportation, Medium Areas tops the fuel-saving by 16 ML/y due to high recovery in MRFs. It can be generalized that MRF is beneficial for landfilled waste reduction in the collecting stage (TWDS) while incineration in the treatment stage. This scenario was consistent with Indonesia's present master plan since the government has been advancing WtE initiatives across the country without any integration plan between Areas. Figure A. 13 in APPENDICES shows the national plan of waste management in Indonesia in Scenario 1 and Scenario 2 since both share the same MSW facilities number.

**Scenario 2: Basic Improvement and Post Area Integration**, improved Scenario 1 with the integration of Areas when there is extra capacity and overcapacity of implemented incinerators in Metropolitan Areas. In all, 40 Areas were scheduled to transfer their MSW to 32 Metropolitan Areas that had surplus room for operation in a total of 100 incinerators. However, 16 of the transferring Areas were from Metropolitan Areas, which means there were many incinerators with overcapacity. This scenario reduced landfilled waste by 62%, resulting in 20 Mt/y of MSW being landfilled. A change in the MSW management system may save most of the investment in MSW facilities while influencing the other sides. Especially the MSW transportation system in this situation. The transportation distance constraint was chosen to be within the relevant average transportation distance, although part of the real landfill in the region was not that far away. This technically escalates the transportation distance and fuel consumption in the operation, yet in total still below BAU at 276 ML/y of fuel for transportation. Scenario 2 requires only an additional 2 ML/y of gasoline to transport the MSW to the incinerators with the new system in comparison to Scenario 1. Nevertheless, the targeted landfilled waste reduction was achieved.

**Scenario 3: Basic Improvement and Prior Area Integration**, lowered the most amid other scenarios up to 34 Mt/y leaving just 19 Mt/y of MSW to be landfilled. Other than utilizing TSs (Figure A. 14 in APPENDICES) as the base collection and MRFs (Figure A. 15 in APPENDICES) as the base recovery, Scenario 3 provided a distinct viewpoint on the integration of Areas in the execution of the WtE program. This scenario provided a combination of Areas to calculate the needed unit number of incinerators beforehand, such that no unused capacity exists. Scenario 3 was successful in integrating 53 Areas to transfer their MSW into 34 Areas with a total of 139 incinerators in Metropolitan Areas (Figure A. 16 in APPENDICES). As a result, the scenario was able to cut landfill waste by 64%. Similarly, this situation was confronted with the same issue of growing transportation distance and fuel needs. However, since the Area mix was predetermined, the maximum possible combination was achieved and impacted on the fuel needs as much as 28 ML/y more fuel required for transportation of MSW in comparison to BAU. Aside from that, this scenario was superior to other scenarios in terms of landfilled waste reduction and achievement of the objective, this scenario was also deemed a promising alternative method for the future of MSW planning. The generated national planning of waste management in Indonesia in Scenario 3 can be seen in Figure A. 17 in APPENDICES.

#### **5.3.4. GHG Emission Reduction**

Following the landfilled waste reduction study, the GHG emissions reduction analysis was carried out using the methods provided in Chapter 5.2.8 as a development of methods in Chapter 3.2.8. prior analysis results were essential components in the GHG emissions reduction study. The details on required GHG emissions analysis data were summarized in Table A. 18 in APPENDICES. Table 5.11 shows the GHG emission estimates for each scenario considered.

Table 5.11 Details on GHG Emission Reduction Analysis Results in National Model.

<b>GHG Emission (MtCO<sub>2</sub>e/y)</b>	<b>SC 0</b>	<b>SC 1</b>	<b>SC 2</b>	<b>SC 3</b>
Transportation	0.8	0.7	0.7	0.9
Landfilling of mix MSW	36.1	10.3	9.7	8.2
Composting	-	0.6	0.6	0.5
Incineration	-	11.4	12.9	13.3
<b>Total GHG Emission</b>	<b>36.9</b>	<b>23.0</b>	<b>23.9</b>	<b>22.8</b>
GHG Emission Reduction	-	13.9	13.0	14.1
GHG Emission Reduction (%)	-	0.49	0.45	0.49

In the current circumstances, GHG emissions from MSW-related activities were started at 36.9 MtCO<sub>2</sub>e/y. However, because reaching the target of 0.38% reduction was determined based on a comparison to the BAU [5], Scenario 0 will not be included in any reduction calculations.

Same as the result of GHG emissions analysis of Surabaya Model (Table 3.10), the activity of landfilling of mix MSW dominated the share of total GHG emissions. The basic improvement in Scenario 1 has the least reduction of this activity to only 10.3 MtCO<sub>2</sub>e/y, while the other two scenarios were reduced further with the integration of Areas to transfer their supposedly landfilled waste to the incinerator in Metropolitan Areas.

Scenario 1 and Scenario 2 have comparable results by only having a difference in the integration post-implementation of MSW facilities in Scenario 2. The distinguishable attribute was less landfilling of mixed MSW and more incineration in Scenario 2 due to the MSW transportation system. Nonetheless, this condition balances the GHG emission from transportation activity at 0.7 MtCO<sub>2</sub>e/y. In any way, the recovery occurring at MRFs also had a role, as seen by the 0.1 MtCO<sub>2</sub>e/y decreases in transportation activity and since incineration placed in the treatment segment where it does not affect the amount of waste needed to be transported. However, having MRFs was associated with having composting sites, which resulted in an additional 0.6 MtCO<sub>2</sub>e/y in composting activity. The addition of an incinerator to

the system also contributes to GHG emissions, although in the grand scheme of things, total GHG emissions were cut far further than the national objective [5] in both Scenarios at 0.49% and 0.45%, respectively for Scenario 1 and Scenario 2.

Scenario 3 had the greatest reduction in GHG emissions at 14.1 MtCO<sub>2</sub>e/y, overcoming the target by 0.11%. This significant decrease in GHG emissions was generated by the greatest reduction in landfill waste. Tradeoffs of GHG emissions due to the integration can be seen in the higher transportation and incineration activity with the lower landfilling of mixed MSW and composting. This came to the picture due to the difference in priority of planning where Scenario 3, unlike Scenario 2, integrated the Areas before any implementation of MSW facilities. It resulted in less MRF unit number and consequently less composting unit number.

Based on the findings, strategic adjustments in the MSW system employing the recycling strategy and energy recovery approach were found to be crucial for the give and take on GHG emissions reduction. The combination of these techniques seems to be the most effective strategy to further cut GHG emissions. One of the potential techniques to be applied in the future is the recovery of recyclables at both the source and collection segments, as well as the management of residue as a source in waste to energy recovery projects.

### **5.3.5. Cost**

The total cost analysis considered both information from landfilled waste reduction analysis and GHG emission reduction analysis. Table 5.12 illustrates the details and direct comparison on cost analysis of each attribute for every scenario studied.

Table 5.12 Details on Cost Analysis Result in National Model.

<b>Cost (trillion IDR/y)</b>	<b>SC 0</b>	<b>SC 1</b>	<b>SC 2</b>	<b>SC 3</b>
Investment	1	6	6	7
OM	12	39	38	41
Fuel for Transportation	2	1	1	2
Tipping for Landfilling	10	3	3	2
<b>Subtotal</b>	<b>24</b>	<b>48</b>	<b>48</b>	<b>52</b>
Revenue of Recyclables	0.01	0.36	0.36	0.33
Revenue of Electricity	-	0.05	0.05	0.05
Revenue of WtE Incentive	-	16.48	16.93	18.15
<b>Total</b>	<b>24</b>	<b>32</b>	<b>31</b>	<b>33</b>

\*1 USD = 14,800 IDR (based on 2020 estimate)

Scenario 0 began with a total cost of 24 trillion IDR/y as the base of all comparisons, taking into account the lifespan of all new MSW facilities. The leading category, like in other scenarios, was OM cost, which accounted for half of the overall cost. This is pictured perfectly in Scenario 1 and Scenario 2 with the most installed MSW facility numbers, resulting in the largest OM cost of all. However, Scenario 3 topped the investment cost with more incinerators for the prior integration system. The fewer MRFs, and composting sites, required were not balancing the investment cost enough, keeping Scenario 3 at the top with 7 trillion IDR/y. As a result, these MSW facilities earned the maximum money from recyclable recovery, electricity, and WtE incentives, squeezing the overall cost into 33 trillion IDR/y, a slightly over Scenario 1 and Scenario 2.

The OM and investment cost consists of mainly the incinerators, due to the unit number and high basic cost requirement of the incinerator itself. TSs took an average of 24% and 7% of total OM and investment costs, respectively, as the basic collecting point in all Areas. On the other hand, incinerators averagely cost 73% and 90% of total OM and investment costs, respectively. Scenario 3, with the prior integration, maximized the possible combination of Areas for integration, resulting in the least landfilled waste (Table 5.10) having the least tipping for landfilling cost and in return the highest fuel for

transportation cost. Higher than the BAU, shows that a strategical integration should be considered instead of maximized one. However, the promised revenue from different sources (recyclables, electricity selling, incentive support) helps incinerators to perform in the system.

Comparing the performances by the cost-benefit analysis (Table 5.13), showed the ratio of MSW facility investment in terms of landfilled waste reduction and GHG emission to the cost required. Scenario 1 led to the least cost required to reduce GHG emissions at 2.32 million IDR/MtCO<sub>2</sub>e while Scenario 2 for the landfilled waste reduction at 0.95 million IDR/Mt. Scenario 3 had less cost required for GHG emissions reduction in comparison to Scenario 2 yet too pricy to reduce the landfilled waste with all those incinerators required.

Table 5.13 Details on Cost-Benefit Analysis Results in National Model.

Details	SC 0	SC 1	SC 2	SC 3
Cost/Landfilled Waste Reduction (million IDR/Mt)	13.18	1.01	0.95	0.98
Cost/GHG emissions Reduction (million IDR/MtCO <sub>2</sub> e)	-	2.32	2.38	2.34

**5.4 SUMMARY**

RA Centroid deemed as valid representative of temporary waste disposal sites (TS or MRF) with 98% compatibility data to determine missing landfill, to establish transportation routes to any treatment facilities, to set up possible integration between Areas, and further to evaluate both cost and GHG emissions reduction. Utilizing centroid allowed the Surabaya Model to be expanded to a national scale model.

According to the findings of the national scale model, Scenario 3 which is equipped with various MSW facilities based on a recycling method in the basic improvement and the integration of Areas, performed the best in most assessments. This scenario meets the national objectives with the highest landfill waste

reduction, the lowest GHG emission, and reasonable cost for such achievements in reductions. This approach and scenario are particularly relevant in other developing nations looking to build waste management systems based on recycling and energy recovery.

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## 6. CONCLUSION

Indonesia is tackling the MSW problems by shifting from landfilling orientation to promoting the recycling and energy recovery orientation. However, establishing a national plan without a credible and adequate database is nearly impossible. Thus, Surabaya City, with the available complete data, was proposed to construct the Surabaya Model as the foundational data and utilize centroid as the replacement and attribute of projecting the missing data on MSW facilities. The secured model and data then expanded to develop a national plan with specific strategies based on recycling and energy recovery to attain the national targets of landfilled waste reduction at 30% and the waste sector of GHG emissions reduction at 0.38% in Indonesia.

The **first chapter** explains the reason for this research was the development of a national model out of the expansion of the Surabaya Model and centroid implementation as the replacement and basic projection of missing MSW facilities. Both general and sectional objectives were described in this chapter.

The **second chapter** provides some background study on MSW management in Indonesia, especially in Surabaya City. Surabaya research's entire data led to it becoming the pilot study and filling up the lacking data for future analysis in this research. This chapter also discusses the demographic categories of cities and regions, as well as the MSW facilities that are promising for further investigation.

Surabaya Model was generated as prior research for the national scale model. **Chapter 3** discusses the implementation of GIS data of TSS, MRFs, landfill, and road networks to develop the Surabaya Model to estimate both cost and GHG emissions. Focusing on the replacement of TS to MRF, this chapter

analyzed 3 additional scenarios. Scenario 3: Distributed MRF System results best in overall cost yet handicapped in transportation cost due to extended transportation distance by the new transportation system. Here, we also conclude that TWDSs and landfill geographical position in each area are highly necessary to expand the Surabaya Model into the national scale model.

**Chapter 4** discusses waste banks in Surabaya as another MSW facility worth considering in the MSW management system. Waste banks may only provide a little reduction in the overall system but provide higher quality material. In Surabaya with 4% of total households participating throughout 755 Unit WBs, 0.16% of generated MSW was recovered. The information on the unit number, recovery rate, recyclable items, and prices are necessary as base calculations in further analysis.

**Chapter 5** demonstrates that Residential and/or Working Area (RA) Centroids are a legitimate representation of temporary waste disposal sites (TS and MRF) with 98% compatibility data that may be used in further in-depth analyses with a correlation of geographical location. Scenario 3: Basic Improvement and Prior Area Integration, did the best in most evaluations since it is equipped with different MSW facilities based on a recycling process and energy recovery. This scenario achieved the national targets with the biggest landfill waste reduction, lowest GHG emissions, and reasonable cost per reduction achieved. This strategy and scenario are also applicable in other developing countries that are striving to construct waste management systems based on recycling and energy recovery.

In summary, this study presented a methodology for developing a national waste management plan that considers recycling and energy recovery as well as population size and area integration in Indonesia which addressed the challenge of reducing landfilled waste and GHG emissions, which is common in Southeast Asia.

## APPENDICES

Table A. 1 Details on Database of TWDSs.

