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AGRICULTURE AND LIFE SCIENCES

INTEGRATION SOLID WASTE MANAGEMENT WITH CIRCULAR ECONOMY MODEL IN SURABAYA, INDONESIA

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1 INTRODUCTION

1.1 Problem Statement

More than half of the expected increase of solid waste generation will take place in developing countries as the result of economic booming and the population growth (Nguyen *et al.*, 2020; Kabir and Kabir, 2022). Indonesia is one of those countries, becoming a huge producer of solid waste. Even though Indonesia generates less solid waste per capita compared with the developed countries, as the home of 230 million Indonesians, the country represents one of the major solid waste generators in the world (Sharma and Jain, 2020). Every year, Indonesia produces 64 million tonnes of waste, most of household waste, which accounts for 44.5% of the total waste that is transported without being processed in landfills (Wikurendra, Abdeljawad and Nagy, 2023). Waste production per day in Java Island was relatively high in 2019 compared to other islands, with Jakarta City being the highest by producing 8291.81 m^3/day followed by Semarang City producing 5080.51 m^3/day and Surabaya City producing 2223.9 m^3/day (Edza Aria Wikurendra *et al.*, 2022). As a city with the third largest amount of waste per day in Indonesia, Surabaya City still has problems regarding waste management. Waste generated in Surabaya City is dominated by household waste and comes from public activities, where 43.5% or 1,212 tonnes/day of household waste is generated (Muhamad *et al.*, 2020). If not managed properly, it is estimated that in the next 4-5 years the landfill will no longer be able to accommodate the waste of the population in Surabaya City. The government as a key player in waste management in Indonesia must ensure good and sustainable waste management according to Law No. 18/2008 (Purba and Erliyana, 2020).

Achieving sustainable waste management in Surabaya, several methods have been proposed in previous studies. Involvement of the private sector as part of stakeholder management of sustainable waste management is one suitable approach. A viable option for sustainable waste management in Indonesia should emphasis on reducing, reusing and recycling (Fatimah *et al.*, 2020). However, the implementation of reduce, reuse and recycle requires a paradigm shift for sustainable waste management in Surabaya, from the current end of pipe approach to a cradle to cradle approach. Cradle to cradle means that a product is designed in such a way that its materials and components can be reused or recycled indefinitely (Sherratt, 2013). This makes the product "circular" and reduces environmental impact. The circular economy approach has received attention recently as a step towards a more sustainable economic model. In the European Union, the circular economy has been applied to address not only the manufacturing sector which is highly correlated with the economy but also to their waste management issues as

part of a systematic economic cycle (Pires and Martinho, 2019).

Circular economy theory suggests that improved resource efficiency and reduced waste during the life cycle of manufactured goods are actually unexplored economic opportunities with potential for economic growth (Yang *et al.*, 2022). Solid waste management with the integration of circular economy is believed to not only address the economic problem of the high cost of solid waste management but can also bring environmental and social benefits (Mandpe *et al.*, 2022). To trigger a change towards sustainable solid waste management, the measurement of predicted environmental and economic opportunities of circular economy integration in solid waste management is also conducted in this study. This can improve the local government's cognition regarding the choice of solid waste management strategy in Surabaya City. Therefore, motivation enhancement and strategic allocation of resources such as funds, policies and organisational changes can be improved. This research will also calculate the waste absorption footprint of the current solid waste management and predict the environmental and economic opportunities of integrating solid waste management with circular economy model from the perspective of waste absorption footprint.

1.2 Research Questions

Waste generation in Indonesia continues to increase every year in line with population growth and urbanization (Kerstens *et al.*, 2016). Circular economy approach has recently gained attention as a step towards a more sustainable economic model (Pieroni, McAloone and Pigosso, 2019). Circular economy theory suggests that increasing resource efficiency and reducing waste during the life cycle of manufactured goods are actually unexplored economic opportunities that have the potential for economic growth (E.A. Wikurendra *et al.*, 2022). The reduce principle implies the use of minimal inputs of energy, raw materials, and waste, for example by applying better technologies, simplifying packaging, and using energy-efficient equipment (Kirchherr *et al.*, 2023). The idea has also been put into practice with the argument that it reduces negative environmental impacts and stimulates new business opportunities (Korhonen, Honkasalo and Seppälä, 2018). Under these conditions, this dissertation analyzes the possibility of integrating solid waste management with circular economy models and evaluates its environmental and economic impacts. Thus, this dissertation aims to provide appropriate recommendations to improve the sustainability of solid waste management in Surabaya, Indonesia. As well as assessing the current solid waste management practices and their environmental impacts from a Waste Absorption Footprint (WAF) and economic perspective to provide strategies to maximize the benefits of solid waste management by applying circular economy principles. With this objective, the following research question (RQ) is addressed:

RQ1: What are the current solid waste management practices in Surabaya, Indonesia?

RQ2: What are the challenges for integrating solid waste management with circular economy model in Surabaya, Indonesia ?

RQ3: What are the feasible circular solid waste management frameworks to Surabaya, Indonesia ? How to enable it?

RQ4: What is the impact of current solid waste management practice from the perspective of waste absorption footprint and economics aspects? Is there any opportunity by integrating the circular economy principles in solid waste management from the perspective of waste absorption footprint and economics ?

2 MATERIAL AND METHODS

The purpose of a research design is to provide a study plan that allows an accurate assessment of the cause and effect relationship between independent and dependent variables as well as a strategy to answer the research question or to test the research hypothesis. This chapter will explain the materials and methods used to obtain answers to the research questions. The results of the research conducted will provide recommendations related to improving municipal waste management in Surabaya City using a circular economy approach.

2.1 Research Frameworks

A research framework is used to implement the steps taken during the research. The research framework is used as a guide to make the research more focused on the scope of the research. The research framework includes step-by-step activities to achieve the research objectives. The research framework consists of seven steps as seen as follows:

Step 1: Briefly describe the objectives of the research project

The objective of this research is to provide recommendations for the implementation of integrated solid waste management with a circular economy model towards viable and sustainable management.

Step 2: Determining the research object

The research object in this study is the implementation of current solid waste management practices in Surabaya City.

Step 3: Establish the nature of the research perspective

This research proposes by analyzing a solid waste management framework with a circular approach as a feasible and sustainable solution to address the less than optimal performance of solid waste management in Surabaya City. The implementation opportunity of solid waste management with circular approach will be analyzed from the perspective of waste absorption footprint and economic potential as a communication tool for the local government to consider the suggestions generated from this research. Therefore, this research is categorized as a type of change research (Verschuren & Doorewaard, 2010).

Step 4: Determining sources of research perspectives

This research uses various scientific literature references in developing its conceptual model in order to obtain new scientific findings. The theories that will be used in this research are shown in Table 1:

Table 1. Source of research perspective

Key concept	Theories and documentation
Solid waste management with circular economy approach	Theory of solid waste management Circular economy framework Theory of waste absorption footprint Theory of economics value

Step 5: Create a schematic presentation of the research framework

The research framework is described in Figure 1.

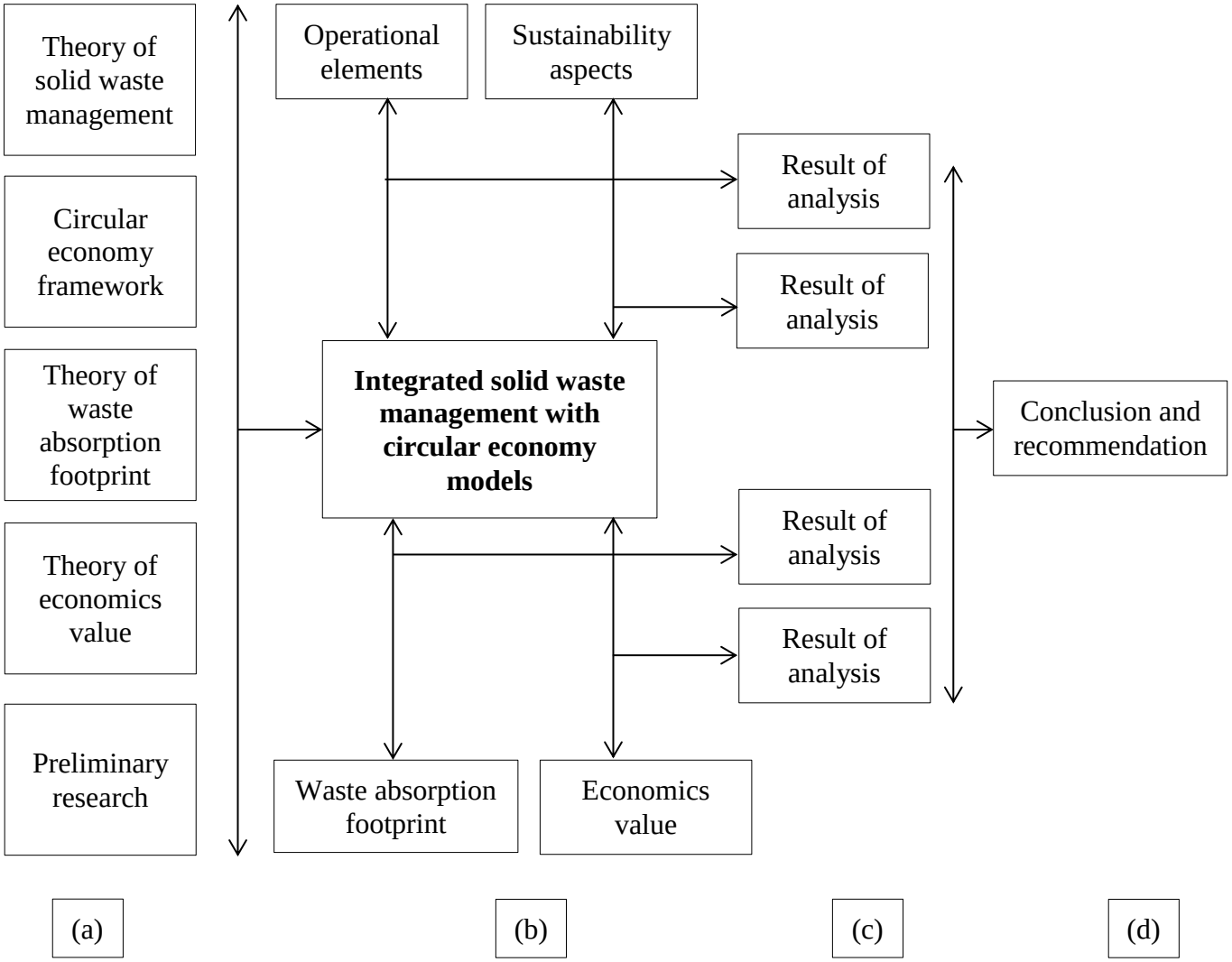

Figure 1. Research framework

Source: Primary Analysis, 2024

Step 6: Formulate the research framework

The research framework was formulated as follows:

(a) Analyze the theories of solid waste management, waste absorption print, economics value, circular economy framework, preliminary research and produce an integration of solid waste management with circular economy model.

