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Original Research Article

Material Flow and Economic Analysis of Wantilan Recycling Center Promoting Circular Economy Principles

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Abstract

Waste is increasingly recognized not just as an environmental challenge but also as an economic opportunity, particularly in developing countries like Indonesia where it can help alleviate employment shortages. This study explores the dual role of waste as both a tradable commodity driven by industrial demands for raw materials, including primary substances, additives, and Refuse Derived Fuel (RDF), and as a means of reducing environmental impact. This phenomenon is important and interesting because it can have a positive impact both in terms of reducing waste, saving natural resources, and as an economic opportunity for society. This study aims to examine the potential of waste that can be utilized as a resource on the one hand and reduce the potential for pollution on the other. The study used the Material Flow Analysis (MFA) method with the Circular Economy principle and used an action research approach to redesign the waste processing system. The results of this study indicate that the current system only manages 34% of the total waste generation and only 4% can be reused with sales of IDR 97.9 million per year. With the development of a new system, the waste managed is 60% with the economic potential generated of 1.08 billion per year.

Keywords: Recycling, circular economy, zero waste system, waste management

1. Introduction

In recent years, cases of environmental pollution stemming from waste disposal have surged, closely paralleling increases in economic and industrial activities. This is understandable because the existence of waste is a logical consequence of human life activities, especially those related to economic and industrial activities. However, waste management, especially in developing countries, remains suboptimal. This inadequacy can be attributed to several factors: insufficient infrastructure, weak governmental policies, low public awareness, limited budget availability, rapid urbanization, population growth, and the presence of informal sectors that operate without environmental considerations

(Nguyen et al., 2023). The problem of pollution due to poor waste management, especially in low-income countries, is increasingly complicated and shows a high level of complexity, therefore a holistic solution is needed (Salvia et al., 2021). If the problem of environmental pollution due to poor waste management is caused by poor waste management, it will cause increasingly serious problems for the environment. This can be seen in incidents in various cities, especially in Indonesia, which are caused by poor waste management. Notable examples include the pervasive marine pollution by plastic waste, the pollution of the Citarum River, labeled as the world's dirtiest river, and catastrophic events at final disposal sites, all of which underscore the critical environmental problems linked to waste management (Jambeck Jenna R et al., 2015).

In addition to potentially polluting the environment, the existence of waste has the potential for resources that can be utilized. The existence of community business activities, especially in developing countries such as Indonesia, which collect certain types of waste and then sell them to collectors, then the collectors sell them to dealers and dealers then sell them to the recycling industry, shows the potential for resources that can become economic opportunities (Satori et al., 2020a). This is what drives the emergence of an idea that is a compromise between environmental interests on the one hand and economic interests on the other, namely the principle of a circular economy. The circular economy is a holistic approach that envisions a shift from the linear "take-make-waste" model to a system that values sustainability, resource efficiency, and environmental management. The goal is to create a regenerative and restorative system that benefits the economy and the environment (Cobo et al., 2018) (Satori et al., 2021). Research conducted by the Ellen MacArthur Foundation and the McKinsey Center for Business and Environment shows that over 15 years, the transition to a circular economy could result in a reduction in virgin material consumption of up to 32% (Romero-Hernández and Romero, 2018). Another study conducted on the Brazilian industry showed that incorporating solid industrial waste into cement composites, specifically as a replacement for hydrated lime, could provide significant economic and environmental benefits, including cost savings, resource conservation, and reduced environmental impacts associated with landfill disposal (de Azevedo et al., 2022).

Several previous studies have identified the potential resources and economic potential contained in waste. A study in Indonesia showed that there was quite a large economic potential at the collector, dealer, and industry levels. For example, research in the Jember Regency showed that the economic value of waste in 2019 was IDR 59,732,280,660 (Mawan Eko Defriatno, 2022). In Bandung City, the economic potential of recyclable waste is around IDR 30,000,000 per day or around IDR 11 billion per year (Indartik et al., 2018). Meanwhile, the potential income generated from scavenger activities is estimated to reach IDR 47.8 billion per year, where on average each scavenger has an income of IDR 12 million per year or IDR 1 million per person per month (Satori et al., 2021). The economic potential of waste also encourages the idea of integrating informal waste pickers who collect certain types of waste into a broader waste management system (Fidelis et al., 2020). These challenges can affect the effectiveness of waste management efforts and the commercialization of recyclable materials. To overcome this problem, a holistic approach may be needed that considers the economic and educational needs of waste pickers as well as improvements in waste management processes. In addition to informal sector businesses, inorganic waste collection activities that have economic value are also carried out by waste banks as a form of community participation (Satori et al., 2020).