TWDS	Latitude	Longitude	Distance to Landfill (km)	Cost/trip (IDR)	Capacity (m3)	Frequency (trip/y)	Fuel (L/trip)	Waste Input (t/y)	Recovered (t/y)	Residue (t/y)
<b>Landfill</b>										
Benowo	-7.2188	112.625	-	-	-	-	-	-	-	-
<b>MRF</b>										
Sutorejo (MRF 1)	-7.258	112.795	26.8	121,847	6	540	23.7	3,687.8	2,488.6	1,199.2
Jambangan (MRF 2)	-7.317	112.717	25.6	121,119	14	360	23.5	1,142.6	687.1	455.5
<b>TS</b>										
Alas Malang	-7.262	112.643	9.8	85,331	8	132	16.6	425.9	14.5	411.4
Ampel Makam	-7.228	112.745	21.5	118,496	6	48	23.0	116.1	3.9	112.2
Ampel Pariwisata	-7.230	112.746	21.6	118,529	14	1,260	23.0	7,113.7	241.5	6,872.2
Asrama Brimob Nginden	-7.302	112.772	18.1	102,998	6	96	20.0	232.3	7.9	224.4

TWDS	Latitude	Longitude	Distance to Landfill (km)	Cost/trip (IDR)	Capacity (m3)	Frequency (trip/y)	Fuel (L/trip)	Waste Input (t/y)	Recovered (t/y)	Residue (t/y)
Asrama Brimob PPI	-7.235	112.724	25.5	121,059	8	180	23.5	580.7	19.7	561.0
Babadan	-7.311	112.674	18.4	103,352	8	360	20.1	1,161.4	39.4	1,122.0
Babat Jerawat	-7.246	112.630	6.9	76,771	14	180	14.9	1,016.2	34.5	981.7
Babatan Pilang	-7.309	112.675	18.2	103,149	14	720	20.0	4,065.0	138.0	3,927.0
Balas Klumprik	-7.328	112.685	21.7	118,612	14	360	23.0	2,032.5	69.0	1,963.5
Balongsari	-7.260	112.679	12.5	97,637	14	360	19.0	2,032.5	69.0	1,963.5
Bangkingan	-7.315	112.649	17.5	102,416	8	132	19.9	425.9	14.5	411.4
Bangkingan Aspol	-7.321	112.652	18.0	102,936	8	132	20.0	425.9	14.5	411.4
Bangunsari	-7.239	112.717	18.6	103,543	14	360	20.1	2,032.5	69.0	1,963.5
Barata Jaya	-7.305	112.761	24.5	120,403	14	540	23.4	3,048.7	103.5	2,945.2
Bendul Merisi	-7.311	112.744	4.2	69,172	14	720	13.4	4,065.0	138.0	3,927.0
Benowo Krajan	-7.236	112.612	20.3	117,714	6	360	22.9	871.1	29.6	841.5

TWDS	Latitude	Longitude	Distance to Landfill (km)	Cost/trip (IDR)	Capacity (m3)	Frequency (trip/y)	Fuel (L/trip)	Waste Input (t/y)	Recovered (t/y)	Residue (t/y)
Benteng	-7.224	112.739	23.8	119,928	14	1,800	23.3	10,162.4	345.0	9,817.4
Bhakti Husada	-7.266	112.765	23.7	119,919	14	720	23.3	4,065.0	138.0	3,927.0
Boezem Morokrembangan	-7.232	112.712	22.1	118,848	6	48	23.1	116.1	3.9	112.2
Bogangin	-7.327	112.709	16.8	101,742	14	360	19.8	2,032.5	69.0	1,963.5
Bogen Tambaksari	-7.251	112.758	24.9	120,621	14	540	23.4	3,048.7	103.5	2,945.2
Bratang	-7.297	112.761	23.9	120,022	14	1,440	23.3	8,129.9	276.0	7,853.9
Bratang Lapangan	-7.302	112.748	23.9	120,006	14	360	23.3	2,032.5	69.0	1,963.5
Bringin	-7.261	112.652	11.0	96,258	14	192	18.7	1,084.0	36.8	1,047.2
Bukit Barisan	-7.26	112.723	20.3	117,712	14	1,080	22.9	6,097.4	207.0	5,890.4
Bukit Mas	-7.301	112.707	23.0	119,431	14	180	23.2	1,016.2	34.5	981.7

TWDS	Latitude	Longitude	Distance to Landfill (km)	Cost/trip (IDR)	Capacity (m3)	Frequency (trip/y)	Fuel (L/trip)	Waste Input (t/y)	Recovered (t/y)	Residue (t/y)
Bulak Banteng	-7.216	112.760	24.3	120,274	14	720	23.4	4,065.0	138.0	3,927.0
Bulak Banteng Timur	-7.220	112.769	24.7	120,551	6	360	23.4	871.1	29.6	841.5
Bungurasih	-7.349	112.725	31.0	138,672	14	360	26.9	2,032.5	69.0	1,963.5
Buntaran	-7.251	112.674	14.5	99,609	8	192	19.3	619.4	21.0	598.4
Candi Lontar	-7.266	112.67	12.2	97,440	14	360	18.9	2,032.5	69.0	1,963.5
Candi Puro	-7.258	112.759	23.2	119,551	10	360	23.2	1,451.8	49.3	1,402.5
Demak Kali	-7.254	112.720	18.7	103,566	14	360	20.1	2,032.5	69.0	1,963.5
Dinoyo	-7.278	112.743	20.0	104,840	14	720	20.4	4,065.0	138.0	3,927.0
Dukuh Bulak Banteng	-7.220	112.768	24.7	120,555	14	540	23.4	3,048.7	103.5	2,945.2
Dupak	-7.243	112.718	18.0	102,945	8	540	20.0	1,742.1	59.1	1,683.0
Dupak Prau	-7.245	112.727	18.6	103,533	14	540	20.1	3,048.7	103.5	2,945.2

TWDS	Latitude	Longitude	Distance to Landfill (km)	Cost/trip (IDR)	Capacity (m3)	Frequency (trip/y)	Fuel (L/trip)	Waste Input (t/y)	Recovered (t/y)	Residue (t/y)
Gayung Pring	-7.338	112.728	26.5	121,651	6	540	23.6	1,306.6	44.4	1,262.2
Gayungsari	-7.332	112.724	26.7	121,792	8	360	23.6	1,161.4	39.4	1,122.0
Gebang Keputih	-7.284	112.785	25.2	120,824	14	720	23.5	4,065.0	138.0	3,927.0
Genting	-7.244	112.713	18.0	102,949	6	360	20.0	871.1	29.6	841.5
Greges	-7.230	112.683	13.3	98,423	14	120	19.1	677.5	23.0	654.5
Griya Citra Asri	-7.254	112.648	9.0	82,923	8	180	16.1	580.7	19.7	561.0
Gubeng Masjid	-7.266	112.753	22.0	118,833	6	360	23.1	871.1	29.6	841.5
Indrapura PLN	-7.231	112.732	19.1	103,968	14	360	20.2	2,032.5	69.0	1,963.5
ITS	-7.290	112.790	26.2	121,460	14	540	23.6	3,048.7	103.5	2,945.2
Jagir	-7.303	112.747	23.9	119,986	14	360	23.3	2,032.5	69.0	1,963.5
Jajar Tunggal	-7.319	112.70	22.9	119,380	14	360	23.2	2,032.5	69.0	1,963.5
Jati Purwo	-7.222	112.75	22.5	119,154	8	360	23.1	1,161.4	39.4	1,122.0

TWDS	Latitude	Longitude	Distance to Landfill (km)	Cost/trip (IDR)	Capacity (m3)	Frequency (trip/y)	Fuel (L/trip)	Waste Input (t/y)	Recovered (t/y)	Residue (t/y)
Jatisrono	-7.218	112.749	22.9	119,400	8	180	23.2	580.7	19.7	561.0
Jawar	-7.225	112.616	1.9	62,581	6	48	12.2	116.1	3.9	112.2
Jayamix	-7.252	112.710	18.0	102,945	14	720	20.0	4,065.0	138.0	3,927.0
Jemur Wonosari	-7.325	112.739	28.3	122,822	10	540	23.8	2,177.7	73.9	2,103.7
Jetis Kulon	-7.308	112.734	23.0	119,460	14	720	23.2	4,065.0	138.0	3,927.0
Jl. Pegirian	-7.234	112.743	22.3	118,973	10	360	23.1	1,451.8	49.3	1,402.5
Jl. Semut Kali	-7.244	112.743	20.6	117,928	14	540	22.9	3,048.7	103.5	2,945.2
Jogoloyo	-7.307	112.713	25.2	120,843	8	360	23.5	1,161.4	39.4	1,122.0
Joyoboyo	-7.300	112.732	22.8	119,339	14	1,440	23.2	8,129.9	276.0	7,853.9
Jurang Kuping	-7.243	112.607	4.9	71,235	8	120	13.8	387.1	13.1	374.0
Kalianak	-7.230	112.706	15.8	100,827	6	120	19.6	290.4	9.9	280.5
Kalibokor	-7.287	112.751	21.9	118,723	14	720	23.1	4,065.0	138.0	3,927.0

TWDS	Latitude	Longitude	Distance to Landfill (km)	Cost/trip (IDR)	Capacity (m3)	Frequency (trip/y)	Fuel (L/trip)	Waste Input (t/y)	Recovered (t/y)	Residue (t/y)
Kalijudan	-7.258	112.783	26.7	121,824	14	360	23.7	2,032.5	69.0	1,963.5
Kalimas Baru	-7.217	112.737	20.5	117,838	14	360	22.9	2,032.5	69.0	1,963.5
Kaliwaron	-7.263	112.769	24.4	120,337	14	720	23.4	4,065.0	138.0	3,927.0
Kandangan	-7.251	112.653	9.3	83,803	14	180	16.3	1,016.2	34.5	981.7
Kangean	-7.272	112.746	22.8	119,300	14	1,080	23.2	6,097.4	207.0	5,890.4
Karah	-7.313	112.714	25.5	121,047	14	360	23.5	2,032.5	69.0	1,963.5
Karang Gayam	-7.253	112.758	22.3	118,995	14	720	23.1	4,065.0	138.0	3,927.0
Karang Pilang	-7.34	112.694	25.3	120,893	14	360	23.5	2,032.5	69.0	1,963.5
Karang Poh	-7.263	112.680	12.8	98,015	14	720	19.0	4,065.0	138.0	3,927.0
Kayon	-7.269	112.748	21.1	118,237	10	360	23.0	1,451.8	49.3	1,402.5

TWDS	Latitude	Longitude	Distance to Landfill (km)	Cost/trip (IDR)	Capacity (m3)	Frequency (trip/y)	Fuel (L/trip)	Waste Input (t/y)	Recovered (t/y)	Residue (t/y)
Kebonsari Makam	-7.330	112.715	27.3	122,145	8	180	23.7	580.7	19.7	561.0
Kebraon	-7.332	112.696	25.5	121,021	14	360	23.5	2,032.5	69.0	1,963.5
Kedondong	-7.272	112.738	20.5	117,867	14	720	22.9	4,065.0	138.0	3,927.0
Kejaksaan Sukomanunggal	-7.270	112.695	15.4	100,448	8	48	19.5	154.9	5.3	149.6
Kejawen Putih	-7.284	112.803	28.4	122,854	14	180	23.9	1,016.2	34.5	981.7
Kembang Kuning	-7.282	112.729	19.9	104,720	14	1800	20.3	10,162.4	345.0	9,817.4
Kemlaten	-7.33	112.708	24.1	120,172	14	360	23.3	2,032.5	69.0	1,963.5
Kendal Sari	-7.314	112.784	28.1	122,667	14	540	23.8	3,048.7	103.5	2,945.2
Kendangsari	-7.329	112.746	26.7	121,795	14	1,080	23.6	6,097.4	207.0	5,890.4
Kendung	-7.256	112.635	8.2	80,493	14	180	15.6	1,016.2	34.5	981.7

TWDS	Latitude	Longitude	Distance to Landfill (km)	Cost/trip (IDR)	Capacity (m3)	Frequency (trip/y)	Fuel (L/trip)	Waste Input (t/y)	Recovered (t/y)	Residue (t/y)
Kendung Makam	-7.248	112.635	8.2	80,558	14	360	15.6	2,032.5	69.0	1,963.5
Keputih Tinja	-7.295	112.807	28.5	122,956	14	120	23.9	677.5	23.0	654.5
Ketintang Baru Selatan	-7.324	112.723	26.7	121,765	14	720	23.6	4,065.0	138.0	3,927.0
Klakah Rejo	-7.253	112.649	9.1	83,101	8	360	16.1	1,161.4	39.4	1,122.0
Klampus	-7.287	112.776	24.4	120,347	14	720	23.4	4,065.0	138.0	3,927.0
Krembangan Barat	-7.236	112.734	21.2	118,304	10	1,080	23.0	4,355.3	147.9	4,207.5
Kutisari PLN	-7.341	112.747	28.6	122,985	14	360	23.9	2,032.5	69.0	1,963.5
Kuwukan	-7.277	112.659	13.4	98,577	8	720	19.1	2,322.8	78.9	2,244.0
Lakar Santri	-7.304	112.633	13.9	99,012	6	180	19.2	435.5	14.8	420.7
Langkir	-7.256	112.626	7.7	79,129	8	120	15.4	387.1	13.1	374.0
Legundi Anggrek	-7.262	112.752	22.3	119,029	14	720	23.1	4,065.0	138.0	3,927.0