(b) This model is used as a criterion to assess solid waste management practices in Surabaya City.

(c) The results of the analysis based on the specified criteria are used as the basis for drawing conclusions and potential recommendations.

(d) Research conclusions that resulted in recommendations were used to improve the sustainability of solid waste management practices in Surabaya City.

Step 7: Checking whether the model requires any change

There is no indication that any change is required.

2.2 Research Strategy

A research strategy is an overall approach relating to the ideation, planning, and execution of a study over a period of time to obtain answers to research questions (Johannesson and Perjons, 2014). This type of research is a case study with a single case study design. Single case study is a study whose research direction is centred on one case or one phenomenon only. In single case studies, the purpose or focus of the research generally leads directly to the context or core of the problem. Another approach used is a literature study to identify data sources that will be used to measure the environmental impact of solid waste management.

2.2.1 Research unit

The research unit for this study is solid waste management and the unit of observation is solid waste management practices. Surabaya City will serve as the locus of the case study in this research.

2.2.2 Selection of research unit

Informants and respondents in this research were selected based on their influence and impact on solid waste management in Surabaya City and represent interests or projects related to this research, among others:

- Surabaya City Environment Agency
- Surabaya City Cleanliness and Green Open Space Agency
- Other actors related to solid waste management in Surabaya City
- Respondents, which are divided into two types of data obtained include:
  (a) In this study, author narrowed down the population, which is the total number of residents in Surabaya City of 2,880,284 respondents by calculating the sample size using the slovin formula. Then analyzed the current waste management practices in Surabaya City using the random sample method. Respondents were asked about

their routine waste activities by sending questionnaires. Based on the calculations, the sample of respondents in this study was adjusted to 100 respondents, this was done to facilitate data processing using SPSS and for better test results.

(b) Household samples were also used in this study to estimate the waste generation and composition of each household. The basis for determining the number of household samples required is Indonesian National Standard (SNI) 19-3964-1994. Stratified random sampling is used to fulfill the requirement of the methodology. Household sample of respondents in this study was adjusted to 182 household.

2.2.3 Research boundary

Research boundaries are based on the researcher's decision regarding the variables to be included and excluded. The limitations of this study limit the research to be more controllable and relevant for researchers so that the research objectives can be answered. The following boundary is set for this research:

- Administrative boundary of Surabaya City was used to localise the discussion (only actors that live in the city were interviewed, the absorptive capacity is provided globally however only land with absorptive capacity used to calculate the environmental impact)
- Environmental opportunity was discussed from the perspective of waste absorption footprint
- Economic impact calculation results based on secondary data
- This research does not cover other issues that are not relevant to the research objectives.

2.3 Research Material

Research data were collected from interviews, questionnaires and field measurements. Several informants were interviewed with semi-structured interviews regarding waste management in Surabaya City. Respondents involved in this interview are:

- 1 informants from Surabaya City Environment Agency
- 1 informant from Surabaya City Cleanliness and Green Open Space Agency
- 1 informants from Surabaya main waste banks
- 1 informants from compost businesses
- 1 informant from waste collection sector
- 1 informant from local creative industry

To collect data on the understanding of community awareness and participation in waste

management, it is necessary to use a questionnaire. Slovin formula in section 4.3.2 is used to determine the number of respondents in this study. Estimated waste generation is calculated using the Indonesian Standard Method number 19-3964-1994 as a baseline for calculating the waste absorption footprint.

2.4 Data Analysis

This section presents the evaluation process of the data obtained in the field based on the analytical framework. The data analysis method and framework are described in this section.

2.4.1 Method of data analysis

This research uses a mixed method research approach by combining the advantages of quantitative and qualitative methods with the aim of producing a more complete and in-depth picture of the problem under study. This research uses quantitative methods to collect numerical data about the problem under study, and then uses qualitative methods to understand more deeply why these problems occur and how these problems occur. Thus, this research method can provide a more complete and in-depth picture of the problem under study see Table 2.

Table 2. Data and method of data analysis

Sub research questions	Required information	Sources of information	Research method
Whatarethose current solid waste management practices?	Current implementation of solid waste management practice in Surabaya City	Head of Surabaya City Environment Agency, cleanliness division, waste sub-division, landfill operation unit and citizen of Surabaya City	Semi-structure interviews, document analysis
What are the challenges for circular solid waste management implementation in Surabaya, Indonesia?	Barriers to achieving high performance solid waste management	Surabaya main waste banks, compost businesses, waste collection sector, local creative industry, Head of Surabaya City Environment Agency, cleanliness division, waste sub-division, landfill operation unit and citizen of Surabaya City	Semi-structure interviews, observation, content analysis, and questionnaire
What are those feasible circular solid waste management frameworks to Surabaya, Indonesia ? And how to enable it?	Suitable solution to overcome the barriers	Surabaya main waste banks, compost businesses, waste collection sector, local creative industry, Head of Surabaya City Environment Agency, cleanliness division, waste sub-division, landfill operation unit and citizen of Surabaya City	Document analysis, semi-structured interviews

What is the impact of current solid waste management practice from the perspective of waste absorption footprint and economics aspects? Is there any opportunity by integrating the circular economy principles in solid waste management from the perspective of waste absorption footprint and economics ?	Parameters for waste absorption footprint measurement and economics benefit for implementation of waste management with circular economy approach	Data collection from household in Surabaya City and document literature	Measurement, semi-structure interviews, document analysis and content analysis

Source: Primary Analysis, 2024

2.4.2 Analytical framework

Analitycal framework conceptualizes the research problem and its objectives and incorporates them into relevant theoretical knowledge and related outcomes of the research. A schematic presentation of the analytical framework is presented in Figure 2.

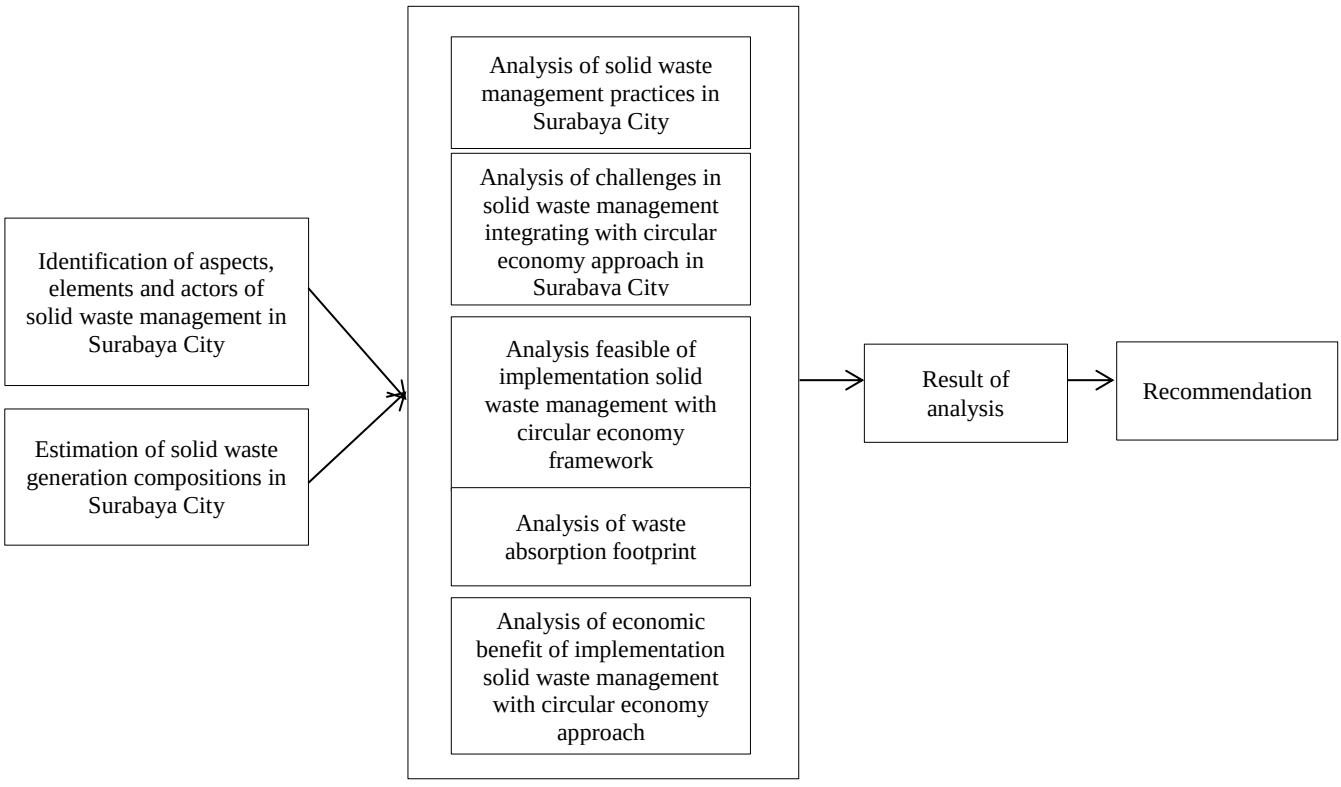

Figure 2. Analytical framework scheme

Source: Primary Analysis, 2024

The data analysis steps were as follows:

(a) The first stage is to understand the current waste management practices in Surabaya City by analyzing each element that affects waste management performance.

(b) Identifying sector challenges from non-governmental organizations in integrating waste management with circular economy approach in Surabaya City.

(c) Identifying the necessary policies in integrating solid waste management with circular economy approach in Surabaya City based on research results and in-depth study results by researchers.

(d) Last stage is to analyze the waste absorption footprint and economic benefits of implementing integrated solid waste management with circular economy approach.

The main research questions can be answered to some extent through the above-mentioned steps. The limitations of the study will be discussed in the conclusion and suggestions section.