The economic potential contained in waste which was then developed into a circular economy approach has not had a significant impact on waste reduction efforts, especially in Indonesia. This could be due to the lack of mature planning by considering various factors that are important to consider in implementing a circular economy. There are at least 9 factors that need to be considered, namely: (1) socio-cultural, (2) economic, and institutional barriers, (3) accurate and open data on waste, (4) shared vision among stakeholders, (5) systemic thinking, (6) processing of waste-based materials, (7) economic benefits, (8) dialogue and cooperation, and (9) harmonization of regulations (Salmenperä et al., 2021). For this reason, a material flow analysis is needed to obtain an overview of the economic potential that can be generated and reduce environmental pollution on the other hand. The results of this study can be used as a consideration in developing a more efficient waste management system and industrial recycling system. This study uses the Material Flow Analysis (MFA) method because this method is quite appropriate for mapping the flow of waste material. MFA is a systematic method used to measure material flows to provide a comprehensive picture of how materials are used, processed and disposed of, and helps identify inefficiencies, optimise resource use and support sustainable management practices with circular economy principles, thus MFA uncovers opportunities to reduce waste, recycle and reuse materials (Khlifa et al., 2024). Meanwhile, the principles that need to be considered in MFA are system definition, data collection, flow quantification, flow diagramming, evaluation and analysis, scenario development, reporting and communication (Owusu-Sekyere and Aladago, 2023). –Further development of this method can be used to analyze material flows on a city scale within the framework of urban metabolism, namely analyzing the balance of input (both consumer and production goods) and output (all types of waste produced).

This research, in addition to identifying each type of material based on the economic potential that applies at the location, also develops treatment options based on trial results using an action research approach so that the alternative treatments have been tested. The benefits of the MFA method are: Increasing the efficiency of resource use, assisting in waste management design, assisting policymakers, assisting the government in planning city infrastructure, and providing information on the economic potential of waste that can be developed. Meanwhile, the weaknesses of the MFA method are: limited data because it is very complex, requires a long time and large resources, the complexity of data and dynamic systems so that data can change and be uncertain, environmental impacts may not all be identified, and requires complex interpretation so that special expertise is needed (Paul H. Brunner; Helmut Rechberger, 2017).

2. Methods

This research was conducted using a mix method, which is a mixture of quantitative and qualitative methods. The principle of this mixed method is important to increase the breadth and depth of data collection and analysis so that researchers can capture complex phenomena from multiple perspectives and validate findings through multiple data sources (Wallwey and Kajfez, 2023). Mixed methods research is a combination of quantitative and qualitative approaches that allow for a more complete understanding by integrating the breadth of quantitative data with the depth of qualitative findings. The approach in this research is important for several reasons as follows: obtaining comprehensive information and understanding, complementarity between quantitative and qualitative and triangulation to verify the data obtained, contextualization of data, and more flexible research (Rogers et al., 2021). In its implementation, this study used two main instruments in data collection, namely measurement data forms and structured questionnaires. The questions were submitted to confirm the measurement data obtained so that the data was valid. Interviews were conducted with both direct waste producers and waste management officers.

Meanwhile, the research stages used in this study used the method used by Rim Khlifa (Khlifa et al., 2024) which was modified by using the action research approach, where the research is participatory in nature, involving researchers working together with participants, in this case, operators, in terms of identifying problems, taking action, and reflecting on the results to bring about change in waste management so that they can feel more involved in the work (Purnomo et al., 2024). The research steps carried out are as follows:

2.1 Objective Definition

Clearly define the objectives of the MFA, such as analyzing current material quantities and flows or identifying weaknesses in current systems.

2.2 System Definition

Define the boundaries of the system, both in terms of the area and the materials to be studied. In the context of administrative areas, this study is limited to the Wantilan Village area, Cipeundeuy District, Subang Regency, West Java. The waste materials studied are household waste and household-like waste, both domestic and industrial in the area.

2.3 Flow Identification

Identify relevant material flows within the system, focusing on inputs (inflows) and outputs (outflows). Material flow identification is carried out in two ways, namely for existing conditions it is carried out by direct observation, while for development it is carried out by field trials (action research).

2.4 Data Collection and Compilation

Collect data on material flows, making sure to include inflows, outflows, and internal circulation. Data collection was carried out using a quantitative approach by collecting and processing data on the quantity of waste in the WRC, and a qualitative approach by conducting interviews with both the community and managers.