TWDS	Latitude	Longitude	Distance to Landfill (km)	Cost/trip (IDR)	Capacity (m3)	Frequency (trip/y)	Fuel (L/trip)	Waste Input (t/y)	Recovered (t/y)	Residue (t/y)
Lidah Kulon	-7.312	112.652	16.9	101,868	14	180	19.8	1,016. 2	34.5	981.7
Lidah Wetan	-7.304	112.668	17.2	102,115	6	360	19.8	871.1	29.6	841.5
Makam Mataram	-7.277	112.713	17.9	102,838	14	1,620	20.0	9,146. 2	310.5	8,835.7
Makam Peneleh	-7.252	112.742	20.9	118,085	6	720	22.9	1,742. 1	59.1	1,683.0
Manukan Kulon	-7.260	112.662	12.0	97,165	14	720	18.9	4,065. 0	138.0	3,927.0
Manukan Telaga	-7.261	112.669	11.6	96,862	8	360	18.8	1,161. 4	39.4	1,122.0
Manyar Sabrangan	-7.289	112.763	25.4	120,985	10	360	23.5	1,451. 8	49.3	1,402.5
Mataram Utara	-7.275	112.715	17.6	102,526	8	540	19.9	1,742. 1	59.1	1,683.0
Mbah Ratu	-7.233	112.722	17.7	102,602	14	720	19.9	4,065. 0	138.0	3,927.0
Medokan Ayu	-7.326	112.796	41.7	166,779	14	720	32.4	4,065. 0	138.0	3,927.0
Medokan Semampir	-7.307	112.783	27.3	122,148	6	360	23.7	871.1	29.6	841.5

TWDS	Latitude	Longitude	Distance to Landfill (km)	Cost/trip (IDR)	Capacity (m3)	Frequency (trip/y)	Fuel (L/trip)	Waste Input (t/y)	Recovered (t/y)	Residue (t/y)
Memet	-7.245	112.790	26.6	121,761	14	360	23.6	2,032.5	69.0	1,963.5
Menanggal YKP	-7.345	112.723	30.5	138,409	14	360	26.9	2,032.5	69.0	1,963.5
Merapi	-7.261	112.728	19.8	104,615	14	360	20.3	2,032.5	69.0	1,963.5
Metro	-7.333	112.782	30.0	123,898	6	180	24.1	435.5	14.8	420.7
Mojoarum	-7.264	112.775	25.0	120,688	14	720	23.4	4,065.0	138.0	3,927.0
Mrutu Kalianyar	-7.213	112.755	23.8	119,935	14	360	23.3	2,032.5	69.0	1,963.5
Ngagel	-7.294	112.742	22.2	118,943	10	540	23.1	2,177.7	73.9	2,103.7
Ngagel Dadi	-7.293	112.749	22.3	119,022	14	540	23.1	3,048.7	103.5	2,945.2
Pacar Keling	-7.261	112.759	23.0	119,466	14	360	23.2	2,032.5	69.0	1,963.5
Pagesangan	-7.335	112.714	33.0	139,624	14	720	27.1	4,065.0	138.0	3,927.0
Pakal Madya	-7.246	112.617	5.7	73,491	8	180	14.3	580.7	19.7	561.0

TWDS	Latitude	Longitude	Distance to Landfill (km)	Cost/trip (IDR)	Capacity (m3)	Frequency (trip/y)	Fuel (L/trip)	Waste Input (t/y)	Recovered (t/y)	Residue (t/y)
Pandegiling	-7.275	112.736	19.2	104,089	10	1,080	20.2	4,355.3	147.9	4,207.5
PBI	-7.241	112.629	6.3	75,236	14	360	14.6	2,032.5	69.0	1,963.5
Pecindilan	-7.244	112.747	21.8	118,693	10	360	23.0	1,451.8	49.3	1,402.5
Penghela	-7.248	112.733	19.4	104,250	14	720	20.2	4,065.0	138.0	3,927.0
Penjaringan Sari	-7.322	112.784	28.8	123,116	14	720	23.9	4,065.0	138.0	3,927.0
Pesapen Pompa	-7.232	112.731	18.9	103,783	14	360	20.2	2,032.5	69.0	1,963.5
Petemon Kuburan	-7.267	112.726	19.3	104,132	8	180	20.2	580.7	19.7	561.0
Pirngadi	-7.253	112.734	20.3	117,753	14	360	22.9	2,032.5	69.0	1,963.5
Platuk Donomulyo	-7.222	112.768	24.5	120,400	14	360	23.4	2,032.5	69.0	1,963.5
Polda Jatim	-7.323	112.729	25.3	120,890	14	180	23.5	1,016.2	34.5	981.7

TWDS	Latitude	Longitude	Distance to Landfill (km)	Cost/trip (IDR)	Capacity (m3)	Frequency (trip/y)	Fuel (L/trip)	Waste Input (t/y)	Recovered (t/y)	Residue (t/y)
Pondok Indah Wiyung	-7.318	112.70	21.5	118,483	8	360	23.0	1,161. 4	39.4	1,122.0
Pondok Manggala	-7.327	112.683	22.1	118,873	6	180	23.1	435.5	14.8	420.7
Prapen	-7.312	112.757	25.9	121,277	14	180	23.5	1,016. 2	34.5	981.7
Prapen 88	-7.316	112.753	26.5	121,638	14	180	23.6	1,016. 2	34.5	981.7
Prapen DKK	-7.317	112.752	26.6	121,734	14	180	23.6	1,016. 2	34.5	981.7
Ps. Asem Rowo	-7.252	112.715	18.2	103,135	8	180	20.0	580.7	19.7	561.0
Ps. Babaan	-7.228	112.735	20.1	117,631	14	720	22.8	4,065. 0	138.0	3,927.0
Ps. Benowo	-7.234	112.612	4.2	69,086	14	180	13.4	1,016. 2	34.5	981.7
Ps. Beras Bendul Merisi	-7.306	112.737	23.0	119,471	14	720	23.2	4,065. 0	138.0	3,927.0
Ps. Gayung Kebonsari	-7.329	112.718	26.8	121,849	8	360	23.7	1,161. 4	39.4	1,122.0
Ps. Genteng	-7.258	112.740	22.1	118,868	14	180	23.1	1,016. 2	34.5	981.7

TWDS	Latitude	Longitude	Distance to Landfill (km)	Cost/trip (IDR)	Capacity (m3)	Frequency (trip/y)	Fuel (L/trip)	Waste Input (t/y)	Recovered (t/y)	Residue (t/y)
Ps. Gubeng Masjid	-7.268	112.753	21.9	118,730	6	180	23.1	435.5	14.8	420.7
Ps. Kapasan	-7.241	112.75	21.8	118,680	14	360	23.0	2,032. 5	69.0	1,963.5
Ps. Kedurus	-7.320	112.705	22.6	119,208	14	360	23.1	2,032. 5	69.0	1,963.5
Ps. Kembang	-7.269	112.729	18.8	103,648	14	720	20.1	4,065. 0	138.0	3,927.0
Ps. Keputran Selatan	-7.278	112.744	20.1	117,571	14	360	22.8	2,032. 5	69.0	1,963.5
Ps. Manukan Wetan	-7.260	112.672	11.8	96,991	8	360	18.8	1,161. 4	39.4	1,122.0
Ps. Pucang	-7.284	112.752	21.4	118,435	14	360	23.0	2,032. 5	69.0	1,963.5
Ps. Sememi	-7.252	112.645	8.6	81,740	6	360	15.9	871.1	29.6	841.5
Ps. Simolawang	-7.237	112.754	22.1	118,851	14	1080	23.1	6,097. 4	207.0	5,890.4
Ps. Wiyung	-7.314	112.694	20.5	117,830	6	720	22.9	1,742. 1	59.1	1,683.0
Puri Lidah Kulon	-7.304	112.652	16.1	101,102	6	180	19.6	435.5	14.8	420.7

TWDS	Latitude	Longitude	Distance to Landfill (km)	Cost/trip (IDR)	Capacity (m3)	Frequency (trip/y)	Fuel (L/trip)	Waste Input (t/y)	Recovered (t/y)	Residue (t/y)
Puri Mas	-7.341	112.789	40.5	166,082	14	180	32.2	1,016.2	34.5	981.7
Putat Gede	-7.285	112.702	22.3	118,975	14	540	23.1	3,048.7	103.5	2,945.2
Raya Prapen	-7.313	112.756	26.0	121,366	14	360	23.6	2,032.5	69.0	1,963.5
Romokalisari	-7.197	112.646	5.9	74,064	6	180	14.4	435.5	14.8	420.7
RSAL	-7.311	112.739	23.8	119,941	6	360	23.3	871.1	29.6	841.5
Rungkut Alang Alang	-7.323	112.772	27.7	122,441	14	1,080	23.8	6,097.4	207.0	5,890.4
Rungkut Asri	-7.327	112.781	29.4	123,541	8	120	24.0	387.1	13.1	374.0
Rungkut Kidul	-7.331	112.771	30.5	138,419	14	1,440	26.9	8,129.9	276.0	7,853.9
Rungkut Menanggal	-7.338	112.778	40.4	166,053	14	720	32.2	4,065.0	138.0	3,927.0
Rusunawa Gunung Sari	-7.302	112.727	23.5	119,743	6	48	23.3	116.1	3.9	112.2
Sememi	-7.240	112.637	7.6	78,890	8	96	15.3	309.7	10.5	299.2
Semolowaru	-7.301	112.782	26.4	121,612	14	720	23.6	4,065.0	138.0	3,927.0

TWDS	Latitude	Longitude	Distance to Landfill (km)	Cost/trip (IDR)	Capacity (m3)	Frequency (trip/y)	Fuel (L/trip)	Waste Input (t/y)	Recovered (t/y)	Residue (t/y)
Semolowaru Bahari	-7.305	112.799	28.3	122,838	14	180	23.9	1,016.2	34.5	981.7
Sidotopo Wetan	-7.233	112.759	24.4	120,308	6	720	23.4	1,742.1	59.1	1,683.0
Simo Hilir	-7.274	112.705	18.7	103,625	8	720	20.1	2,322.8	78.9	2,244.0
Simo Katrungan	-7.271	112.714	16.8	101,741	8	360	19.8	1,161.4	39.4	1,122.0
Simo Rukun	-7.262	112.712	16.7	101,726	14	1,080	19.8	6,097.4	207.0	5,890.4
Simpang Dukuh	-7.26	112.741	21.5	118,509	10	360	23.0	1,451.8	49.3	1,402.5
Siti Khatijah	-7.308	112.734	23.0	119,452	6	180	23.2	435.5	14.8	420.7
Siwalankerto Landasan	-7.339	112.73	27.3	122,183	14	720	23.7	4,065.0	138.0	3,927.0
SMA 16	-7.309	112.76	25.5	121,011	6	120	23.5	290.4	9.9	280.5
Sonokwijenan	-7.280	112.697	23.9	120,009	14	720	23.3	4,065.0	138.0	3,927.0
Srikana	-7.274	112.758	22.1	118,848	10	1,440	23.1	5,807.1	197.1	5,610.0

TWDS	Latitude	Longitude	Distance to Landfill (km)	Cost/trip (IDR)	Capacity (m3)	Frequency (trip/y)	Fuel (L/trip)	Waste Input (t/y)	Recovered (t/y)	Residue (t/y)
Sukomanunggal	-7.265	112.697	14.4	99,451	14	540	19.3	3,048.7	103.5	2,945.2
Sulung	-7.244	112.742	20.5	117,848	14	720	22.9	4,065.0	138.0	3,927.0
Sumberejo	-7.228	112.601	4.6	70,332	6	48	13.7	116.1	3.9	112.2
Suryanata	-7.227	112.606	3.7	67,837	8	180	13.2	580.7	19.7	561.0
Taman Ketampon	-7.288	112.737	20.8	118,042	10	360	22.9	1,451.8	49.3	1,402.5
Tambak Asri	-7.240	112.714	17.8	102,711	6	720	19.9	1,742.1	59.1	1,683.0
Tambak Deres	-7.231	112.786	26.6	121,725	14	540	23.6	3,048.7	103.5	2,945.2
Tambak Dono	-7.216	112.605	5.3	72,233	10	360	14.0	1,451.8	49.3	1,402.5
Tambak Oso Wilangun	-7.212	112.653	7.8	79,417	8	180	15.4	580.7	19.7	561.0
Tambak Rejo	-7.243	112.76	22.1	118,885	10	2,160	23.1	8,710.6	295.7	8,414.9
Tambak Wedi	-7.209	112.775	26.8	121,843	6	360	23.7	871.1	29.6	841.5
Tanjung Sadari	-7.228	112.722	20.9	118,088	14	720	22.9	4,065.0	138.0	3,927.0

TWDS	Latitude	Longitude	Distance to Landfill (km)	Cost/trip (IDR)	Capacity (m3)	Frequency (trip/y)	Fuel (L/trip)	Waste Input (t/y)	Recovered (t/y)	Residue (t/y)
Teluk Kumai	-7.212	112.734	20.7	118,003	14	360	22.9	2,032.5	69.0	1,963.5
Tengger Kandangan	-7.257	112.656	10.4	95,647	14	360	18.6	2,032.5	69.0	1,963.5
Tenggilis Mejoyo	-7.318	112.764	27.0	121,958	14	720	23.7	4,065.0	138.0	3,927.0
Tenggilis Utara	-7.318	112.754	27.0	122,015	14	540	23.7	3,048.7	103.5	2,945.2
Thp Kenjeran	-7.238	112.795	28.1	122,677	6	360	23.8	871.1	29.6	841.5
THR	-7.253	112.753	21.8	118,700	14	120	23.0	677.5	23.0	654.5
Tubanan	-7.261	112.684	13.1	98,223	14	540	19.1	3,048.7	103.5	2,945.2
Tulus Harapan	-7.323	112.78	28.7	123,034	6	720	23.9	1,742.1	59.1	1,683.0
Waru Gunung 1	-7.346	112.685	26.3	121,567	14	540	23.6	3,048.7	103.5	2,945.2
Wiguna Timur	-7.338	112.804	39.8	142,866	14	360	27.7	2,032.5	69.0	1,963.5
Wisma Permai	-7.274	112.796	26.6	121,757	14	360	23.6	2,032.5	69.0	1,963.5

TWDS	Latitude	Longitude	Distance to Landfill (km)	Cost/trip (IDR)	Capacity (m3)	Frequency (trip/y)	Fuel (L/trip)	Waste Input (t/y)	Recovered (t/y)	Residue (t/y)
Wiyung	-7.314	112.694	20.5	117,844	8	360	22.9	1,161. 4	39.4	1,122.0
Wonobojo	-7.294	112.728	24.3	120,255	14	360	23.4	2,032. 5	69.0	1,963.5
Wonokromo	-7.300	112.737	22.1	118,889	8	720	23.1	2,322. 8	78.9	2,244.0
Wonokusumo Kidul	-7.225	112.752	22.9	119,392	14	720	23.2	4,065. 0	138.0	3,927.0
Wonorejo	-7.312	112.79	28.5	122,926	14	360	23.9	2,032. 5	69.0	1,963.5

Table A. 2 Mass Balance of All TSs in Scenario 0 and Scenario 1.