3 RESULTS AND DISCUSSIONS

3.1 Current Pratice of Solid Waste Management in Surabaya City

Identification of stakeholders in solid waste management practices in Surabaya City starts from the community as a waste producer, government as a waste manager, private sector and education sector such as schools and universities. Practice of waste management in Surabaya City is officially and structurally the responsibility of Cleanliness and Green Open Space Agency. Technical waste management is carried out by the Cleanliness and Green Open Space Agency but in its implementation there are two divisions that are responsible. Cleaning division is responsible for the transportation of waste and waste sourced from road and pedestrian cleaning. Waste management division is responsible for waste utilization, liquid waste management and handling hazardous and toxic waste. Organizational structure of the Cleanliness and Green Open Space Agency can be seen in Figure 3. According to Mrs. Anna Fajriatin as Head of Surabaya City Cleanliness and Green Open Space Agency, the city has made various efforts and programs in reducing waste generation. Solid waste management practices in Surabaya City are among the best in Indonesia. The solid waste management involves several stakeholders with the aim of sustainability. The main stakeholders of solid waste management in Surabaya are summarized in the PLAN-DO-CHECK-ACT (PDCA) matrix presented in Table 3.

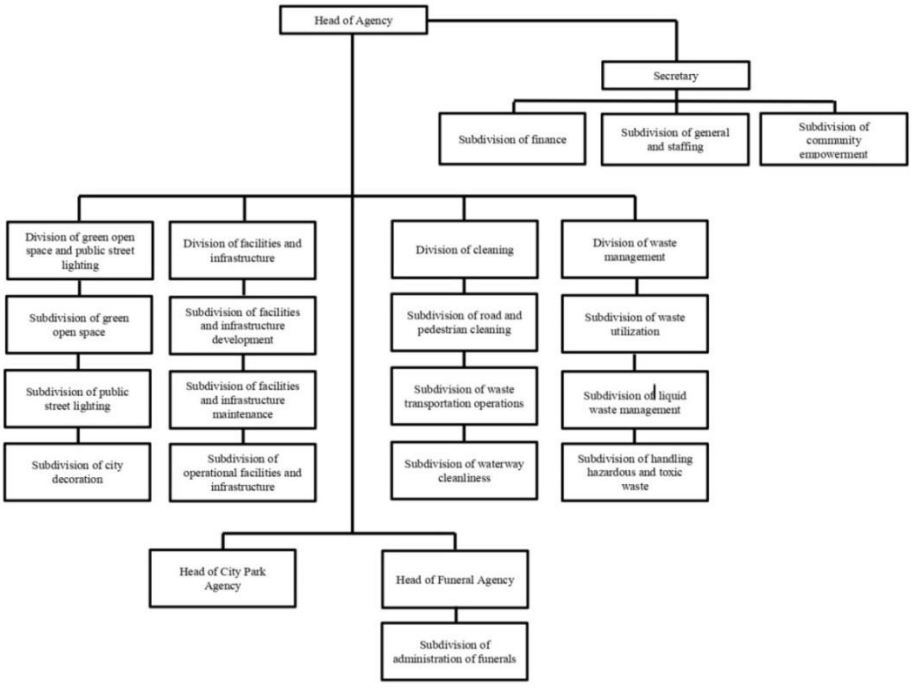

Figure 3. Organizational structure of cleanliness and green open space agency

Source: Primary Analysis, 2024

Table 3. Stakeholders of solid waste management in Surabaya City

PDCA	Stakeholder	Key unit	Level of operation	Main tasks
Plan	City Development Planning Agency	Department of urban planning, settlement and environment	City	Urban development planning includes: - defining goals - measuring action plans - analyzing results
Do	Cleanliness and Green Open Space Agency	- Cleaning division - Waste management division - Main waste bank	City	- Operation and transportation of solid waste from transfer station to landfill - Material recovery management and composting facilities - Collecting and managing waste from waste bank units
	Community organization	Neighbourhood/ hamlet (RT/ RW)	Village	Operation and transportation of household solid waste to the transfer station
	Private-formal sector	Recycling industry	City	- Managing waste in landfill - Recycling (mainly) plastic waste to produce raw materials
	Informal sector	Waste bank	Village	Management of recyclable household waste, e.g. paper and plastic waste
		Collectors (small scale)	Subdistrict	Recyclable waste collection business by receiving waste from waste bank units and households
		Collectors (big scale)	City	Recyclable waste collection business by accepting waste from main waste banks and small-scale waste vendors
Check	Surabaya City Environment Agency	Supervision and control division	City	Monitor, control, and evaluate the results and processes of municipal solid waste management
Action	Universities and non-governmental organizations	All university in Surabaya City and organization related with waste issues	City	Observe the process and contribute to research and development planning and actively engage in city planning and development deliberations.

Source: Primary Analysis, 2024

Implementation of waste management in Surabaya City involves not only the Cleanliness and Green Open Space Agency but also community organizations as well as the formal and informal sectors. The formal sector of sustainable waste management in Surabaya City includes Neighborhood/ hamlet (RT/ RW) and recycling industry. Informal sector includes waste banks as well as small and large-scale recycling companies. Waste banks are a common type of community-based waste management in Indonesia. They are managed by community organizations at the sub-district level on a voluntary basis. Waste collected in the waste bank units will then be sold to the main waste bank or small-scale waste collectors. Small-scale waste

collectors in Surabaya City are people or small business units that collect recyclable materials (e.g. plastic and paper waste) from waste banks or households and then sell them to large-scale waste collectors.

Agency responsible for checking the process is the Surabaya City Environment Agency. In terms of urban waste management, the agency has the responsibility to monitor, control and evaluate the results and processes of urban waste management. The agency has not addressed plastic waste management in its strategic plan specifically but contributes to environmental monitoring and control measures. Universities, research institutions, and non-governmental organizations are stakeholders responsible for scrutinizing the implementation of urban waste management in Surabaya City. These organizations are actively involved in city planning through city planning and development deliberations.

3.1.1 Solid waste management elements in Surabaya City

A comprehensive solid waste management system consists of six basic functional elements, including solid waste generation, on-site handling and storage, collection, transfer and transportation, material and resource recovery, and disposal (Rajput, Prasad and Chopra, 2009; Kadafa *et al.*, 2014). In this section we will discuss in depth six important elements of solid waste management in Surabaya City.

3.1.1.1 Solid waste generation

Surabaya City has two categories of solid waste that are of importance in solid waste management: residential generated solid waste and non-residential generated solid waste.

Table 4. Solid waste generation in Surabaya City

SOLID WASTE GENERATION OF SURABAYA CITY	Weight per cap	0.704 kg/ capita/ day
	Volume per cap.	2.39 litre/ capita/ day
	Weight generated	2,032.61 tonnes/ day
	Volume generated	5,761.37 m^3/ day
COMPOSITION	Organic	54.31%
	Paper/ paper materials	14.63%
	Plastic	19.44%
	Metal	0.48%
	Glass	1.12%
	Rubber	1.14%
	Wood/ wood products	1.61%
	Leather	1.19%
	Fabric/ textiles	1.47%
	Ceramics	0.17%
	Toxic hazardous materials	0.86%
	Other	3.58%

Source: Primary Analysis, 2024

According to Table 4, the solid waste production in Surabaya City is predicted to be 0.704 kg/ capita/ day, resulting in a daily generation of 2,032.61 tonnes/ day or 5,761.37 m^3/ day. These figures are based on calculations done by Cleanliness and Green Open Space Agency. More than half (54.31%) of the solid waste is decomposable organic waste, the other components are: paper/ paper materials (14.63%), plastic (19.44%), metal (0.48%), glass (1.12%), rubber (1.14%), wood/ wood products (1.61%), leather (1.19%), fabric/ textiles (1.47%), ceramics (0.17%), toxic hazardous materials (0.86%) and others (3.59%).

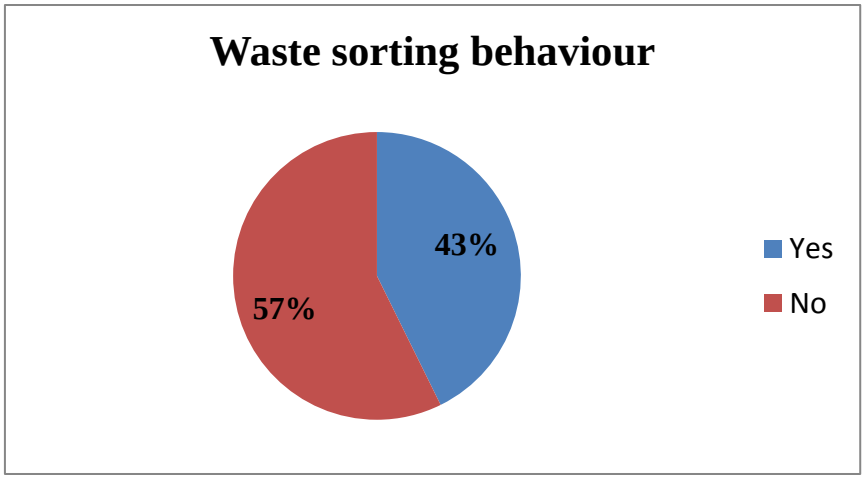

Figure 4. Waste sorting behavior of respondent in Surabaya City

Source: Primary Analysis, 2024

Based on the interviews, it has been determined that the waste collected is not processed at the location where it is generated. Instead, the sorting process is carried out by the Cleanliness and Green Open Space Agency. Survey results depicted in Figure 4 corroborate this assertion, revealing that a mere 42.7% of individuals possess the ability to categorise their refuse. Waste sorting is performed by several groups, such as scavengers, homes that sell sorted waste to itinerant waste buyers, students, and households that sell waste to waste banks. Additionally, waste officers serve as crew members for trucks responsible for collecting recyclable waste.

3.1.1.2 Solid waste collection and transportation

Waste transportation is a sub-system that aims to carry waste from the transfer location or from the waste source directly to the final processing site, or landfill. Waste transportation is one of the important components and requires careful calculation (Jayasinghe, Derrible and Kattan, 2023). Waste transportation in Surabaya City is 70% the responsibility of the Cleanliness and Green Open Space Agency and 30% by the private sector (supervised daily by independent Cleanliness and Green Open Space Agency supervisors). Besides being responsible for waste transportation, the Cleanliness and Green Open Space Agency is also responsible for street

sweeping around the city center, markets, and other public places. Currently, the Cleanliness and Green Open Space Agency of Surabaya City has a total of 628 vehicles and 190 temporary shelter location to support waste transportation including 468 wheelie bin, 53 compactors, 26 dump trucks and 81 armrolls.