2.5 Mass Flow and Stock Calculation

Quantify the mass of each material flow, including the stock in the system. Quantity generation data can be done using secondary data confirmed in the field to estimate the mass and process of materials. To measure the mass of each material flow in the context of Material Flow Analysis (MFA), apply a specific equation model to calculate the inflow, outflow, and stock changes at each stage, namely as follows (Gao et al., 2024a):

- The mass balance principle:

$$F_{inflow}(t) - F_{outflow}(t) = \Delta S(t) \quad (1)$$

Where:

$F_{inflow}(t)$ = Total inflow at time t (material entering the system).

$F_{outflow}(t)$ = Total outflow at time t (material leaving the system).

$\Delta S(t)$ = Change in stock (how much material is stored within the system) at time t.

- Inflows include inputs, Import, and recycling:

$$F_{inflow}(t) = F_{input}(t) + F_{import}(t) + F_{recycling}(t) \quad (2)$$

Where:

F_{input} (t) = Domestic material production entering the system.

F_{import} (t) = Material imports, for this study = Input from outside the village = 0

$F_{recycling}$ (t) = Recycled material entering the system.

- Outflows include outputs, losses, and exports

$$F_{outflow}(t) = F_{output}(t) + F_{loss}(t) + F_{export}(t) \quad (3)$$

Where:

$F_{output}(t)$ = Material leaving the current stage to the next

$F_{loss}(t)$ = Losses (e.g., in the form of waste or inefficiencies)

$F_{export}(t)$ = Material exports, for this case = 0.

2.6 Illustration and Interpretation of Results

The flow and quantity of each material are presented in an easy-to-understand graphical or diagrammatic format. Illustration of material flow using the modified Sankey method, namely is a type of flow diagram used to depict the movement of material, energy, or resources through a system, where the defining characteristic of the diagram is indicated only by the percentage of material, not by the size of the line as in the Sankey method in general (Gao et al., 2024b).

3. Result and Discussion

3.1. WRC business process

Wantilan Recycling Center (WRC) is one of the waste management businesses managed by the Village Business Entity (BUMDES) which originates from the Wantilan Village community and several surrounding industries. The waste managed is household waste and similar types of household waste, excluding hazardous. The business processes carried out by WRC are illustrated by Fig. 1, and described as follows:

a. Waste Source

Based on the survey data that has been conducted previously, which was then confirmed with daily data in the field, the total waste generated from households in Wantilan Village is 7,800 kilograms per day (kpd), then waste from industry is 1,300 kpd (Grace Majestyka Prastya, 2024).

b. Collection process

The waste collection process at source is an important step in waste management. Collection principles need to ensure efficient, safe, and sustainable waste management and support recycling programs, in addition to considering the health aspects of operators (Sinduja and Kumar, 2024). Collection from waste sources, namely household and industrial, is carried out using two types of transportation, namely dump trucks and 3-wheeled motorbikes. Currently, waste collection is still mixed, while in further development, after there is a sorting program at the source, the collection will be carried out separately. Sorting at source is very urgent: to increase recycling capacity, reduce environmental impact, increase cost-effectiveness, support a circular economy, and comply with government policy (Redman and Redman, 2022).

c. Loading process

After being collected, the waste is then taken to the WRC, and upon arrival at the WRC, the waste is unloaded and unloaded from the vehicle to be further sorted. Mixed waste is dropped at the sorting location while the separated waste, for food waste, is dropped at the organic waste processing location, while waste that is suitable for recycling is dropped at the inorganic waste processing location. Residual waste is immediately transferred to a truck to be disposed of at the TPA.

d. Separation process

Mixed waste sorting is done manually on a conveyor belt. The sorting is done by taking inorganic waste and residue that runs on the conveyor belt so that at the end of the conveyor belt only organic waste remains. The inorganic waste that has been separated is then put into the container that has been provided, while organic waste goes directly into the funnel of the organic waste shredder machine. Waste sorting at TPS 3R should be the second stage of sorting after sorting at the source. However, generally waste sorting at the source is not optimal so that sorting at TPS 3R requires a long time supported by human resources and technology. The effectiveness of sorting at TPS 3R is influenced by several factors: community participation, processing capacity, technology and infrastructure, and institutional and government support (Khodijah and Pharmawati, 2023).