<b>Composition</b>	<b>Input (t/y)</b>	<b>%</b>	<b>Recycled (t/y)</b>	<b>%</b>	<b>Residue (t/y)</b>	<b>%</b>
Food Waste	175,987	37.5			175,987	38.8
Garden Waste	95,687	20.4			95,687	21.1
Plastic	68,144	14.5	7,859	49.3	60,286	13.3
Paper	24,469	5.2	5,655	35.5	18,814	4.1
Glass	4,734	1.0	1,324	8.3	3,410	0.8
Metal	2,332	0.5	1,098	6.9	1,234	0.3
Textile	17,302	3.7			17,302	3.8
Leather/Rubber	4,393	0.9			4,393	1.0
Hazardous Waste	1,087	0.2			1,087	0.2
Others	75,273	16.0			75,273	16.6
<b>Total</b>	<b>469,407</b>	<b>100.0</b>	<b>15,936</b>	<b>100.0</b>	<b>453,471</b>	<b>100.0</b>

Table A. 3 Mass Balance of MRF 1 in Scenario 0 and Scenario 1.

<b>Composition</b>	<b>Input (t/y)</b>	<b>%</b>	<b>Recycled (t/y)</b>	<b>%</b>	<b>Residue (t/y)</b>	<b>%</b>
Food Waste	1,730	46.9	1,390	55.9	339	28.3
Garden Waste	941	25.5	756	30.4	185	15.4
Plastic	372	10.1	169	6.8	203	17.0
Paper	268	7.3	121	4.9	146	12.2
Glass	63	1.7	28	1.1	34	2.9
Metal	52	1.4	24	0.9	28	2.4
Textile	99	2.7			99	8.2
Leather/Rubber	17	0.5			17	1.4
Hazardous Waste	4	0.1			4	0.4
Others	143	3.9			143	11.9
<b>Total</b>	<b>3,688</b>	<b>100.0</b>	<b>2,489</b>	<b>100.0</b>	<b>1,199</b>	<b>100.0</b>

Table A. 4 Mass Balance of MRF 2 in Scenario 0 and Scenario 1.

<b>Composition</b>	<b>Input (t/y)</b>	<b>%</b>	<b>Recycled (t/y)</b>	<b>%</b>	<b>Residue (t/y)</b>	<b>%</b>
Food Waste	536	46.9	410	59.6	126	27.7
Garden Waste	291	25.5	223	32.4	69	15.1
Plastic	115	10.1	27	3.9	88	19.4
Paper	83	7.3	19	2.8	64	14.0
Glass	19	1.7	5	0.7	15	3.3
Metal	16	1.4	4	0.5	12	2.7
Textile	31	2.7			31	6.7
Leather/Rubber	5	0.5			5	1.2
Hazardous Waste	1	0.1			1	0.3
Others	44	3.9			44	9.7
<b>Total</b>	<b>1,143</b>	<b>100.0</b>	<b>687</b>	<b>100.0</b>	<b>455</b>	<b>100.0</b>

Table A. 5 Total Mass Balance in Scenario 0 and Scenario 1.

<b>Composition</b>	<b>Input (t/y)</b>	<b>%</b>	<b>Recycled (t/y)</b>	<b>%</b>	<b>Residue (t/y)</b>	<b>%</b>
Food Waste	178,252	37.6	1,800	9.4	176,452	38.8
Garden Waste	96,919	20.4	979	5.1	95,941	21.1
Plastic	68,632	14.5	8,054	42.1	60,577	13.3
Paper	24,820	5.2	5,795	30.3	19,024	4.2
Glass	4,816	1.0	1,357	7.1	3,459	0.8
Metal	2,400	0.5	1,126	5.9	1,274	0.3
Textile	17,431	3.7			17,431	3.8
Leather/Rubber	4,415	0.9			4,415	1.0
Hazardous Waste	1,092	0.2			1,092	0.2
Others	75,460	15.9			75,460	16.6
<b>Total</b>	<b>474,237</b>	<b>100.0</b>	<b>19,111</b>	<b>100.0</b>	<b>455,126</b>	<b>100.0</b>

Table A. 6 Mass Balance of All TSs in Scenario 2.

<b>Composition</b>	<b>Input (t/y)</b>	<b>Recycled (t/y)</b>			<b>Residue (t/y)</b>	
Food Waste	83,458	37.5			83,458	38.8
Garden Waste	45,378	20.4			45,378	21.1
Plastic	32,316	14.5	3,727	49.3	28,589	13.3
Paper	11,604	5.2	2,682	35.5	8,922	4.1
Glass	2,245	1.0	628	8.3	1,617	0.8
Metal	1,106	0.5	521	6.9	585	0.3
Textile	8,205	3.7			8,205	3.8
Leather/Rubber	2,083	0.9			2,083	1.0
Hazardous Waste	515	0.2			515	0.2
Others	35,696	16.0			35,696	16.6
<b>Total</b>	<b>222,605</b>	<b>100.0</b>	<b>7,557</b>	<b>100.0</b>	<b>215,048</b>	<b>100.0</b>

Table A. 7 Mass Balance of MRF 1 in Scenario 2.

<b>Composition</b>	<b>Input (t/y)</b>	<b>Recycled (t/y)</b>			<b>Residue (t/y)</b>	
Food Waste	1,730	46.9	1,390	55.9	339	28.3
Garden Waste	941	25.5	756	30.4	185	15.4
Plastic	372	10.1	169	6.8	203	17.0
Paper	268	7.3	121	4.9	146	12.2
Glass	63	1.7	28	1.1	34	2.9
Metal	52	1.4	24	0.9	28	2.4
Textile	99	2.7			99	8.2
Leather/Rubber	17	0.5			17	1.4
Hazardous Waste	4	0.1			4	0.4
Others	143	3.9			143	11.9
<b>Total</b>	<b>3,688</b>	<b>100.0</b>	<b>2,489</b>	<b>100.0</b>	<b>1,199</b>	<b>100.0</b>

Table A. 8 Mass Balance of MRF 2 in Scenario 2.

<b>Composition</b>	<b>Input (t/y)</b>	<b>Recycled (t/y)</b>		<b>Residue (t/y)</b>		
Food Waste	536	46.9	410	59.6	126	27.7
Garden Waste	291	25.5	223	32.4	69	15.1
Plastic	115	10.1	27	3.9	88	19.4
Paper	83	7.3	19	2.8	64	14.0
Glass	19	1.7	5	0.7	15	3.3
Metal	16	1.4	4	0.5	12	2.7
Textile	31	2.7			31	6.7
Leather/Rubber	5	0.5			5	1.2
Hazardous Waste	1	0.1			1	0.3
Others	44	3.9			44	9.7
<b>Total</b>	<b>1,143</b>	<b>100.0</b>	<b>687</b>	<b>100.0</b>	<b>455</b>	<b>100.0</b>

Table A. 9 Mass Balance of New MRFs in Scenario 2.

<b>Composition</b>	<b>Input (t/y)</b>	<b>Recycled (t/y)</b>		<b>Residue (t/y)</b>		
Food Waste	92,529	37.5	72,556	55.8	19,973	17.1
Garden Waste	50,310	20.4	39,450	30.3	10,860	9.3
Plastic	35,828	14.5	12,310	9.5	23,519	20.1
Paper	12,865	5.2	4,420	3.4	8,445	7.2
Glass	2,489	1.0	855	0.7	1,634	1.4
Metal	1,226	0.5	421	0.3	805	0.7
Textile	9,097	3.7			9,097	7.8
Leather/Rubber	2,309	0.9			2,309	2.0
Hazardous Waste	571	0.2			571	0.5
Others	39,576	16.0			39,576	33.9
<b>Total</b>	<b>246,802</b>	<b>100.0</b>	<b>130,013</b>	<b>100.0</b>	<b>116,789</b>	<b>100.0</b>

Table A. 10 Total Mass Balance in Scenario 2.

<b>Composition</b>	<b>Input (t/y)</b>	<b>Recycled (t/y)</b>		<b>Residue (t/y)</b>		
Food Waste	178,252	37.6	74,357	52.8	103,896	31.2
Garden Waste	96,919	20.4	40,429	28.7	56,490	16.9
Plastic	68,632	14.5	16,232	11.5	52,399	15.7
Paper	24,820	5.2	7,242	5.1	17,577	5.3
Glass	4,816	1.0	1,516	1.1	3,300	1.0
Metal	2,400	0.5	969	0.7	1,431	0.4
Textile	17,431	3.7			17,431	5.2
Leather/Rubber	4,415	0.9			4,415	1.3
Hazardous Waste	1,092	0.2			1,092	0.3
Others	75,460	15.9			75,460	22.6
<b>Total</b>	<b>474,237</b>	<b>100.0</b>	<b>140,746</b>	<b>100.0</b>	<b>333,491</b>	<b>100.0</b>

Table A. 11 Mass Balance of All TSs which Transported Directly to Landfill in Scenario 3.

<b>Composition</b>	<b>Input (t/y)</b>	<b>Recycled (t/y)</b>		<b>Residue (t/y)</b>		
Food Waste	82,808	37.5			82,808	38.8
Garden Waste	45,024	20.4			45,024	21.1
Plastic	32,064	14.5	3,698	49.3	28,367	13.3
Paper	11,514	5.2	2,661	35.5	8,853	4.1
Glass	2,227	1.0	623	8.3	1,604	0.8
Metal	1,097	0.5	517	6.9	580	0.3
Textile	8,141	3.7			8,141	3.8
Leather/Rubber	2,067	0.9			2,067	1.0
Hazardous Waste	511	0.2			511	0.2
Others	35,419	16.0			35,419	16.6
<b>Total</b>	<b>220,873</b>	<b>100.0</b>	<b>7,498</b>	<b>100.0</b>	<b>213,375</b>	<b>100.0</b>

Table A. 12 Mass Balance of MRF 1 in Scenario 3.

<b>Composition</b>	<b>Input (t/y)</b>	<b>Recycled (t/y)</b>		<b>Residue (t/y)</b>		
Food Waste	4,068	42.2	3,270	54.9	798	21.7
Garden Waste	2,212	22.9	1,778	29.8	434	11.8
Plastic	1,186	12.3	538	9.0	648	17.6
Paper	601	6.2	273	4.6	329	8.9
Glass	131	1.4	59	1.0	71	1.9
Metal	92	1.0	42	0.7	50	1.4
Textile	307	3.2			307	8.3
Leather/Rubber	67	0.7			67	1.8
Hazardous Waste	17	0.2			17	0.5
Others	959	10.0			959	26.1
<b>Total</b>	<b>9,640</b>	<b>100.0</b>	<b>5,959</b>	<b>100.0</b>	<b>3,681</b>	<b>100.0</b>

Table A. 13 Mass Balance of MRF 2 in Scenario 3.

<b>Composition</b>	<b>Input (t/y)</b>	<b>Recycled (t/y)</b>		<b>Residue (t/y)</b>		
Food Waste	2,430	42.2	1,858	59.0	572	21.9
Garden Waste	1,321	22.9	1,010	32.1	311	11.9
Plastic	709	12.3	166	5.3	543	20.8
Paper	359	6.2	84	2.7	275	10.5
Glass	78	1.4	18	0.6	60	2.3
Metal	55	1.0	13	0.4	42	1.6
Textile	183	3.2			183	7.0
Leather/Rubber	40	0.7			40	1.5
Hazardous Waste	10	0.2			10	0.4
Others	573	10.0			573	22.0
<b>Total</b>	<b>5,759</b>	<b>100.0</b>	<b>3,149</b>	<b>100.0</b>	<b>2,610</b>	<b>100.0</b>

Table A. 14 Mass Balance of New MRFs in Scenario 3.

<b>Composition</b>	<b>Input (t/y)</b>		<b>Recycled (t/y)</b>		<b>Residue (t/y)</b>	
Food Waste	89,216	37.5	69,959	55.8	19,258	17.1
Garden Waste	48,509	20.4	38,038	30.3	10,471	9.3
Plastic	34,546	14.5	11,869	9.5	22,677	20.1
Paper	12,405	5.2	4,262	3.4	8,143	7.2
Glass	2,400	1.0	825	0.7	1,575	1.4
Metal	1,182	0.5	406	0.3	776	0.7
Textile	8,771	3.7			8,771	7.8
Leather/Rubber	2,227	0.9			2,227	2.0
Hazardous Waste	551	0.2			551	0.5
Others	38,159	16.0			38,159	33.9
<b>Total</b>	<b>237,965</b>	<b>100.0</b>	<b>125,358</b>	<b>100.0</b>	<b>112,607</b>	<b>100.0</b>

Table A. 15 Total Mass Balance in Scenario 3.