Waste transportation activities are carried out in each house using wheelie bin, while in shopping areas and markets/ trades, strong and closed bin containers are provided which are then directed to temporary storage locations, compost houses, temporary disposal sites (reduce, reuse and recycle), and waste power plants for waste sorting. Currently the coverage area served by waste transportation is divided into 5 specific areas including West Surabaya, East Surabaya, Central Surabaya, North Surabaya and South Surabaya. Based on information from the Environmental Agency, the Surabaya City government is able to transport around 88.12% of the total waste generation in Surabaya City. In the analysis of the survey results, it is known that all research respondents receive waste transportation services.

3.1.1.3 Treatment and disposal

Treatment is a process of activities in handling waste that aims to reduce the amount of waste generation before entering the landfill (Ustohalova, 2011). So that waste processing or management can take place properly, waste management is carried out from the source first, because less waste is generated and the more waste that has been processed will facilitate waste management at the next stage. Activity starts from sorting or separating dry waste and wet waste, then wet waste will be made into compost. Accordance with the research from Nguyen *et al.* (2023), waste management efforts need government intervention and support from residents, for example the Cleanliness and Green Open Space Agency socializes waste management activities for the community and the management is supported by community members, then from the private sector and the Cleanliness and Green Open Space Agency provide waste management facilities for residents. These efforts are made to create a clean environment.

3.1.1.4 Recycling and material recovery

Waste recycling in Surabaya City is primarily conducted by both governmental and non-governmental entities. Typical recycling activities include the sorting and resale of recyclable material, the shredding of plastic, and the creation of handicrafts. Recycling process commences by gathering recyclable waste materials, including plastic, glass, and metal. Typically, scavengers are responsible for collecting this kind of waste, however homeowners and waste banks often participate in its collection. Based on the observations made during the data collecting period, there are multiple entities involved in recycling and material recovery in Surabaya City. These entities are listed in the Table 5 below:

Table 5. Actor of solid waste management in Surabaya City

Actors in technical material's loop	Actor in Biological material's loop
Scavengers	Compost house
Waste processing center	Waste processing center
Waste bank	Farmers
Waste power plant	

Source: Primary Analysis, 2024

In 2020, Surabaya City was able to process 322.83 m^3/ day of compost material from all waste processing facilities. The following waste processing facilities are owned by the Surabaya City Government is compost house, market waste processing, 3R (reduce, reuse and recycle) waste processing centers, composter for parks and greenways and waste power plant (PLTSa). Overall, in 2020 Surabaya City through waste handling activities is able to process 53,258.89 tons/ year. Waste management practices in Surabaya City can be illustrated as in Figure 5.

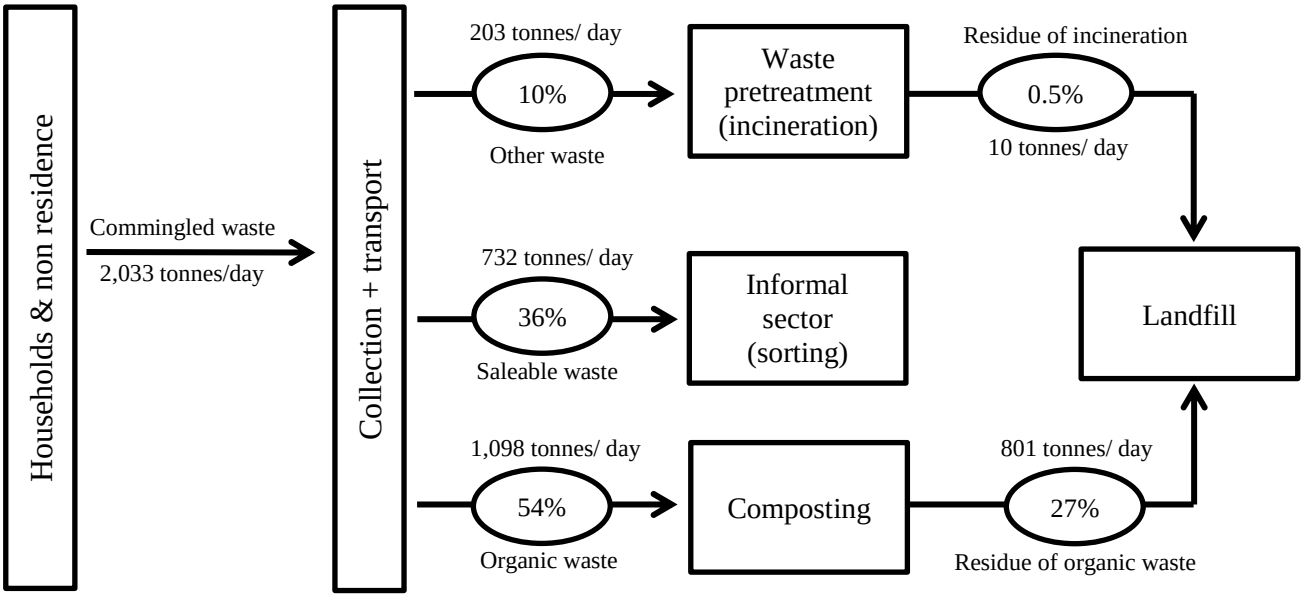

Figure 5. Material flow of generated solid waste in Surabaya City

Source: Brunner and Fellner, 2007

3.1.2 Aspects of current solid waste management practice in Surabaya City

Waste management in industrialized city is often defined as control over the generation of waste, starting from the storage, collection, transfer, transportation, processing, and final disposal of waste, with the best principles for health, economy, engineering, conservation, aesthetics, environment, and also to the attitude of society (Ferronato and Torretta, 2019). The success of management does not only depend on technical aspects but also includes non-technical aspects, such as how to regulate the system so that it can function, how the institution or organization should manage it, how to finance the system, and last but not least how to involve the waste-

producing community in handling the waste. A waste management system must involve various disciplines, such as urban planning, geography, economics, public health, sociology, demography, communication, conservation, and materials science (Hannon, 2020). Before Law Number 18 of 2008 was issued, urban waste management (issued by the Ministry of Public Works) in Indonesia positioned that urban waste management was a system consisting of 5 subsystem components (Figure 6), that is (Abdul and Syafrudin, 2018).

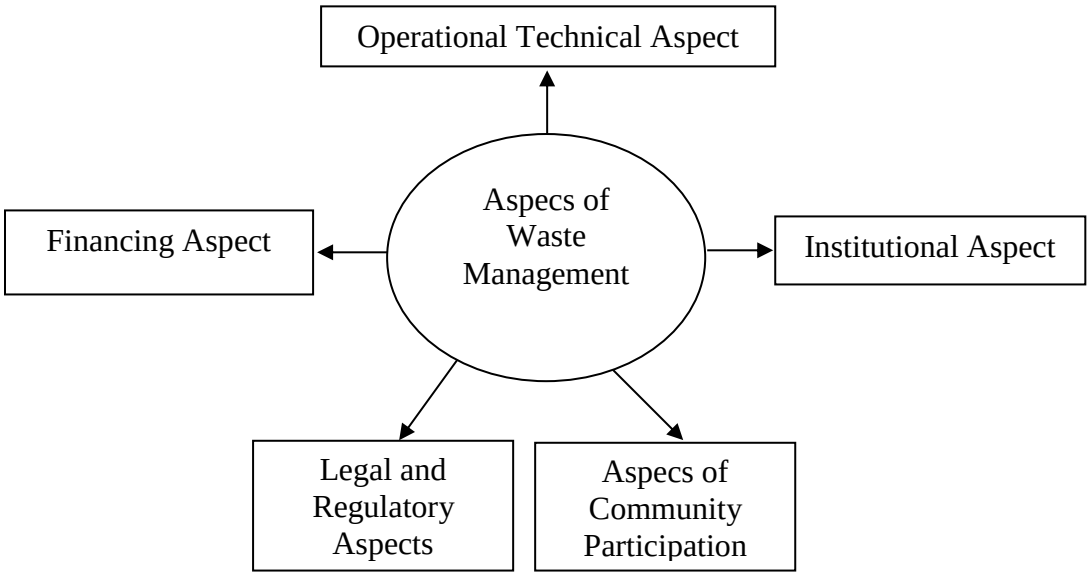

Figure 6. Aspects of urban waste management

Source: Abdul and Syafrudin, 2018

3.1.2.1 Regulations/ laws

Regulatory aspect is based on the fact that Indonesia is a state of law where life joints rely on applicable laws. Solid waste management in Surabaya City requires strength and a legal basis, such as forming organizations, collecting levies, public order, and so on (Purba and Erliyana, 2020). Regulations needed in the implementation of the waste management system in urban areas are those that regulate public order related to waste handling, waste management master plan for cities, form of management institutions and organizations, procedures for implementing management, number of service fees or levies and cooperation with various related parties. Table 6 shows the list of municipal solid waste management regulations in Indonesia that do not include hazardous waste management.

Table 6. List of regulations on solid waste management

Title	Subject
The Law 18/2008	About solid waste management
The Law 32/2009	About environmental protection and management
Government Regulation 81/2012	About solid waste management
Ministry of Public Work Reg. 21/PRT/M/2006	About national policies and strategies for development of

	solid waste management system
Ministry of Home Affairs Regulation 33/2010	About solid waste management guidelines
Ministry of Environment Reg. 16/2011	About content guidelines of local regulation design about domestic solid waste
Ministry of Environment Reg. 13/2012	About implementation guidelines of reduce, reuse, recycle through waste banks
Ministry of Public Work Reg. 03/2013	About domestic solid waste management
Ministry of Environment & Forestry Reg. P.59/Menlhk/Setjen/Kum.1/7/2016	About leachate quality standards of solid waste final processing site for business and / or activities

Source: Primary Analysis, 2024

3.1.2.2 Institutions and organizations

Aspect of organization and management is a multi-disciplinary activity based on technical and management principles concerning the economic, social, cultural, and physical conditions of the city area and pays attention to the parties served, namely the city community (Taelman *et al.*, 2018). Design and selection of the organizational form are adjusted to government regulations that foster it, pattern of the operating system applied, working capacity system, scope of work and tasks to be handled. Responsibility for waste management in Surabaya City is assigned to a specific position within the Cleanliness and Green Open Space Agency.

3.1.2.3 Operational technical

Based on the Indonesian National Standard (SNI) 19-2454-2002, the operational and technical procedures for urban waste management include the basics of planning for service area, service level and operational technical, starting from waste container, waste collection, waste removal, waste transport, waste processing and sorting and final disposal of waste. Sorting and recycling activities are carried out as much as possible from the collection to the final disposal of the waste. Waste generation in Surabaya City to increase from year to year and is not proportional to the quality of waste management (Wikurendra *et al.*, 2023).