e. Treatment Process

Waste processing is carried out based on the previously separated waste types. Processing consists of processing organic waste, recyclable waste, and residual waste. At the time the study was conducted, organic waste was only processed into compost using Maggot BSF (Black Soldier Fly), and even then only food waste. BSF is a type of fly, namely Hermetia illucens, whose larvae are used in the bioconversion process to manage organic waste which is believed to be very efficient in consuming and reducing organic waste (Zahra et al., 2023). In addition to using the BSF method, further development of organic waste is processed using the aerobic Bata Terawang method so that in addition to processing food waste, it also processes organic garden waste. The Bata Terawang Composter is a tool or media for processing organic waste into compost using an aerobic method made of red bricks arranged in a tub with a capacity of 1.5 m3 and equipped with holes between the bricks and an aerator that functions to blow air into the compost pile (Satori, 2024). These two organic waste processing methods are used because they are simpler and cheaper (da Silva and Hesselberg, 2020). In further development, the compost is processed into organic granules so that the business value and usefulness increases. Organic granules refer to a form of organic fertilizer that is processed and compressed into small, easy-to-use granules. These granules are usually made from composted organic materials such as plant residues, animal manure, or other biodegradable materials (Ivanchenko and Yelatontsev, 2024).

Meanwhile, for waste that is suitable for recycling, the process carried out is to separate more specific waste which generally consists of 4 groups, namely: plastic, paper, cloth, metal, and glass. In addition to being separated, for packaging waste, especially plastic, it is cleaned by removing the label and bottle cap where the type of plastic is different from one another, then pressed. For paper waste after being separated based on its type, it is also pressed. For other inorganic waste that is suitable for recycling, it is immediately packed so that it is ready to be sold. The activities of managing and processing inorganic waste that is suitable for recycling are generally almost the same in every 3R TPS in Indonesia, namely sorting, cleaning, packing, and selling, usually to large dealers, or some sell directly to factories (Aulia et al., 2024) (Khodijah and Pharmawati, 2023).

was still very dominant and was the majority of waste, where handling was carried out in two ways, namely burning and dumping in the landfill. Burning waste that does not comply with technical standards is of course prohibited because it will pollute the environment. Waste included in the residual group is waste that is indeed worthless or mixed waste. In further development, mixed waste can be reduced by maximizing sorting and treatment at the 3R TPS. The residual waste produced can be utilized as RDF (Refuse Deriv ed Fuel) with off-takers. Refuse-Derived Fuel (RDF) merupakan jenis bahan bakar yang terbuat dari sampah kota dimana material yang bernilai kalori dan tidak dapat didaur ulangtinggi diextrasi, umumnya terdiri dari material yang mudah terbakar seperti plastik, kertas, dan tekstil, yang telah diproses untuk meningkatkan kepadatan energinya (Jaisue et al., 2024a)

f. Commercialization and selling

Commercially valuable products produced from WRC generally consist of four types, namely compost, organic granule fertilizer, maggot, and recyclable inorganic materials. The compost, product produced during the study was produced from BSF Maggot while during the development it was produced using the Bata Terawang method and further developed into organic fertilizer granules that have better selling power and price. The sale of compost, organic fertilizer granules and maggot are carried out in collaboration with the organic farming business unit of the Village-Owned Enterprise. Meanwhile, the sale of inorganic waste that is suitable for recycling is carried out either through collectors or directly to the recycling industry.

The need for compost and organic fertilizer in Indonesia continues to increase over time. The increase in the need for organic fertilizer in Indonesia is influenced by the increasing public awareness of the importance of more environmentally friendly agricultural practices and increasingly expensive chemical fertilizers. (Nurdin et al., 2023). In addition to producing compost, processing organic waste using the maggot cultivation method will also produce fresh maggots that have very beneficial nutrients for both poultry and fisheries (FAHMI, 2015). Therefore, the maggot business is a business that has economic value and has increasing market opportunities not only in Indonesia but also in various countries (Ahmad et al., 2022),

Meanwhile, the prospect of recycling business shows a tendency to increase from year to year. This is also driven by the increasingly limited natural resources, the increasing amount of materials that become waste even though they can still be used, and the increasing public awareness of the importance of sustainability. The recycling business outlook is very promising, especially for companies that can adapt to sustainability trends, technological innovations, and policy support so that businesses that invest in sustainable practices and recycling infrastructure will have a better chance of thriving in this ever-changing market (Guo et al., 2023).

For this business process to become a standard procedure carried out as an effective cycle, it needs to be made in the form of a standard operating procedure (SOP). This SOP can be made as part of the regulations and policies in the Village Business Entity (BUMDesa) in Wantilan Village. The importance of SOPs in WRC business for several reasons, namely: ensuring that tasks are carried out in a uniform manner, SOPs provide a clear set of instructions on how to perform tasks, ensuring that all processes follow predetermined standards, helping employees comply with rules, reducing the risk of violations that can lead to fines or legal action, allowing employees to focus on their tasks without distraction, ensuring that everyone knows what they are responsible for, increasing sustainability, ensuring occupational safety and health (Varisco et al., 2018). The existence of SOPs related to waste management, it can help in optimizing BUMDESa efforts in managing and processing waste so as to maximize benefits and minimize risks, both economic, social, and environmental.