<b>Composition</b>	<b>Input (t/y)</b>		<b>Recycled (t/y)</b>		<b>Residue (t/y)</b>	
Food Waste	178,523	37.6	75,086	52.9	103,436	31.1
Garden Waste	97,066	20.5%	40,826	28.8%	56,240	16.9%
Plastic	68,505	14.4%	16,270	11.5%	52,234	15.7%
Paper	24,878	5.2%	7,279	5.1%	17,599	5.3%
Glass	4,836	1.0%	1,525	1.1%	3,311	1.0%
Metal	2,426	0.5%	977	0.7%	1,449	0.4%
Textile	17,402	3.7%			17,402	5.2%
Leather/Rubber	4,401	0.9%			4,401	1.3%
Hazardous Waste	1,089	0.2%			1,089	0.3%
Others	75,111	15.8%			75,111	22.6%
<b>Total</b>	<b>474,237</b>	<b>100.0%</b>	<b>141,964</b>	<b>100.0%</b>	<b>332,273</b>	<b>100.0%</b>

Activity	Direct GHG Emissions	Indirect GHG Savings	Net GHG Emissions	Unit
Transportation	12.75	0.00	12.75	kg of CO2-eq/tonne of waste
Landfilling of mix MSW	710.94	0.00	710.94	kg of CO2-eq/tonne of mix waste
Composting	189.57	1043.73	-854.16	kg of CO2-eq/tonne of organic waste
Anaerobic digestion	0.00	0.00	0.00	kg of CO2-eq/tonne of organic waste
Mechanical Biological Treatment (MBT)	0.00	0.00	0.00	kg of CO2-eq/tonne of waste
Recycling	0.00	0.00	0.00	kg of CO2-eq/tonne of mixed recyclables
Incineration	0.00	0.00	0.00	kg of CO2-eq/tonne of incinerated waste
Open burning	0.00	0.00	0.00	kg of CO2-eq/tonne of open burned waste
<b>GHG emission from whole system</b>	<b>720.53</b>	<b>6.33</b>	<b>714.20</b>	<b>kg of CO2-eq/tonne of collected waste</b>

Figure A. 1 Summary of GHG Emissions in Scenario 0 of Surabaya Model.

Activity	Direct GHG Emissions	Indirect GHG Savings	Net GHG Emissions	Unit
Transportation	12.74	0.00	12.74	kg of CO2-eq/tonne of waste
Landfilling of mix MSW	710.94	0.00	710.94	kg of CO2-eq/tonne of mix waste
Composting	189.57	1043.73	-854.16	kg of CO2-eq/tonne of organic waste
Anaerobic digestion	0.00	0.00	0.00	kg of CO2-eq/tonne of organic waste
Mechanical Biological Treatment (MBT)	0.00	0.00	0.00	kg of CO2-eq/tonne of waste
Recycling	0.00	0.00	0.00	kg of CO2-eq/tonne of mixed recyclables
Incineration	0.00	0.00	0.00	kg of CO2-eq/tonne of incinerated waste
Open burning	0.00	0.00	0.00	kg of CO2-eq/tonne of open burned waste
<b>GHG emission from whole system</b>	<b>720.51</b>	<b>6.33</b>	<b>714.18</b>	<b>kg of CO2-eq/tonne of collected waste</b>

Figure A. 2 Summary of GHG Emissions in Scenario 1 of Surabaya Model.

Activity	Direct GHG Emissions	Indirect GHG Savings	Net GHG Emissions	Unit
Transportation	12.19	0.00	12.19	kg of CO2-eq/tonne of waste
Landfilling of mix MSW	622.93	0.00	622.93	kg of CO2-eq/tonne of mix waste
Composting	177.56	1043.73	-866.17	kg of CO2-eq/tonne of organic waste
Anaerobic digestion	0.00	0.00	0.00	kg of CO2-eq/tonne of organic waste
Mechanical Biological Treatment (MBT)	0.00	0.00	0.00	kg of CO2-eq/tonne of waste
Recycling	0.00	0.00	0.00	kg of CO2-eq/tonne of mixed recyclables
Incineration	0.00	0.00	0.00	kg of CO2-eq/tonne of incinerated waste
Open burning	0.00	0.00	0.00	kg of CO2-eq/tonne of open burned waste
<b>GHG emission from whole system</b>	<b>521.07</b>	<b>267.26</b>	<b>253.82</b>	<b>kg of CO2-eq/tonne of collected waste</b>

Figure A. 3 Summary of GHG Emissions in Scenario 2 of Surabaya Model.

Activity	Direct GHG Emissions	Indirect GHG Savings	Net GHG Emissions	Unit
Transportation	15.77	0.00	15.77	kg of CO2-eq/tonne of waste
Landfilling of mix MSW	623.27	0.00	623.27	kg of CO2-eq/tonne of mix waste
Composting	177.55	1043.73	-866.18	kg of CO2-eq/tonne of organic waste
Anaerobic digestion	0.00	0.00	0.00	kg of CO2-eq/tonne of organic waste
Mechanical Biological Treatment (MBT)	0.00	0.00	0.00	kg of CO2-eq/tonne of waste
Recycling	0.00	0.00	0.00	kg of CO2-eq/tonne of mixed recyclables
Incineration	0.00	0.00	0.00	kg of CO2-eq/tonne of incinerated waste
Open burning	0.00	0.00	0.00	kg of CO2-eq/tonne of open burned waste
<b>GHG emission from whole system</b>	<b>523.77</b>	<b>269.94</b>	<b>253.83</b>	<b>kg of CO2-eq/tonne of collected waste</b>

Figure A. 4 Summary of GHG Emissions in Scenario 3 of Surabaya Model.



Entrance



Waste to be Cleaned



Tricycle Unloading



Weighing Machine



Cardboard



Oil Container



Hard Plastics



Price List



Mix Plastics



Bottle Caps



Bags of Cleaned PET Bottle



Baler

Figure A. 5 Surabaya Central Waste Bank.

Table A. 16 Recovered Recyclables Load, Value, and Value in each Ton Recovered (Jan, Feb, Jun, Jul).

Type	Item	Value (IDR)	Unit to kg	Total Recovered (kg)	% in Type	Load in Type (kg)	Value in Type (IDR)	% in each Ton	Value in each Ton (IDR)
Metal	Copper	40,000		3	0	0	14,372	0.2	85
	Brass	20,000		6	0	1	14,952	0.2	44
	Bronze	5,500		56	1	7	38,830	0.6	32
	Aluminum Plate	8,500		18	0	2	19,653	0.3	25
	Aluminum Elbow	8,000		50	1	6	50,670	0.8	60
	Aluminum Skillet	5,000		78	1	10	49,155	0.7	36
	Aluminum Pot	8,500		169	2	21	181,111	2.7	229
	Aluminum Can	7,500		115	1	15	109,199	1.6	122
	Thick Iron	2,000		1,436	18	181	361,980	5.4	108
	Thin Iron	1,300		2,668	34	336	437,322	6.5	84
	Nail/Bicycle	1,000		45	1	6	5,701	0.1	1
	Can	300		2,996	38	378	113,330	1.7	5
	Zinc	300		291	4	37	10,989	0.2	0
<b>Total</b>				7,932	100	<b>1,000</b>	<b>1,407,263</b>		
Paper	Cardboard (Good Condition)	1,200		12,961	35	355	425,810	6.3	76
	Cardboard (Bad Condition)	900		5,561	15	152	137,031	2.0	18
	Newspaper	2,600		419	1	11	29,810	0.4	12
	HVS Paper	1,900		3,617	10	99	188,128	2.8	53
	Recycled Paper	900		5,386	15	147	132,721	2.0	18
	Paper Sack	1,300		771	2	21	27,446	0.4	5

Type	Item	Value (IDR)	Unit to kg	Total Recovered (kg)	% in Type	Load in Type (kg)	Value in Type (IDR)	% in each Ton	Value in each Ton (IDR)
	Duplex Paper	300		7,811	21	214	64,153	1.0	3
	<b>Total</b>			36,526	100	<b>1,000</b>	<b>1,005,098</b>		
	Syrup Bottle	50	0.55	2,599	46	834	41,722	0.6	0
	Sauce Bottle	300	0.53	439	8	146	43,848	0.7	2
	Gasoline Bottle	800	0.29	226	4	140	111,773	1.7	13
Glass	Beer Bottle	500	0.55	322	6	103	51,677	0.8	4
	Colored Glass Bottle/Shard	50		884	16	156	7,800	0.1	0
	Clear Glass Bottle/Shard	100		1,195	21	211	21,093	0.3	0
	<b>Total</b>			5,664	100	<b>1,000</b>	<b>277,913</b>		
	Clear Plastic	1,000		2,929	6	59	59,280	0.9	9
	Plastic Bag	300		604	1	12	3,665	0.1	0
	Thin Screen-Printed Plastic	300		2,818	6	57	17,111	0.3	1
	Multi-layer Packaging	25		2,053	4	42	1,039	0.0	0
	Thick Screen-Printed Plastic	250		531	1	11	2,688	0.0	0
Plastic	Plastic Glass (Clean)	3,500		427	1	9	30,285	0.4	16
	Plastic Glass (Dirty)	1,500		664	1	13	20,157	0.3	4
	Clear PET (Clean)	3,000		3,483	7	71	211,513	3.1	94
	Clear PET (Dirty)	2,000		218	0	4	8,821	0.1	3
	Blueish PET (Clean)	2,000		2,984	6	60	120,788	1.8	36
	Blueish PET (Dirty)	1,000		1,085	2	22	21,961	0.3	3
	Green/Dark Blue PET (Clean)	1,000		299	1	6	6,054	0.1	1

Type	Item	Value (IDR)	Unit to kg	Total Recovered (kg)	% in Type	Load in Type (kg)	Value in Type (IDR)	% in each Ton	Value in each Ton (IDR)
	Green/Dark Blue PET (Dirty)	500		148	0	3	1,499	0.0	0
	Mix Plastic Lid	1,500		2,479	5	50	75,274	1.1	17
	Mixed Tub	1,300		1,770	4	36	46,585	0.7	9
	Colored Thick Plastic Glass	1,500		767	2	16	23,295	0.3	5
	Black Bucket	900		3,916	8	79	71,332	1.1	10
	Hard Plastic	200		7,221	15	146	29,232	0.4	1
	Plastic Strap	300		6,980	14	141	42,382	0.6	2
	PVC Pipe	400		7,920	16	160	64,124	1.0	4
	CD	2,500		49	0	1	2,481	0.0	1
	Plastic Sack (5-20kg)	400		60	0	1	1,209	0.0	0
	Cable	1,000		2,929	6	59	59,280	0.9	9
	<b>Total</b>			<b>49,405</b>	<b>100</b>	<b>1,000</b>	<b>860,776</b>		
Other	Used Cooking Oil	4,800		5,180	60	604	2,899,792	43.1	2,067
	Used Shoe/Sandal	200		1,842	21	215	42,967	0.6	1
	Dried Rice	1,400		1,452	17	169	237,030	3.5	49
	Hose	400		43	1	5	2,006	0.0	0
	Plastic Sack (25kg)	200	0.04	23	0	3	531	0.0	0
	Plastic Sack (50kg)	200	0.07	31	0	4	725	0.0	0
	Plastic Sack (100kg)	200	0.09	4	0	0	88	0.0	0
	<b>Total</b>			<b>8,574</b>	<b>100</b>	<b>1,000</b>	<b>3,183,139</b>		
<b>Total</b>				<b>108,101</b>			<b>6,734,190</b>	<b>100</b>	<b>3,369</b>

Table A. 17 Detail Comparison of Fuel of Transportation Cost Between TWDS and Both Centroids.

District	Trip/y	TWDS		AB Centroid		RA Centroid	
		Cost/Trip	Cost/y	Cost/Trip	Cost/y	Cost/Trip	Cost/y
AsemRowo	1,500	508,278	153,656,133	99,128	148,692,005	99,291	148,937,153
Benowo	2,628	916,896	220,958,229	83,122	218,444,340	84,183	221,231,913
Bubutan	2,700	546,949	295,492,726	103,934	280,621,995	103,382	279,132,386
Bulak	1,260	366,163	153,729,265	122,197	153,967,939	121,581	153,192,152
Dukuh Pakis	540	240,275	65,001,263	118,088	63,767,470	118,351	63,909,791
Gayungan	3,600	1,007,210	450,553,805	121,672	438,017,611	121,294	436,657,264
Genteng	2,700	711,419	320,075,594	118,657	320,373,114	118,512	319,981,274
Gubeng	7,020	956,338	839,188,246	166,852	1,171,299,373	123,773	868,887,481
Gunung Anyar	1,440	598,899	223,186,406	120,811	173,968,335	120,750	173,880,433
Jambangan	1,620	503,934	209,694,709	121,581	196,961,338	121,247	196,419,579
Karang pilang	2,700	823,984	318,516,344	120,701	325,893,015	120,438	325,182,999
Kenjeran	2,340	603,657	282,327,583	118,733	277,835,361	118,666	277,679,427
Krembangan	4,368	888,101	480,978,557	103,409	451,690,304	102,694	448,566,815
Lakarsantri	1,164	609,449	118,224,712	101,490	118,134,665	101,335	117,954,045
Mulyorejo	1,440	488,282	175,600,314	121,257	174,610,466	121,062	174,329,554
Pabean Cantikan	4,500	799,080	523,939,449	104,704	471,167,342	104,596	470,684,057
Pakal	2,136	835,644	171,582,662	63,096	134,772,918	71,596	152,929,204
Rungkut	6,420	1,164,881	841,996,847	166,021	1,065,854,591	123,084	790,197,634
Sambikerep	852	183,909	82,239,500	97,027	82,667,351	98,659	84,057,279
Sawahan	5,940	738,284	630,619,739	102,357	608,001,479	102,317	607,765,601

District	Trip/y	TWDS		AB Centroid		RA Centroid	
		Cost/Trip	Cost/y	Cost/Trip	Cost/y	Cost/Trip	Cost/y
Semampir	3,648	835,180	435,158,321	119,569	436,187,633	119,436	435,701,143
Simokerto	3,960	475,389	470,705,478	118,423	468,954,952	118,408	468,895,337
Sukolilo	3,816	1,076,169	461,074,000	121,369	463,142,999	121,219	462,570,575
Sukomanunggal	3,648	644,234	393,652,384	99,862	364,298,229	99,862	364,298,229
Tambaksari	3,360	955,232	401,895,273	119,614	401,903,229	119,589	401,817,513
Tandes	3,612	781,943	352,709,962	96,583	348,859,178	96,965	350,239,030
Tegalsari	3,960	666,057	432,212,630	104,090	412,198,087	104,128	412,347,500
Tenggilis Mejoyo	3,000	973,820	365,550,721	122,967	368,900,824	122,282	366,847,219
Wiyung	3,060	798,144	345,487,024	104,754	320,546,946	104,661	320,263,910
Wonocolo	1,260	191,994	116,127,869	122,288	154,082,979	121,720	153,367,637
Wonokromo	6,348	1,434,506	758,095,381	118,684	753,404,486	118,627	753,046,912