3.1.2.4 Financing/ levies

As with other activities, the financing component of a municipal solid waste management system is ideally calculated based on investment costs, operation and maintenance costs, management fee, cost for development and cost of counseling and community development. Financing aspect is a driving resource so that the city's waste management system's wheels can move smoothly (Yao & Woerden, 2018). It is Surabaya City solid waste management system will lead to 'self-financing, including forming local companies. This financing sector involves several aspects, such as Revenue Expenditure Regional Budget (APBD) for waste management, retribution, and waste management costs, cost for salaries, transportation, maintenance, education and development, and administration, proportion between retribution and community income and applicable levy structure and withdrawal.

3.1.2.5 Community participation

Without the participation of the waste-producing community, all planned waste management programs will be in vain. One approach to the community to assist Surabaya government programs in cleanliness is to familiarize the community with behavior following the program's objectives. Includes how to change public perception towards orderly and orderly waste management, local social, structural, and cultural factors and habits in waste management. According to Damanhuri et al. (2014), problems that occur are related to community participation in waste management including unequal distribution of population, no desire in community to protect environment, no standard method for community development that can be used as a guideline for implementation, many cleaning managers who have not included counseling in their programs and managers are concerned that community initiatives will not be compatible with existing management concepts.

Low public awareness in waste management is one of the obstacles in Surabaya City. Although in some places there are already community groups that care about waste, but in general, community participation in waste management is still relatively low. Disposal of waste out of place (even into rivers and waterways) is a common occurrence. Regulations and Standard Operating Procedures (SOPs) that have been made regarding waste management have not been fully informed to the community. Surabaya government continues to encourage people to start managing waste from their homes in various ways. For example, 3R promotion, composting, and waste banks.

3.1.2.6 Technical waste management

Waste management operational system also includes a waste processing and processing subsystem, which needs to be developed in stages by considering processing that relies on reuse, either directly, as raw materials, or as energy sources (Beraud, Barroca and Hubert, 2012). The implementation of the waste management system currently carried out in Surabaya City is open dumping, composting, burning (incineration), and sanitary landfill.

3.2 Circular Economy Situation of Solid Waste Management in Surabaya City

Concept of a circular economy is unfamiliar to many individuals in Surabaya City, and they lack awareness of the associated benefits. Consequently, it is unclear to them if they have the capability and desire to adopt the principles of a circular economy. Identification of circular economy techniques in Surabaya City was hindered by this condition. In addition, in a linear economic society like Indonesia or Surabaya City specifically, where the take-make-dispose approach is seen as a more affordable and convenient solution for daily activities, concepts such as circular economy or related terms (such as closing the loop or cradle to cradle) have never

been familiar.

In order to examine the present implementation of circular economy concepts in solid waste management in Surabaya City, a number of activities pertaining to solid waste management were identified. Based on the observations made during the data collection period, it can be concluded that the waste bank business is the predominant type of business in Surabaya City. While the city does have a few waste regeneration enterprises, the extent of their application is restricted. Ellen Macarthur Foundation stated that the adoption of a circular economy is intimately linked to the regeneration efforts in the solid waste management sector (Ellen MacArthur Foundation, 2012).

Solid waste management enterprises in Surabaya City are positioned towards the lower to middle levels of the hierarchy. This indicates that the economic component of these businesses does not have a big impact on the recycling industry, unlike the actors at the top of the hierarchy. Primary impetus for the founding of Surabaya City's central waste bank was a social concern regarding the subpar execution of solid waste management in the city. Waste bank programme was selected as a method to raise awareness among the residents of Surabaya City regarding the concealed worth of waste. Enterprises involved in the management of solid waste in Surabaya City are structured as foundations or operate separately without a formal union. Furthermore, based on interviews and conversations with multiple officers at the Cleanliness and Green Open Space Agency, it has been determined that these enterprises had sufficient expertise to provide higher levels of value for the recycled materials. They need sufficient assistance in terms of financial, technological, and managerial factors. Successful implementation of a circular economy in Surabaya City necessitates more than conventional collaboration across sectors. Successful implementation of circular economy necessitates collaboration across sectors, including access to capital investment, strategic marketing, and other factors that enhance the capabilities of circular economy actors (Hina *et al.*, 2022). Relying solely on the support of the local government is insufficient.

3.3 Challenges of Integration Solid Waste Management with Circular Economy Model in Surabaya City

This section examines the challenges of integrating solid waste management into the circular economy model in Surabaya City by identifying the current barriers. This section provides further elaboration on key challenges to integrating solid waste management with the circular economy model, including net profitability, capital, and transaction costs.

3.3.1 Net profitability

According to data from Table 8, the proportion of waste that can be sold amounts to 36.67% of the total waste produced, which is equivalent to 725 tons per day. Daily quantities of plastic waste, paper, glass, and metal are 395 tons, 297 tons, 22.77 tons, and 9.76 tons, respectively. Economic value of plastic is IDR 790,000,000/ 46,500 € per day, paper is IDR 297,000,000/ 17,450 € per day, glass is IDR 91,080,000/ 5,350 € per day, and metal is IDR 9,760,000/ 575 € per day (these prices were obtained from the interview with waste bank owner). This demonstrates that the economies of scale associated with non-biodegradable recycling are substantial, indicating great prospects for recycling various types of plastic. Quantity of organic matter derived from Surabaya City waste is around 1,104 tons per day, which is nearly double the amount of waste that may be sold. Compost yield amounts to merely half the weight of biodegradable materials, resulting in a production of 552 tons of compost (Ayilara *et al.*, 2020). Current market value of compost is IDR 1,500 per kilogram (Sitanggang and Siahaan, 2021), indicating that the economic potential of the compost might amount to IDR 828,000,000/ 48,650 € per day. Attaining this outcome necessitates a substantial amount of exertion, since it demands a composting process lasting 21-40 days to obtain the compost.

3.3.2 Capital

Waste regeneration enterprises are characterized as informal businesses (Katusiimeh, Burger and Mol, 2013). While a few firms claim to be self-sufficient, the majority acknowledge that lack of financial resources is the primary obstacle preventing them from effectively managing waste in Surabaya City. Nevertheless, certain enterprises, such as waste banks, exhibit comparatively more resilience in terms of capital. This is because of their distinctive procurement system, wherein they may acquire and store the gathered waste without the need for physical currency, as is typically expected of traditional waste collectors.

3.3.3 Technology

Participation of the informal sector is distinguished by limited technical adaptation, which is substituted by the utilization of inexpensive human resources (Hettiarachchi *et al.*, 2018). Hence, the informal sector requires technological adaptation to enhance its efficiency. Recycling methods in Surabaya City are now restricted to the sorting and selling of materials to external waste collectors, with little emphasis on the internal circulation of materials within the city. Based on the interview with Mr. Anjar in the creative industry, it can be inferred that the main problems are the scarcity of proficient personnel and the limited access to technology inside the city. Creative industry relies on technological innovations to effectively collaborate with

recycling firms (Corral-Marfil *et al.*, 2021). An example of ownership can be seen in the domain of plastic recycling technologies. This technology will facilitate the advancement of solid waste management in the recycling hierarchy, consequently improving the integration of solid waste management with the circular economy model. Furthermore, the creative industry in Surabaya City has the potential to be advanced through technology innovations, making it a significant contributor to waste management.

3.3.4 Externalities

Purchase decisions of Surabaya City citizens are significantly influenced by price sensitivity. Conclusion is based on the survey findings presented in Table 7, indicating that 70% of the participants concurred that affordability is a crucial factor when buying recyclable materials. Furthermore, the community highly values the item's distinctiveness and creative merit, making it a sought-after purchase.

Table 7. Criteria to purchase recycled goods

Reason for purchase	Criteria (Percentage %)				
	Very unimportant factor	**Unimportant factor**	**Fairly important factor**	**Important factor**	**Very important factor**
Can be used for daily activities	5%	10%	25%	20%	40%
Durable	2.5%	7.5%	20%	45%	25%
Affordable price	7.5%	2.5%	32.5%	20%	37.5%
Artistic value	7.5%	7.5%	20%	22.5%	42.5%
Uniqueness	10%	10%	40%	25%	15%
Fashionable/ trendy	15%	15%	25%	25%	20%
Branded	20%	25%	25%	15%	15%
Can be used as symbol (environmental conservation symbol)	17.5%	15%	22.5%	30%	15%

Source: Primary Analysis, 2024

3.3.5 Infrastructure

Lack of infrastructure poses a significant challenge for waste entrepreneurs in Surabaya City, particularly in attracting investors involved in composting and the separation of biodegradable waste. Implementing waste segregation practices will lower the expenses associated with waste management, therefore making it more appealing to potential investors. Survey findings indicate that the lack of waste segregation infrastructure is a significant issue contributing to people's hesitancy to separate waste. Implementation of measures such as the introduction of dedicated receptacles for homeowners will enhance the potential for private sector participation in waste management. Lack of transportation options hinders solid waste management enterprises from achieving maximum revenue. Accessibility of affordable transportation will decrease the operational expenses of solid waste management enterprises.

Presence of transportation options greatly facilitates the growth of waste bank operations. The presence of several transportation modes has been demonstrated to significantly enhance the extent and capability of waste collection, surpassing previous levels. This demonstrates the significance of infrastructure for waste businesses. Having waste segregation infrastructure in place can significantly contribute to the expansion of their waste management enterprise. According to the study, over 60% of the respondents believe that having waste segregation facilities is vital. This finding is further reinforced by the survey results, which indicate that 76% of the respondents agree to sell the waste they generate. Furthermore, the survey findings indicate that individuals have a preference for door-to-door waste pickup, even when presented with a lesser cost option.

3.3.6 Imperfect information

Implementing circular economy concepts necessitates innovative and non-traditional methods to recognize potential opportunities (Ellen MacArthur Foundation, 2012). A strong information role is inevitable in turning these opportunities into practical action. Majority of waste recycling enterprises struggle to develop innovative methods for waste regeneration prospects, as they continue to focus on traditional opportunities provided by waste regeneration businesses (Ezeudu and Ezeudu, 2019). Hence, the rapid increase in information poses a significant obstacle to the integration of solid waste management with the circular economy model in Surabaya City.

3.3.7 Transaction cost

Informal actors in the waste recycling industry in Surabaya City often occupy the lowest position in the recycling business hierarchy, as previously stated. This factor renders them significantly reliant on purchasers. Players are unable to ascertain the selling price of the recycled materials. Instead, the price is established by the buyer acting as an intermediary. Informal waste recyclers are compelled to either compare the buyer's maximum price or retain and sell the stockpiled raw materials when the price provided rises, due to this mechanism.