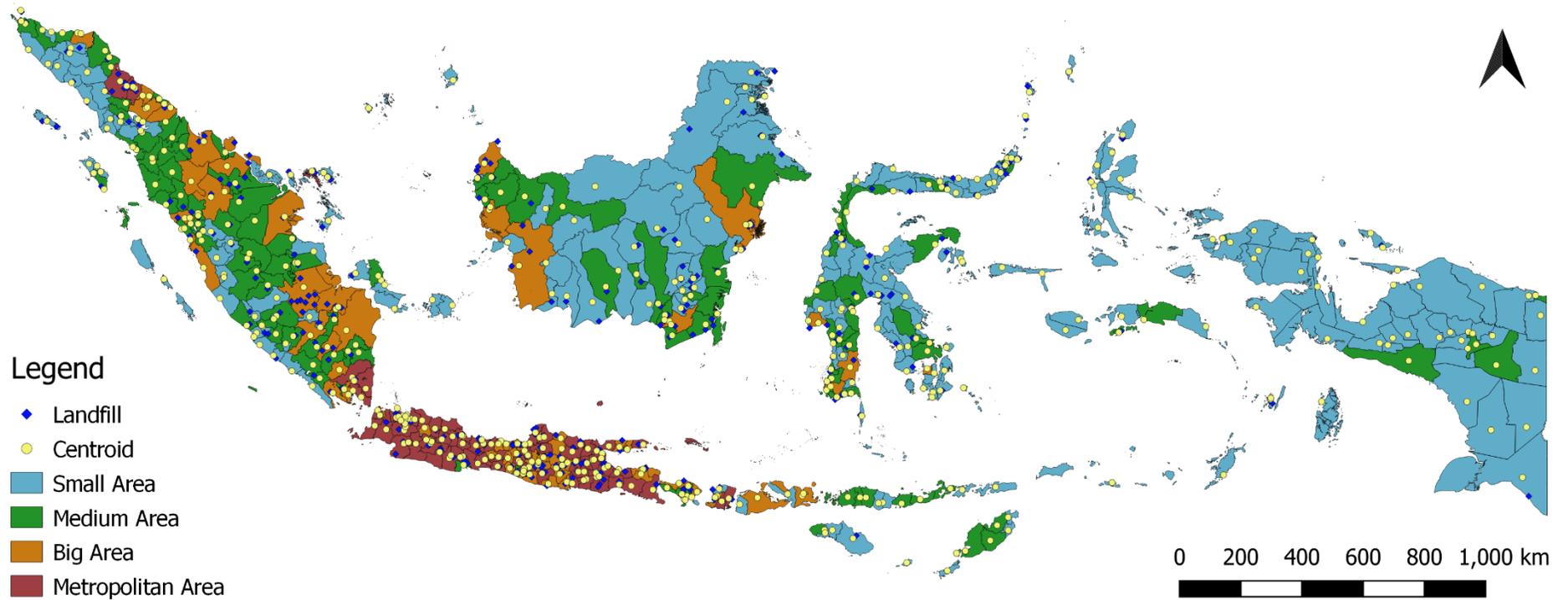


Figure A. 6 Centroids and Available Landfill by Area Class.

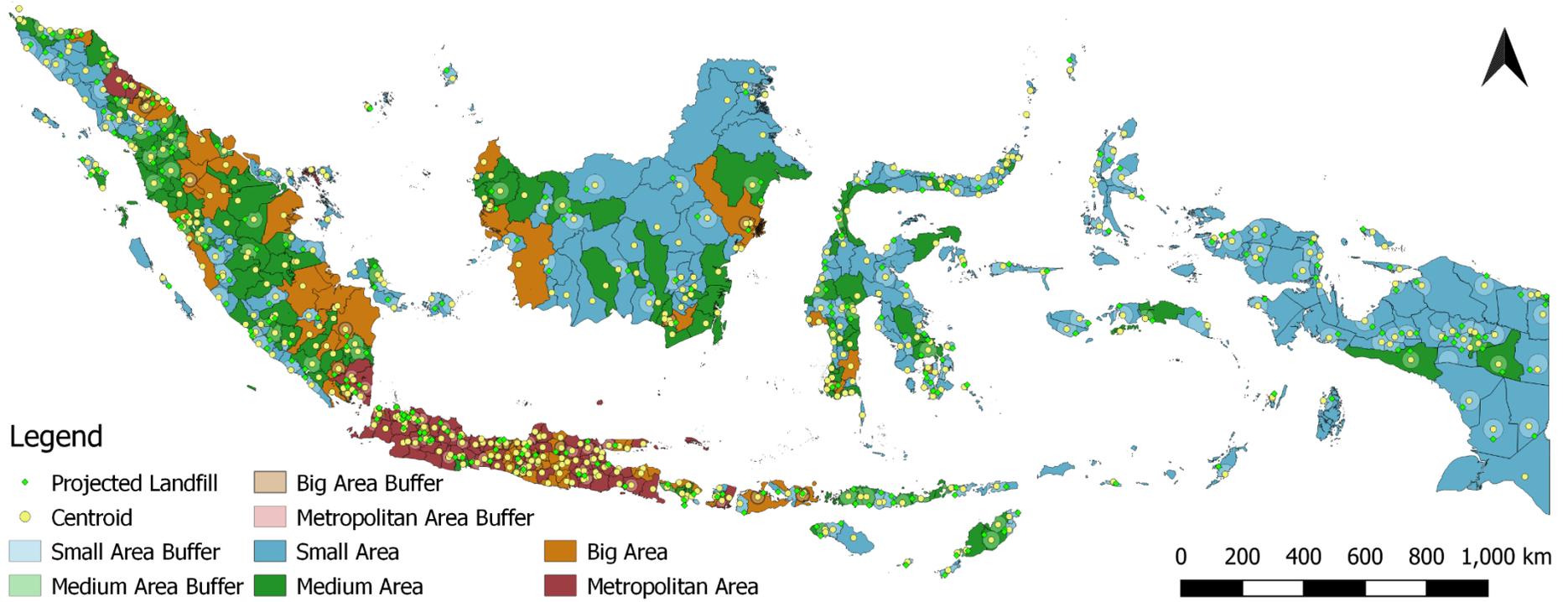


Figure A. 7 Buffered Areas and Predicted Landfill Locations.

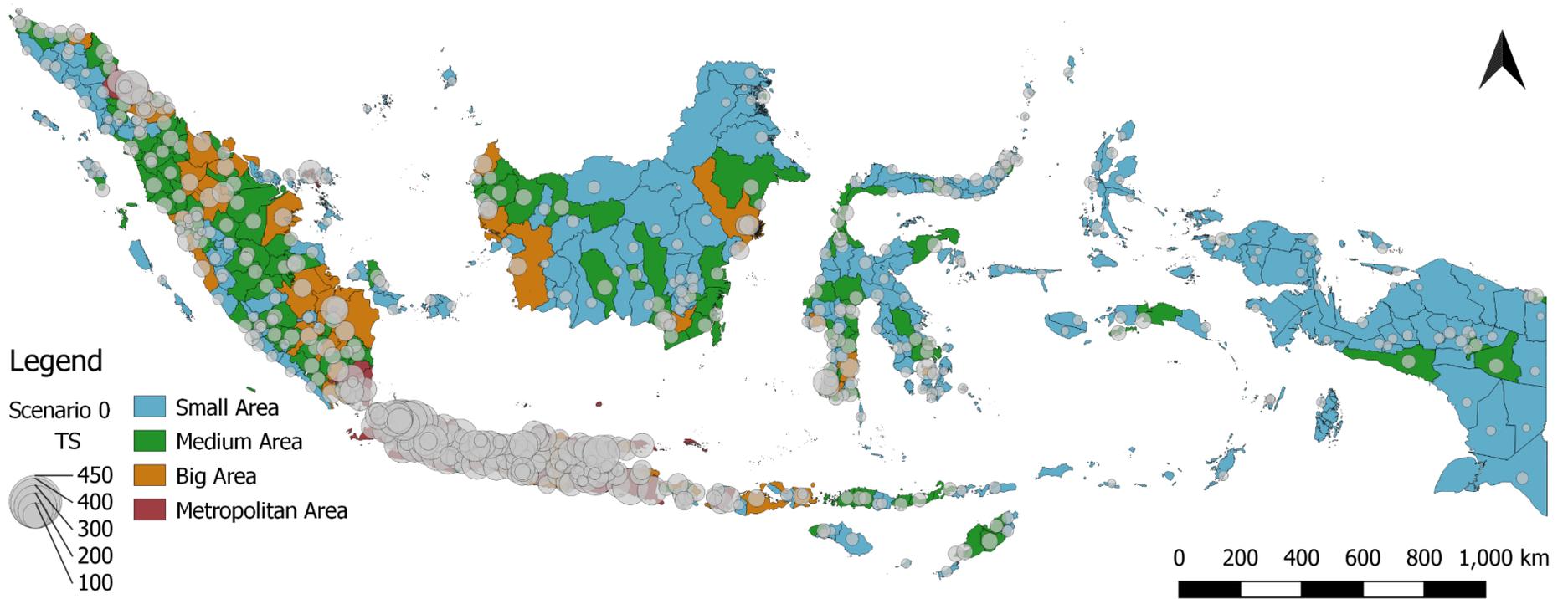


Figure A. 8 Distribution of Transfer Stations in Scenario 0.

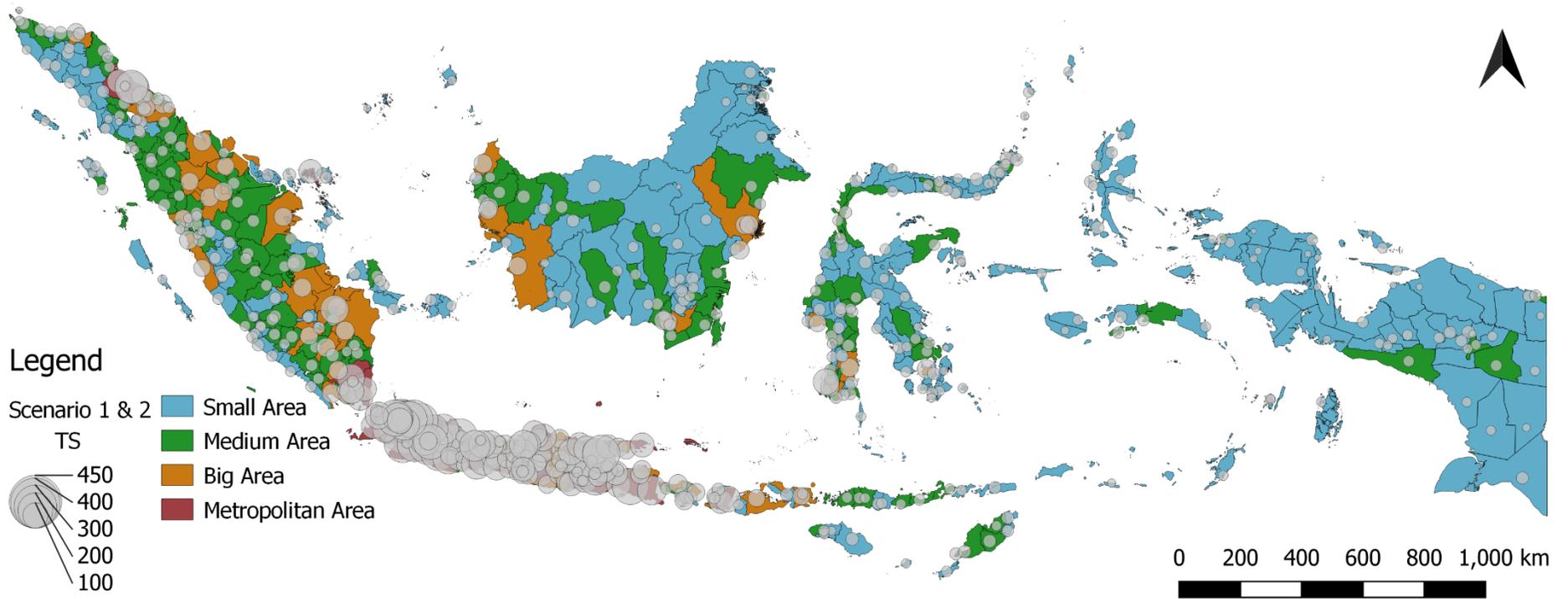


Figure A. 9 Distribution of Transfer Stations in Scenario 1 and Scenario 2.

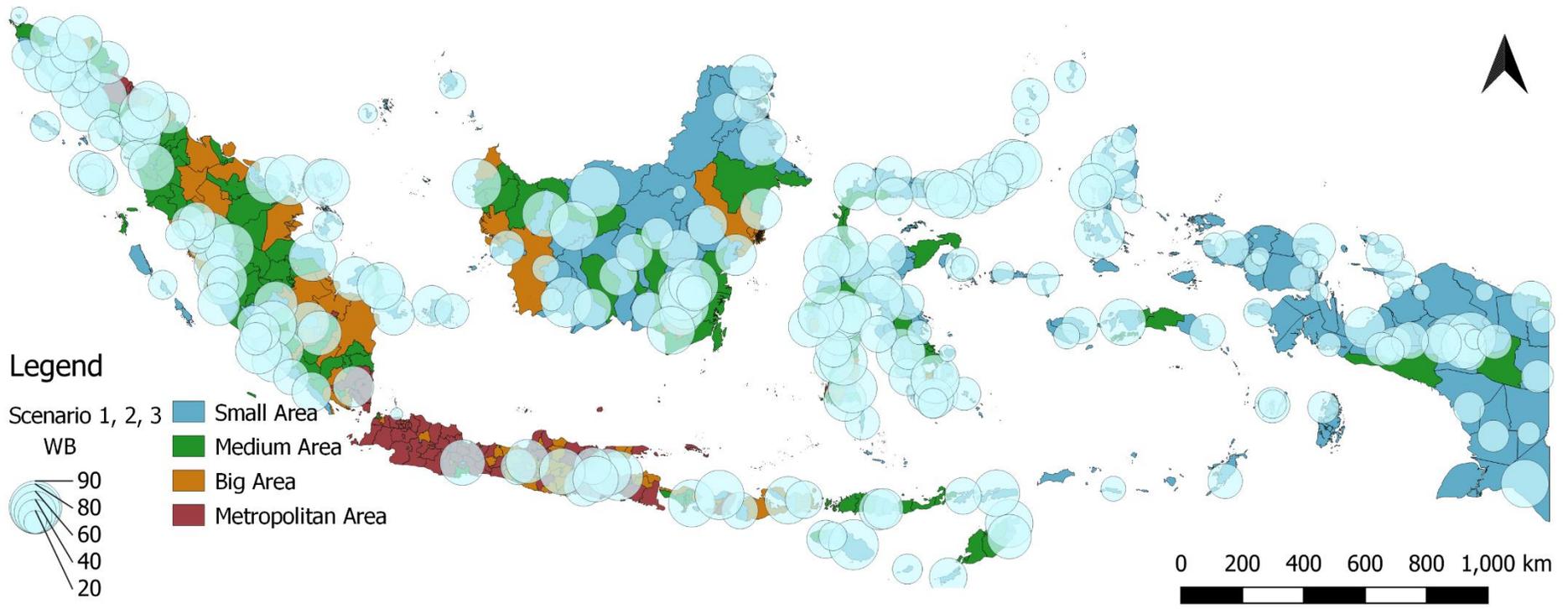


Figure A. 10 Distribution of Waste Banks in Scenario 1, Scenario 2, and Scenario 3.

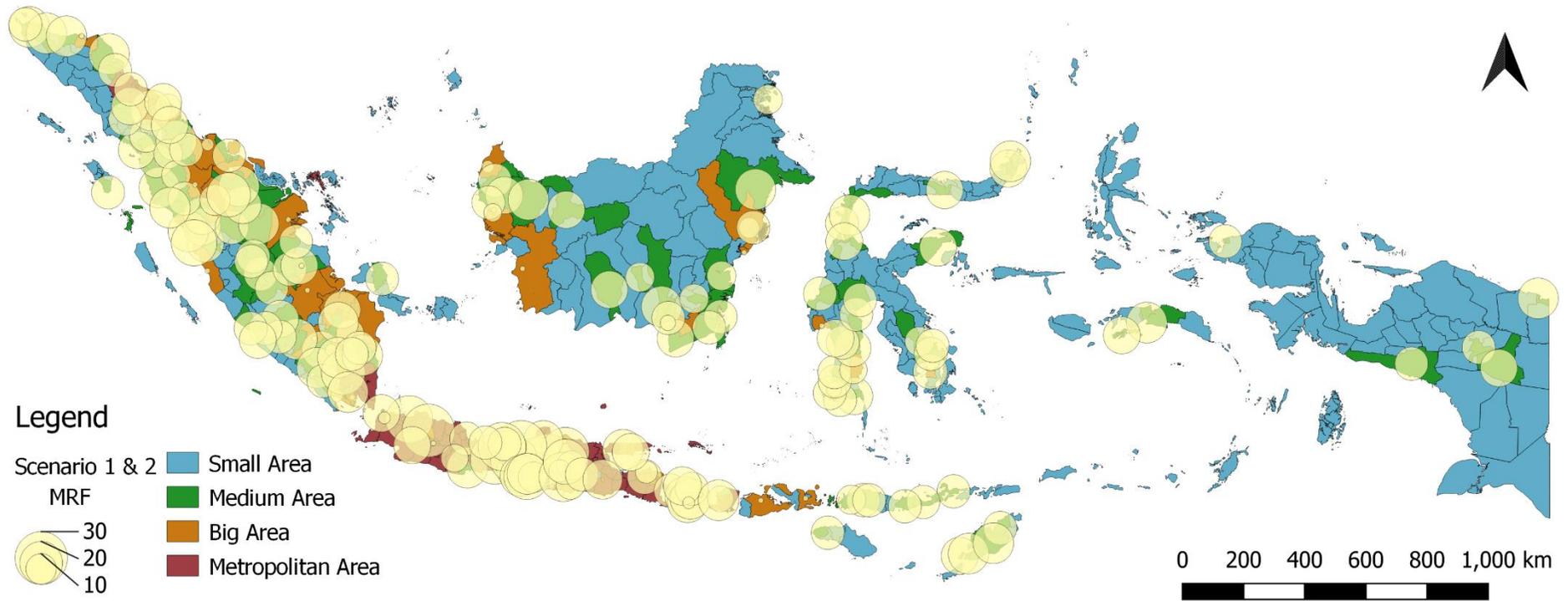


Figure A. 11 Distribution of Material Recovery Facility in Scenario 1 and Scenario 2.

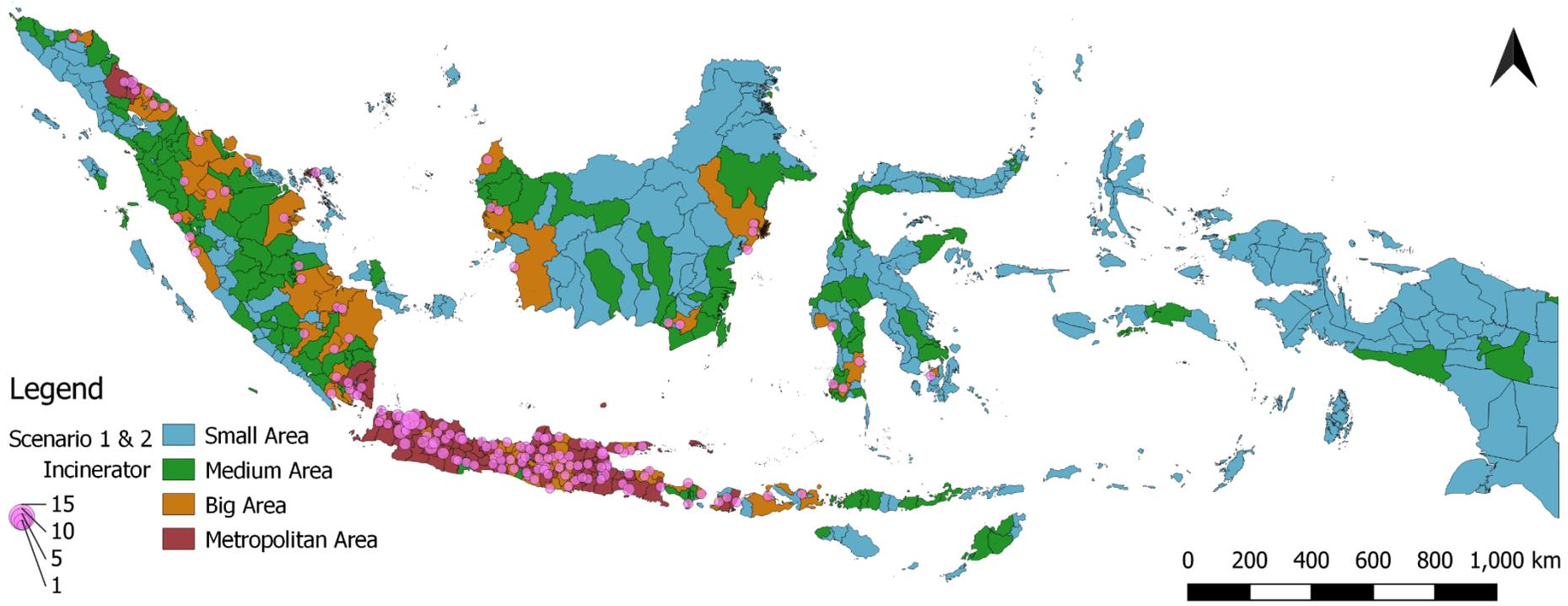


Figure A. 12 Distribution of Incinerator in Scenario 1 and Scenario 2.

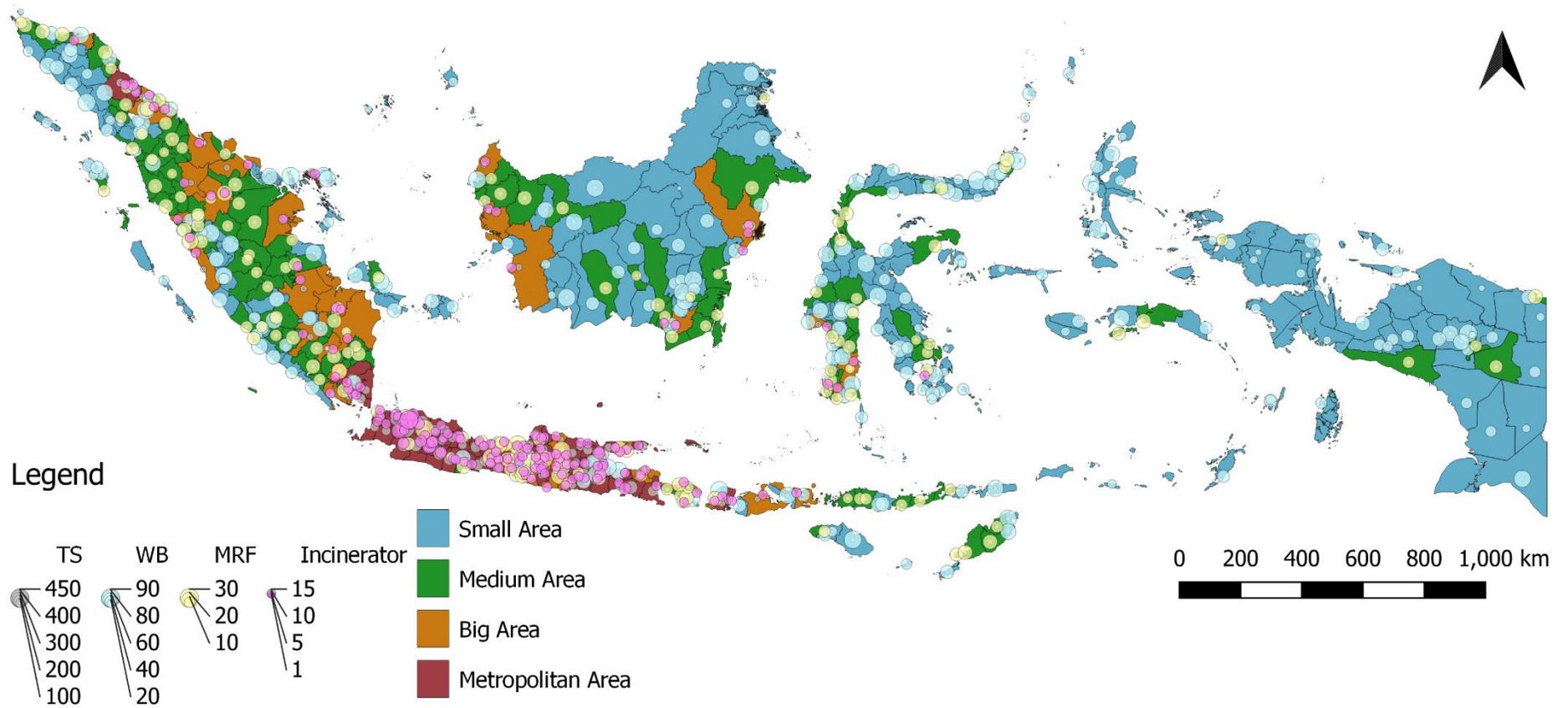


Figure A. 13 National Plan of Waste Management in Indonesia in Scenario 1 and Scenario 2.

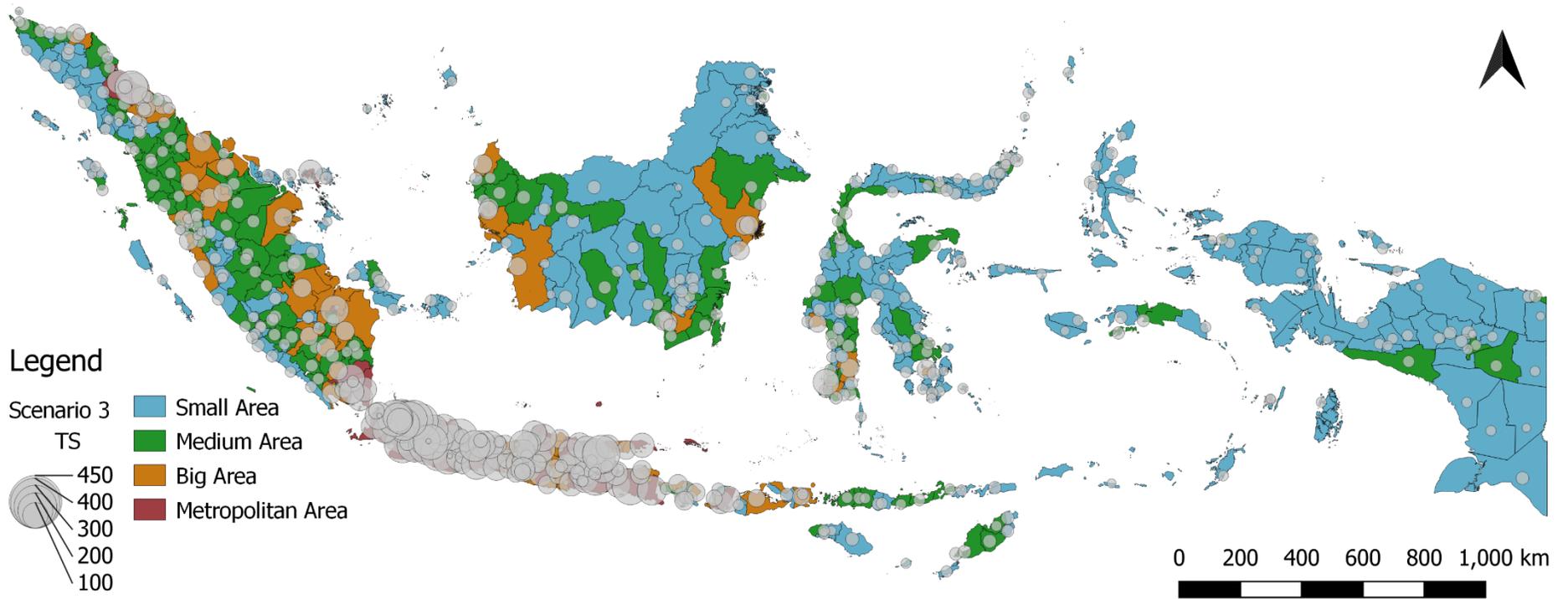


Figure A. 14 Distribution of Transfer Stations in Scenario 3.