3.3.8 Inadequately defined legal

Interviews found that laws and regulations do not hinder the informal sector from operating solid waste management businesses in Surabaya City. The Cleanliness and Green Open Space Agency promotes the involvement of the informal sector in solid waste management and assists informal actors by providing equipment support for their operations. Nevertheless, certain sectors within the local government lack the ability to accurately establish legislation pertaining to solid waste.

3.3.9 Poorly defined target and objectives

Residents active engagement in solid waste management, particularly their willingness to separate their waste, might contribute to the availability of higher-quality recyclable materials for recycling initiatives. Consequently, sorting these resources at their origin will result in a higher commercial value (Ellen MacArthur Foundation, 2015). Discovering superior-grade recyclable resources in Surabaya City would enhance the potential for utilizing these materials in the production of economically valuable products. Nevertheless, the government has never taken into account the execution of regulations pertaining to solid waste separation.

3.3.10 Capabilities and skills

An important challenge in implementing the circular economy model is enhancing the capacities and expertise of informal enterprises in the field of solid waste management. Hence, the utilization of novel knowledge and/ or technology has the potential to unveil fresh perspectives in their commercial methodologies. Thus, waste management enterprises can be appealing ventures, even for established corporations to engage in.

3.3.11 Custom and habit

Integration of solid waste management with the circular economy concept is greatly impacted by customs and habits. Survey results indicate that the community is in favor of the practice of waste reduction and reuse. Nevertheless, the community's adherence to waste sorting remains insufficient, posing a challenge to the successful integration of solid waste management with a circular economy model in Surabaya City.

3.4 Solution to the Challenges

In order to address the difficulties associated with integrating solid waste management into the circular economy model in Surabaya City, a framework inspired by the Ellen MacArthur Foundation is employed. Proposed remedies for the obstacles in the integration are outlined in Table 8. Higher government policies and regulations may constrain the application of the circular economy model at the city level. Some recommendations in this framework are not open to discussion. Furthermore, it is not feasible to suggest remedies exclusively for specific sectors. Utilizing the economic factors can expedite the integration of solid waste management with the circular economy model in Surabaya City. Primary driving force behind many recycling enterprises in Surabaya City is their economic incentive.

Based on the interviews, it is evident that the informal sector significantly contributes to solid waste management in Surabaya City, encompassing activities ranging from waste collection to

recycling. A major obstacle faced by the informal sector is the limited access to finance, which hinders its ability to play a more significant role in solid waste management. One possible method to address this issue is to offer incentives to capital proprietors, specifically banks. Presently, the national government has implemented a scheme called Kredit Usaha Rakyat (KUR) that allows for borrowing funds from banks without the need for collateral. Kredit Usaha Rakyat is a microcredit program designed for unregistered enterprises or individual entrepreneurs, which offers a non-collateralized loan of up to IDR 50,000,000/ €2,950 (Leksono, 2016). Significant number of informal recycling enterprises are unaware of the Kredit Usaha Rakyat (KUR) program. Present condition of waste management necessitates the involvement of additional participants in the management of solid waste. Inviting numerous economic-based business players to participate in waste recycling in Surabaya City is not suitable due to their relatively low economies of scale. Suggesting the implementation of a Public Private Partnership (PPP) is one of the potential strategies to resolve this predicament. By enhancing community engagement, the existing stakeholders can effectively manage a greater volume of waste.

To overcome technological limitations, it is crucial to offer organizations regular training on solid waste management (Aparcana, 2017). These trainings should encompass not just the technical components but also encompass financial solutions, legal needs, and managerial abilities. Trainings can also serve as regular gatherings for the informal sector to discover emerging prospects and obstacles to growth, while also enhancing collaborative endeavors such as joint sales of waste materials to wholesalers (Ferronato and Torretta, 2019). These monthly meetings can also serve as opportunities to enhance one's knowledge and extend recycling networks, such as establishing commercial connections with end users.

Development of waste banks, which are community-based organizations, is crucial. Waste banks facilitate cooperative initiatives between citizens and the informal sector. Waste banks can facilitate awareness and education initiatives for community members regarding their responsibilities in managing solid waste (Wulandari, Utomo and Narmaditya, 2017). They can also spread information about the drawbacks of unlawful activities like waste incineration. Waste banks can employ social pressure mechanisms to ensure that members adhere to the agreed-upon practice of segregating waste. Waste banks can serve as a central institution for the informal sector to play a significant role in the management of solid waste inside the city (Kubota, Horita and Tasaki, 2020).

Table 8. Suggested solutions for barriers in circular economy

High relevance **Medium relevance** **Low relevance** **Barriers**		Information and awareness	Collaboration platforms			Business support scheme		Public procurement and infrastructure		Regulatory framework					Fiscal framework
		Public communication campaign	Public private partnerships	Industry collaboration platform	R&D and programmes	Financial support	Technical Support	Public procurement rules	Public investment in infrastructure	Government strategy and targets	Product regulations	Waste regulations	Industry, consumer, competition and trade	Accounting, reporting, financial, regulation	VAT and excise duty reductions
Economics	Net profitable														
	Capital														
	Technology														
Market failures	Externalities														
	Infrastructure														
	Insufficient competition														
	Imperfect information														
	Split incentives														
	Transaction cost														
Regulatory failures	Inadequately defined legal														
	Poorly defined legal														
	Implementation														
	Unintended consequences														
Social factor	Capabilities and skill														
	Custom and habit														

Source: Primary Analysis, 2024

3.5 Suitable Circular Solid Waste Management Framework in Surabaya City and How to Enable It

As previously stated, regeneration activities, such as recycling and material recovery, are strongly associated with the implementation of solid waste management principles within a circular economy model. This association is higher compared to other activities, such as sharing, optimizing, looping, virtualizing, and exchanging (Ellen MacArthur Foundation, 2012). Participation of the formal sector is widely regarded as enhancing the effectiveness of solid waste management in numerous developed nations. Insufficient funding for implementing comprehensive solid waste management is a significant obstacle to engaging the formal business sector in Surabaya City solid waste management efforts. While engaging the community in implementing effective solid waste management is the most cost-effective and optimal method to address the waste issue, depending only on community involvement will necessitate significant amounts of energy and time (Sinthumule and Mkumbuzi, 2019). Similarly, like in several urban areas in emerging nations, Surabaya City also has an informal sector engaged in the recycling and reclamation of waste products. Majority of individuals are motivated by economic factors, hence engaging them in the formal establishment of solid waste management will encounter minimal opposition (Brunner and Fellner, 2007; Salvia *et al.*, 2021). Regarding Surabaya City, the participants engaged in solid waste management operations include scavengers, itinerant waste buyers, waste collectors, and waste banks.

It is crucial for the Surabaya City Council to explore potential collaborations with these informal sectors in order to enhance solid waste management (Muheirwe, Kombe and Kihila, 2023). Establishment of an optimal environment for the solid waste management industry in Surabaya City necessitates the active participation of both the local government and the community. It is suggested that a collaborative structure involving the government, informal

companies, and the community be established to effectively integrate solid waste management with the circular economy model in Surabaya City.

3.5.1 Initiative from the municipality

Informal enterprises are characterized by their independent, unstructured, and uneducated nature (Günther and Launov, 2012). It is difficult to build an organization to bring informal company owners together even for bigger economic rewards. Conducting regular meetings to promote the advantages of collaborative work can help raise awareness among informal business participants and encourage them to establish formal organizations. Supportive policies such as legalizing the business activities of informal organizations in solid waste management, providing incentives for waste collection and treatment services carried out by organizations can be used to increase the contribution of informal actors in solid waste management (Gutiérrez-Galicia *et al.*, 2021; Zisopoulos *et al.*, 2023).

3.5.2 Increase the capacity of informal actors

Wilson, Velis and Cheeseman (2006) propose numerous measures to augment the involvement of the informal sector in the management of solid waste. These measures are enabling them to streamline, enhance the structure of recycling enterprises, and maximize the capacity to generate and extract value from recycled waste. In Indonesia, waste banks as a type of cooperative organization have defined requirements for founding an organization as indicated in the Minister of Environment Regulation No. 13/2012. Several waste banks in Indonesia had comparable challenges during their inception and expansion, making it more feasible to devise an effective framework for organizing and operating waste banks (Latanna, 2022; Eka *et al.*, 2023). Local administration can potentially implement a Public-Private Partnership (PPP) with a waste bank, as stated in Article 39 of Local Regulation 8/2015. Surabaya City has implemented several past Public-Private Partnership (PPP) projects specifically

focused on solid waste management. Exploring collaborative ties with industries, such as the creative industry, is also an option. Local government has acknowledged waste banks as significant participants in the management of solid waste. Consequently, the local government has provided substantial support for the establishment and growth of waste banks.

After organizing the informal sector in waste management, the subsequent task is to enhance the efficiency of the informal sector in the waste recycling hierarchy. A possible approach is to avoid the involvement of middlemen in the waste recycling cycle (Suthar, Rayal and Ahada, 2016). Waste banks must interact directly with the final users of the recycled products. This can be achieved through the exploration and establishment of novel commercial partnerships with end-users. These users may belong to the agricultural sector or the creative industries. Final stage in bolstering the capabilities of informal players is to augment their capability to both contribute to and derive value from the reclaimed waste. An individual actor from the informal sector is not capable of undertaking this activity due to the significant time investment needed to accumulate a big amount of waste, and they also lack the ability to get remuneration throughout the collection process. This condition is exacerbated by the economic status of the majority of individuals in the informal sector who belong to the low-income bracket (Korsunova *et al.*, 2022). These limitations hinder the ability of numerous informal sector participants to expand their firm. This can be accomplished by creating a unified corporation that effectively collects a significant amount of waste within a short period of time and then sells the reusable materials to manufacturers. This strategy enables the extraction of greater value from the accumulated waste.

3.5.3 Increase the participation of community

It is necessary to develop community engagement, enhance awareness, and improve the organizational and technical capabilities of the community. Important to promote and provide assistance to waste banks, which are

community-based organizations (CBOs), in order to educate the community about the significance of improving waste management. Community is more likely to readily accept knowledge shared by community-based organizations (CBOs) like waste banks, as opposed to information provided by the government (Bratianu, 2015; Aljuwaiber, 2016). Figure 8 exemplifies the integration of solid waste management into a circular economy framework, which entails collaboration among waste banks, citizens, informal actors, local government, and creative industries. Waste bank serves as a waste collection facility exclusively for its members, offering segregated waste collection services.