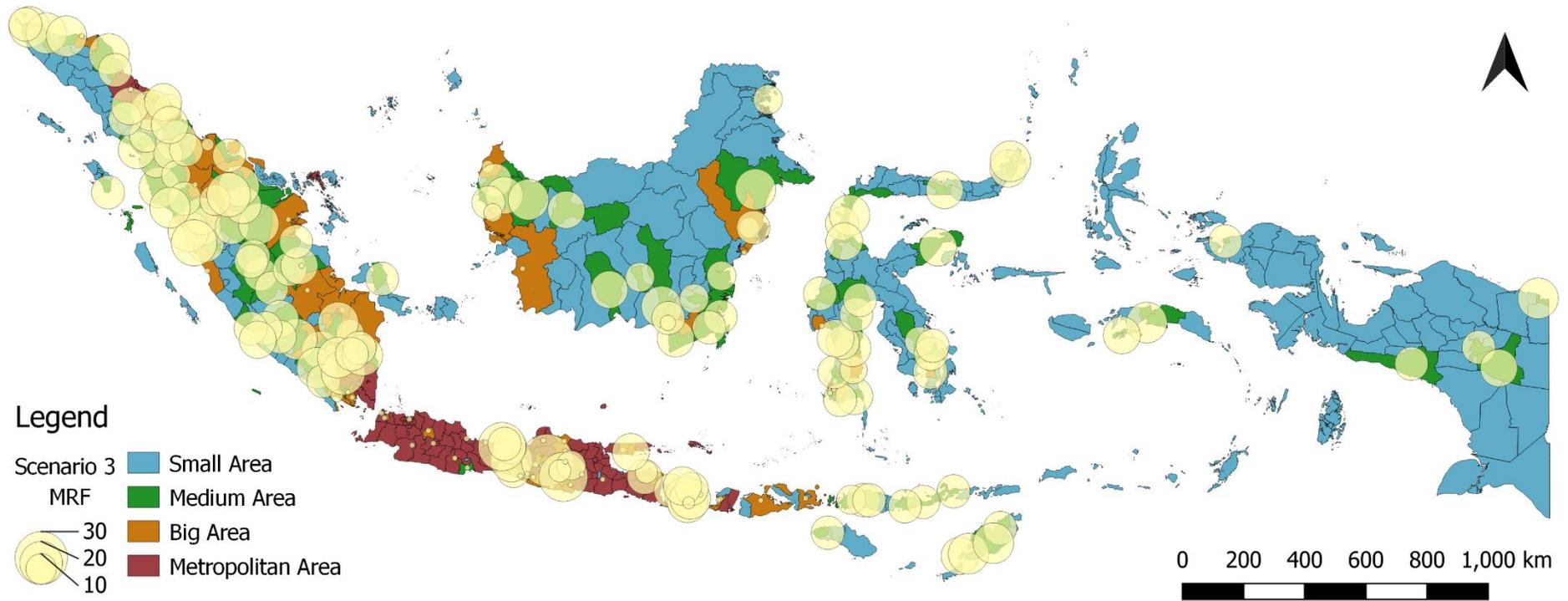


Figure A. 15 Distribution of Material Recovery Facility in Scenario 3.

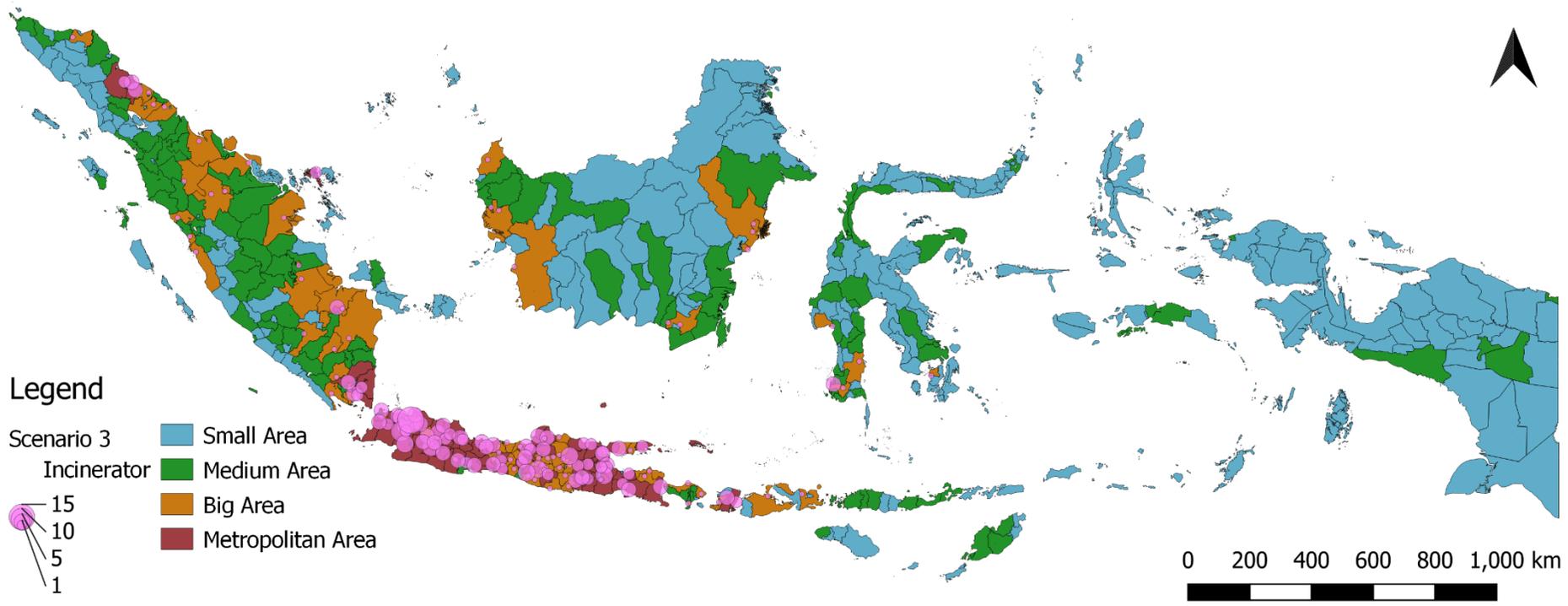


Figure A. 16 Distribution of Incinerator in Scenario 3.

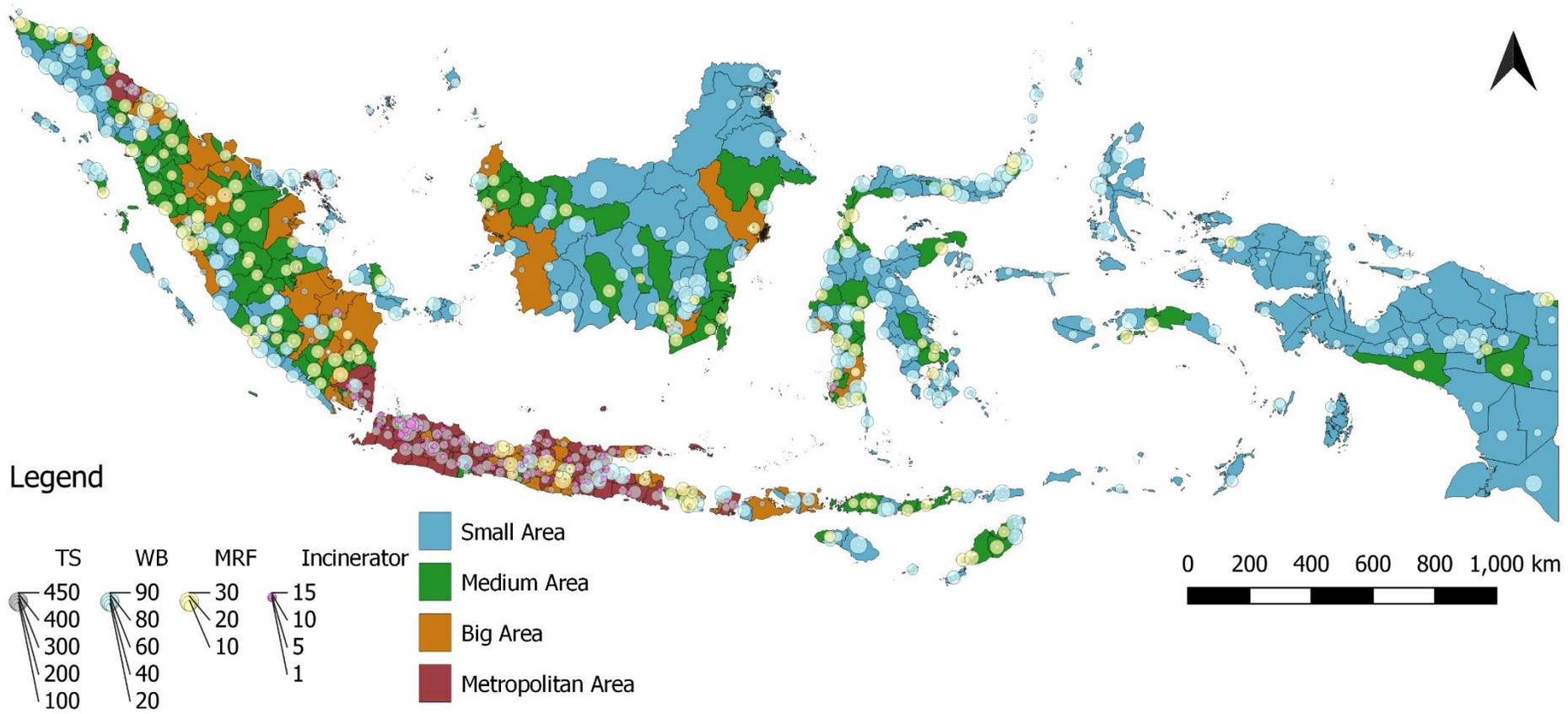


Figure A. 17 National Plan of Waste Management in Indonesia in Scenario 3.

Table A. 18 Details on Required GHG Emissions Analysis Data in National Model.

	SC 0	SC 1	SC 2	SC 3
<b>Transportation</b>				
Total waste transported (ton/month)	4,233,788	3,826,303	3,887,590	4,376,520
Total fuel consumed (L/month)	24,693,335	22,088,433	23,000,788	27,036,400
<b>Mix Waste Landfilling</b>				
Total waste landfilled (ton/month)	4,233,788	1,729,598	1,669,148	1,574,352
Total fuel for machinery in landfill (L/month)	5,852,589	2,390,916	2,307,351	2,176,310
food waste (%)	38.81	25.49	24.72	25.16
garden waste (%)	21.10	13.86	13.44	13.68
plastic (%)	13.29	9.62	9.35	7.73
paper (%)	4.15	3.77	3.68	1.65
textile (%)	0.75	0.76	0.74	0.23
leather/rubber (%)	0.27	0.42	0.41	(0.07)
glass (%)	3.82	18.08	18.97	20.25
metal (%)	0.97	6.45	6.80	7.53
hazardous waste (%)	0.24	0.17	0.17	0.14
others (%)	16.60	21.37	21.73	23.70
<b>Composting</b>				
Total food waste composted (ton/month)	-	182,801	182,801	140,696
Total garden waste composted (ton/month)	-	99,393	99,393	76,499
Total fuel for machinery in composting site (L/month)	-	45,090	45,090	34,785
Total compost produced (ton/month)	-	6,093	6,093	4,689

	SC 0	SC 1	SC 2	SC 3
Percentage of compost utilized (%)	-	100	100	100
<b>Incineration</b>				
Total waste incinerated (ton/month)	-	2,717,862	2,792,460	2,876,349
Total fuel for operation (L/month)	-	625,108	642,266	661,560
Total amount of grid electricity use for the operation activities (kWh/month)	-	207,894	207,894	226,186
Food waste	-	38.81	38.81	38.81
Garden waste	-	21.10	21.10	21.10
Plastics	-	13.29	13.29	13.29
Paper	-	4.15	4.15	4.15
Textile	-	0.75	0.75	0.75
Leather/rubber	-	0.27	0.27	0.27
Glass	-	3.82	3.82	3.82
Metal	-	0.97	0.97	0.97
Hazardous waste	-	0.24	0.24	0.24
Others	-	16.60	16.60	16.60
Total amount of electricity produced (kWh/month)	-	2,047,760	2,047,760	2,227,935
Percentage of electricity use for onsite operation activities	-	10%	10%	10%