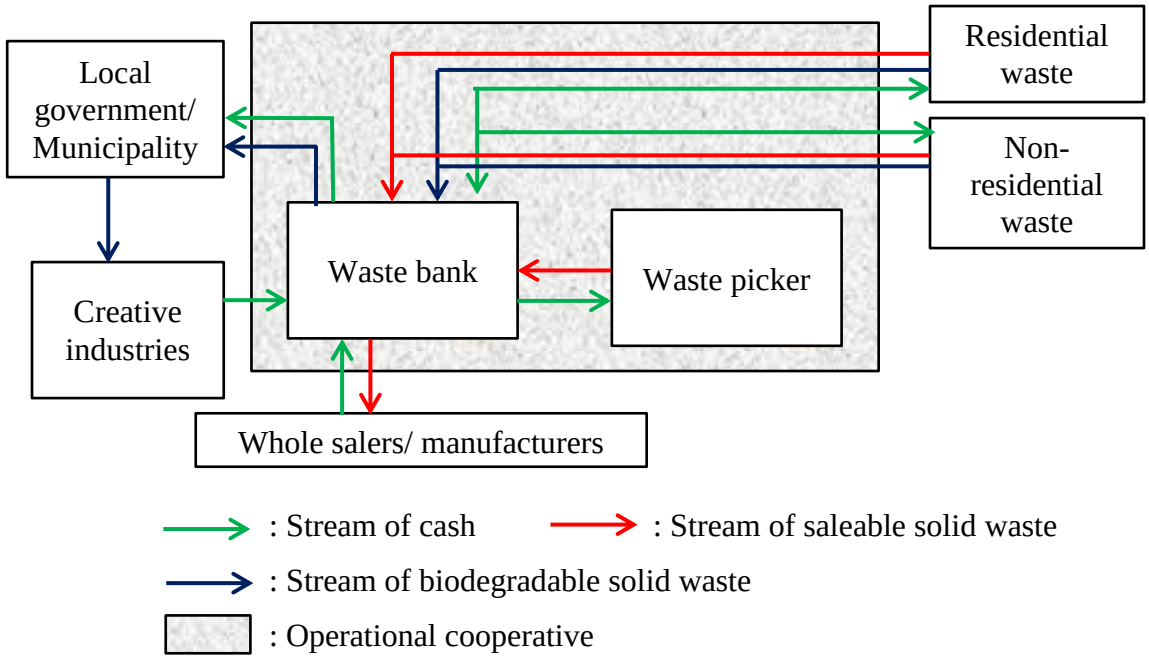

Figure 19. Proposed model for integration solid waste management with circular economy approach in Surabaya City

Source: Primary Analysis, 2024

3.6 Waste Absorption Footprint

This section provides an estimation of the environmental impact of the current waste management system, specifically focusing on the waste footprint. This study does not provide a comprehensive waste footprint calculation, which includes the nutrient footprint, although it is feasible to determine the waste footprint of solid waste management in Surabaya City. This is a result of the lack of access to the necessary data. This study focuses solely on quantifying gas emissions (CH_4, N_2O, and CO_2) when assessing the environmental impact of solid waste management. WAF_{CO2} analysis was performed by analyzing the activities of solid waste management.

3.6.1 Collection, transportation (emissions)

Emissions resulting from collecting and transportation activities were calculated using IPCC tier 1 methodology to estimate $CO_2/CH_4/N_2O$ emissions. Respondents reported that 739,768 liters of diesel fuel are used annually for collecting and transportation activities. According to Ministry of Environment (2012), the calorific value of diesel fuel is 36 x 10^{-6} TJ/liter. Emission factors for diesel engines, according to the IPCC, (2019) methodology for mobile sources are 74,100 kg CO_2/TJ; 3.9 kg CH_4/TJ and; 3.9 kg N_2O/TJ. Yearly emissions resulting from the collecting and transportation activities amount to 1,973,283 kg CO_2; 103.857 kg CH_4; and 103.857 kg N_2O.

Waste collection manages 88.12% of the waste produced in the city. In order to fully address the waste requirements of the city, it is necessary to enhance waste collection and transportation operations. Nevertheless, this will lead to increased fuel consumption and the generation of additional CO_2, CH_4, and N_2O emissions. This study does not consider the calculation of such plans because there is no available data on actions linked to collection and transportation.

3.6.2 Disposal activity emission

Similar methodology employed to calculate emissions from collection and transportation activities was also applied to disposal activities. According to interviews, it was ascertained that the yearly fuel consumption totals 399,874 liters. Fuel used throughout the collection and transportation phase is the same as the one employed specifically diesel fuel. Assessment of emissions arising from disposal activities is conducted comprise of 1,066,704 kg CO_2; 56.14 kg CH_4; and 56.14 kg N_2O.

3.6.3 Landfill emission

Emissions of the landfill were calculated by gathering operating details through interviews. Informants stated that the site is transitioning from unregulated dumping to a regulated landfill. Site lacks a gas collection infrastructure and the height of the pile is approximately 4 meters. Based on the IPCC technique, amount of methane produced can be determined using the following formula:

$$Y_{methane} = \left(MSW_T . MSW_F . MCF . DOC . DOC_F . F . {}^{16}/_{12} - R\right).(1 - OX) \quad (1)$$

Table 5 presents data on solid waste production, indicating a daily generation of 2,032.61 ton/ day or 741.90 Gg/ year. It is noteworthy that 88.12% of this waste was really disposed of in landfills, as revealed in the interview with respondent. Moisture content factor (MCF) for shallow unmanaged landfill is 0.5. DOC was determined using IPCC Equation 6, yielding a value of 0.1759. Values for the DOC_F, F, and OX parameters were obtained by utilizing the default values provided by the IPCC, which are 0.5, 0.5, and 0.1, respectively. On-site gas recovery based on PT. Sumber Organik data resulted in an R-value of 0.0028. Based on this data, the annual methane generation in the landfill amounts to 20.793 Gg CH_4. Landfill produces a yearly total of 619.626185 Gg $CO_{2\text{-eq}} \approx$ 619,626.185 tonnes $CO_{2\text{-eq}}$/ year.

3.6.4 Waste absorption capacity of carbon sequestration in Surabaya City

Determine the quantity of CO_2 that may be stored by biomass, it is important to identify potential reservoirs for carbon dioxide. Capability for carbon sequestration in Surabaya City is facilitated by the presence of green open space and agricultural land, which have the ability to absorb waste. Green open space in Surabaya City comprises tombs, fields and stadiums, ponds/reservoirs/boezems, public facilities and residential social facilities, protected areas, botanical forest parks, and parks or greenways. Total green open space in Surabaya City is 7,358.87 hectares.

Green open space in Surabaya City has the capacity to absorb 642,794.59 ton CO_2/ year. Local absorption capacity for CO_2 is calculated by dividing the overall CO_2 absorption capacity by the total area available for CO_2 absorption. In this case, it is equal to 642,794.59 tons CO_2/ year divided by 7,358.87 hectares, resulting in an absorption capacity of 87.35 tons CO_2/ hectare. Surabaya City has a carbon sequestration capability of 642,794.59 tons CO_2/ year. Due to the calculation being restricted to the city area, a regional supply factor of "1" is utilized. Waste absorption capacity of $CO_{2\text{-eq}}$ in Surabaya City is 7,358.87 hectares.

3.6.5 WAF_{CO2} of solid waste management in Surabaya City

Emissions in the present solid waste management techniques are the cumulative result of emissions generated by each individual action in the solid waste management process. Solid waste management activities, which include collection, transportation, and disposal, result in annual emissions of 3,088.436 tonnes $CO_{2\text{-eq}}$. Landfilling is the primary source of pollution in solid waste disposal, releasing 619,626.185 tonnes $CO_{2\text{-eq}}$/ year. Total annual $CO_{2\text{-eq}}$ emissions generated from solid waste management techniques amount to 622,714.621 tons/ year. It is evident that landfilling procedures are the primary source of CO_2 emissions in the management chain. Equation in below can be used to compute the WAF_{CO2} of solid waste management operations after

determining the total emission resulting from these practices.

$$WAF_{CO2} = \frac{W_{CO2}}{LA_{CO2}} \times \text{rSF}_{CO2} = \frac{622{,}714.621}{87.35} \times 1 = 7{,}128.9596\ Ha \quad (2)$$

WAF_{CO2} represents the entire quantity of CO_2 equivalent emissions, which is 622,714.621 tons. LA_{CO2} refers to the local absorptivity of CO_2, specifically 87.35 tons CO_2/ hectare. rSF_{CO2} represents the regional supply factor for CO_2 absorption, which is 1 in this particular situation. Analysis reveals that the WAF_{CO2} for solid waste management operations in Surabaya City is 7,128.9596 Ha. This indicates that an area of 7,128.9596 Ha is required to fully absorb the emissions generated by solid waste management practices in Surabaya City.

3.6.6 Current WAF_{CO2} status

Waste absorption footprint accounting of solid waste management techniques in Surabaya City reveals that the WAC_{CO2}, which measures 7,358.87 hectares, is still larger than the WAF_{CO2}, which measures 7,128.9596 hectares. Thus, the current solid waste management practices in Surabaya City are deemed sustainable as the city has the capacity to mitigate the negative effects of CO_2 emissions resulting from these practices. Nevertheless, this study does not take into account the ecological consequences resulting from unregulated disposal of solid waste. Uncontrolled disposal of solid waste has a substantial environmental impact, as it accounts for 11.88% of the total solid waste created in Surabaya City and contributes considerably to the formation of emissions from waste management. Furthermore, the ability to capture carbon dioxide extends beyond just absorbing emissions from solid waste management to include other activities like transportation.

Hence, to ensure the sustainable management of carbon emissions in the solid waste practices of Surabaya City, a viable approach would be to acquire sufficient land areas capable of absorbing the generated carbon dioxide. Given

the city's current carbon absorptive capacity of 87.35 ton $CO_{2\text{-eq}}$/ Ha, each individual in Surabaya must possess 0.303 m^2 of land capable of absorbing carbon.

3.6.7 Environmental opportunities of circular economy integration from the perspective of waste absorption footprint

As previously stated, the incorporation of solid waste management concepts into the circular economy model focuses on promoting actions that promote regeneration, such as fostering public-private partnerships in management. By promoting public-private partnership (PPP) initiatives in their operations, corporations have the opportunity to explore the utilization of reclaimed materials from solid waste, commonly known as "waste". An example that exemplifies the environmental opportunity is a waste bank located in Malang, East Java.

Malang waste bank manages a daily volume of 2.5 tons of recyclable waste, which is equivalent to 7.16 tons of waste management per day (Suryani, 2014). Thus, a single waste bank has the potential to decrease landfill waste by 0.35%. Equation from IPCC can be used to compute the annual emissions of waste that can be prevented from reaching the landfill in this situation. Calculation findings indicate that waste bank activities can prevent the annual emission of 66.262 tonnes $CO_{2\text{-eq}}$/ year. If the 603 waste banks in Surabaya City are equipped with this capacity, the integration of solid waste management in the circular economy model can result in a reduction of 39,955.986 tons $CO_{2\text{-eq}}$/ year or a decrease in WAF_{CO2} by 467.424 Ha, which is equivalent to 1.62 m^2/ capita. Estimation demonstrates that the incorporation of solid waste management with a circular economy model can offer environmental prospects for Surabaya City.

3.7 Economic Value

Analysis of the potential economic value of implementing waste management with a circular economy model is based on informal sector income related to waste management. Activities carried out in waste management, both through reduction and handling, the estimated amount of waste that was transported to the landfill in 2020 was 1,645,350 kg/day. This estimated amount of waste generation is calculated based on household waste entering the landfill, then divided by the total population. This is because waste in Surabaya City that is transported from temporary disposal sites can serve several regions. In addition, compactor trucks that transport waste from temporary disposal sites also transport from various regions based on predetermined routes so that transportation is expected to be fast and effective. Efforts in reducing and handling waste by the community and the Surabaya City Government are also followed by savings in waste transportation costs incurred by the Surabaya City Government. Estimated economic value of implementing the circular economy model in the informal sector, with an emphasis on the 5Rs, in Surabaya City is summarized in Table 9 and amounts to IDR 20,171,164,657.

Table 9. Economic value of implementation the circular economy model in informal sector focusing on 5Rs in Surabaya City

Solid waste management facilities	Amount of waste treated (tons/ year)	Economic value (IDR/ year)
Composting process in compost houses and markets	47,366.750	17,939,588,162
Super depot sutorejo	2,178.293	825,002,334
Jambangan recycling center	831.975	315,100,547
Bratang waste sorting	373.956	141,631,324
3R solid waste processing facility (TPS 3R) – Tambak Osowilangun	736.570	278,967,048
3R solid waste processing facility (TPS 3R) – Tenggilis	321.630	121,813,502
3R solid waste processing facility (TPS 3R) – Kedungcowek	207.325	78,521,855
3R solid waste processing facility (TPS 3R) – Gunung Anyar	192.335	104,734,312
3R solid waste processing facility (TPS 3R) – Karang Pilang	209.335	72,884,573
3R solid waste processing facility	146.236	79,283,119

(TPS 3R) – Waru Gunung		
Garden and greenway composter		55,385,130
Waste power plant (PLTSa) - Bratang	18.875	7,148,679
Waste power plant (PLTSa) - Wonorejo	19.020	7,203,596
Waste power plant (PLTSa) - Jambangan	25.430	9,631,307
Waste power plant (PLTSa) - Tambak Osowilangun	23.980	9,082,137
Organic waste sweeping	47.230	17,886,420
Plastic waste for surabaya bus	68.747	26,037,305
Other waste (old tires, used sandals, coconut shells and used ceramics)	214.669	81,303,307
TOTAL	53,258.891	20,171,164,657

Benefit of this circular economy implementation is the new source of income obtained from the implementation of the circular economy model in informal sector focusing on 5Rs. Implementation of the circular economy model in informal sector focusing on 5Rs provides economic benefits in the form of revenue of 0.7% of the total environmental management budget of Surabaya City which reaches IDR 2,862,212,000,165. This means that the implementation of the circular economy model in Surabaya City has an economic impact but the amount is still far from the environmental management budget. Some strengthen the researcher's argument that the integration of solid waste management with a circular economy model has an economic impact (Tomić and Schneider, 2020; Paliwal, 2022).

4 CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusion

Primary aim of this study is to investigate the integration of solid waste management into the circular economy model in Surabaya City, Indonesia. Problems can be found in nearly all aspects of waste management, including the generation, containerization, collection, transportation, and disposal of solid waste. Estimation of waste generation indicates that approximately 2,032.61 tonnes/ day (equivalent to 5,761.37 m3/ day) of waste is produced in Surabaya City. Solid waste management activities, which include collection, transportation, and disposal, result in annual emissions of 3,088.436 tonnes CO2-eq. Landfilling is the primary source of pollution in solid waste disposal, releasing 619,626.185 tonnes CO2-eq/ year.

The study has discovered multiple participants engaged in recycling activities throughout Surabaya City. Individuals mentioned are actors who reside in a certain area, engage in waste picking, purchase waste materials, collect waste, manage waste banks, work in creative industries, and attend schools. Incorporation of solid waste management into the circular economy model holds significant promise as a means to enhance the efficacy of solid waste management in Surabaya City. Findings also indicate that by using the circular economy model, there are possibilities to achieve sustainable performance in solid waste management.

Challenges in integrating solid waste management with a circular economy model in Surabaya City include limited economies of scale in waste recycling, limited access to capital for informal actors, low adoption of technology, high transaction costs, ambiguous regulations, and insufficient community participation. Proposed solutions to solve these problems include receiving assistance from the city administration, seeking new corporate partnerships, enhancing infrastructure, facilitating public procurement, and raising public

knowledge regarding solid waste recycling. Active participation of citizens can enhance the likelihood of the private sector being able to utilize resources that have been recovered from solid waste.

Analysis findings suggest that an effective approach to improve regeneration efforts in Surabaya City is to incorporate informal recycling participants into solid waste management methods. Analysis of waste absorption footprint reveals that the solid waste management procedures in Surabaya City necessitate 7,128.9596 Ha of land for absorption from 7,358.87 Ha out of the total possible carbon absorption land. If the circular economy model is adopted in Surabaya City, the requirement for sequestration land can be decreased to 467.424 Ha, which is comparable to 1.62 m2/ capita. This calculation demonstrates the potential environmental benefits of implementing a circular economy model in Surabaya City. Analysis of the economic potential of implementing a circular economy model in the informal sector focusing on the 5Rs in Surabaya City shows that there is a saving of 0.7% of the total environmental management budget of Surabaya City. Economic potential is relatively low but still contributes to revenue.

4.2 Recommendations

This study's suggestions have two components. Initial section pertains to the proposed measures for municipal governance. Second element pertains to the need for further research.

4.2.1 Recommendations for future actions

Recommendations for activities to be undertaken are derived from the findings and ideas provided to the city government, which is responsible for coordinating solid waste management in Surabaya City. The suggestions are as follows:

(a) Incorporate the principles of the circular economy model into the strategic plan for waste management in Surabaya City.

(b) Acknowledging the significance of informal actors as crucial stakeholders in the attainment of sustainable solid waste management.
(c) Collecting data on individuals or groups involved in the management of solid waste in Surabaya City.
(d) Promote the formation of Public Private Partnerships between individuals and non-official participants in initiatives aimed at recycling solid waste.
(e) Schedule frequent meetings for stakeholders in the solid waste management industry.
(f) Establish the Public Private Partnership through cooperative teamwork.
(g) Advocate for the implementation of Public Private Partnership initiatives.
(h) In order to advance in the hierarchy
(i) Promoting waste segregation campaigns

4.2.2 Recommendations for further research

This study highlights the significance of integrating solid waste management with a circular economy model in Surabaya City. Additional investigation into this subject, including the potential job prospects resulting from the adoption of the framework and the potential conflicts of interest among the stakeholders arising from its implementation, will be necessary, as this study cannot address all elements comprehensively. This research exclusively concentrates on the process of regeneration, neglecting other forms of activities such as sharing, looping, and virtualization, which are not within the scope of this study. Hence, investigating these activities would be intriguing.

5 NEW SCIENTIFIC RESULTS

This dissertation explores the integration of solid waste management into a circular economy framework, taking into account the actual circumstances at the research site. Specific findings that may be inferred from this research are as follows:

(a) Identification of the current solid waste management in Surabaya City is needed to know the details of the problems that occur. Researcher findings state that although nationally, Surabaya City is the city with the best solid waste management, solid waste management problems still occur. Solid waste management stakeholders in Surabaya City still do not collaborate and synergize in waste management. Process of waste collection, transportation, treatment, disposal, recycling and recovery materials can only overcome 88.12% of the total waste in Surabaya City. Looking at the five aspects of urban waste management, the most important problem in Surabaya City is the lack of community participation in managing waste. Informal sector (scavenging operations, itinerant waste buyers, waste trading organizations, waste banks, and creative industries) still does not have an optimal contribution to solid waste management. Absence of collaboration between the informal sector and other stakeholders has resulted in the potential of waste management not being maximized.

(b) Before integrating solid waste management into the circular economy model in Surabaya City, researchers need to identify the current barriers. Researchers found that there are several barriers in integrating solid waste management into the circular economy model. Net profitability of waste management business in Surabaya City is quite low when compared to its population. Lack of financial resources is another barrier that prevents the informal sector from managing waste with a circular economy model. In addition, the current recycling method in Surabaya City is limited to sorting

and selling materials to external waste collectors without any further processing due to inadequate infrastructure and technology. Results also found that the purchasing decisions of Surabaya City residents are significantly influenced by price sensitivity thus forming consumptive habits. Lack of information and unclear regulations result in the targets and goals of the informal sector in waste management not being achieved. Finally, the lack of capacity that makes informal sector financing dependent on the price of the buyer adds to the obstacles in the integration of waste management with the circular economy model in Surabaya City.

(c) To overcome the barriers and challenges of integrating solid waste management into the circular economy model in Surabaya City, a framework inspired by the Ellen MacArthur Foundation is proposed by the researcher. Some solutions from the proposed framework that can be implemented include utilizing economic factors so as to accelerate the integration of waste management with the circular economy model in Surabaya City. Providing regular training to organizations on waste management by utilizing the latest technology. Maximizing community involvement in municipal waste management. As well as facilitating cooperation between citizens, local government and the informal sector. From these solutions, the researcher designed a circular waste management framework that is suitable for Surabaya City. The way to activate it requires city government initiatives, increasing the capacity of informal actors and increasing community participation. Integration of waste management into the circular economy framework requires collaboration between waste banks, citizens, informal actors, local government, and creative industries. If the integration of waste management into the circular economy framework is adopted in Surabaya City, the absorption land requirement can be reduced to 467.424 Ha, which is comparable to 1.62 m^2 /capita. While the economic potential shows a saving of 0.7% of the total environmental management budget in Surabaya City.

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