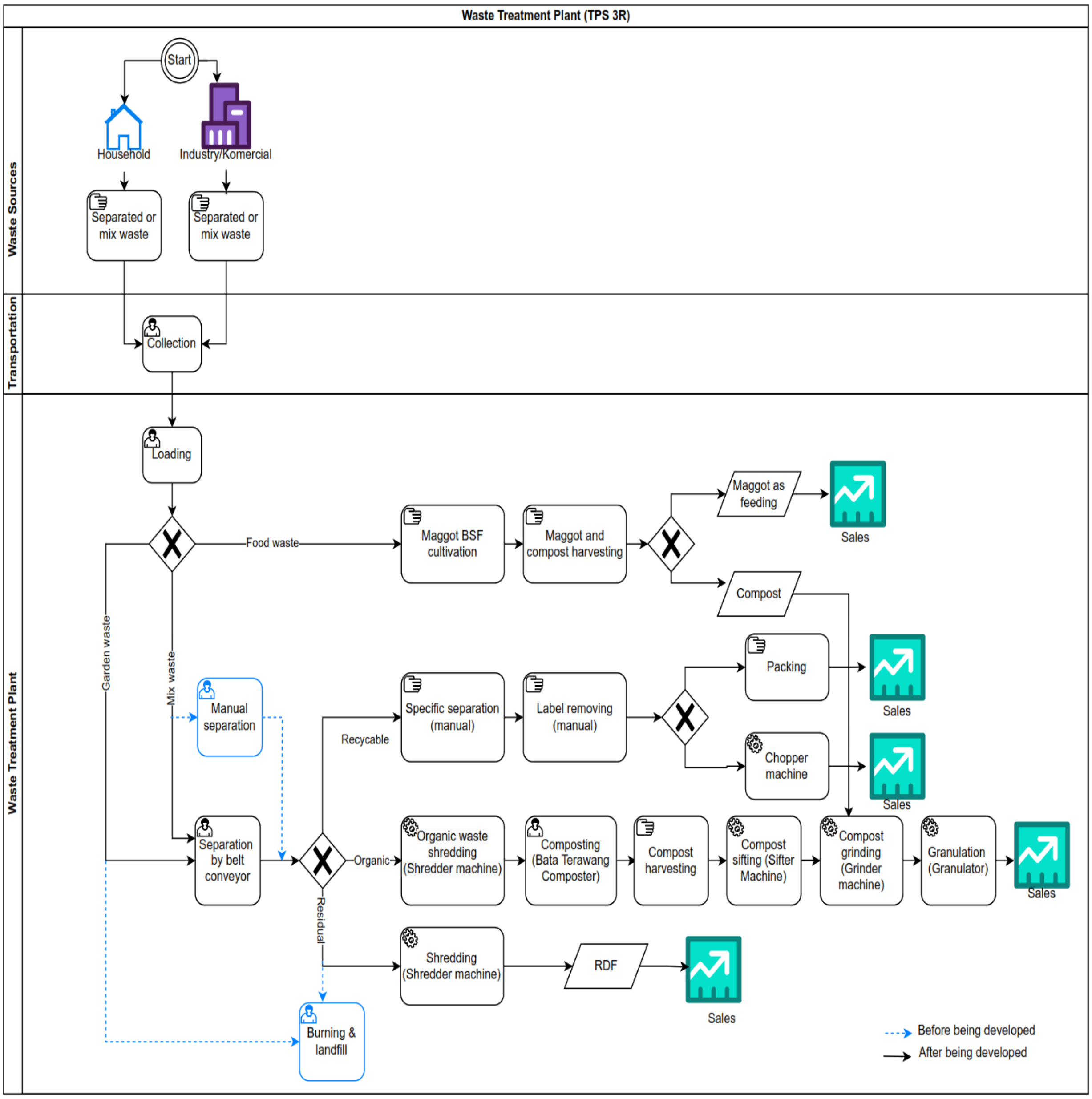

Figure 1. Business process of Wantilan Recycling center (before and after developed)

3.2. Material flow and quantity

The waste managed and processed by WRC comes from residential areas and 5 industries around the village. Based on sampling results, the level of residential waste generation at the study location (Wantilan Village) is 0.7 kg/person per day, which comes from household activities (inside the house) of 0.27 kg/person/day and garden waste and outdoor activities. amounting to 0.43 kg/person per day. Based on the survey results, show that the majority of the people of Wantilan Village carry out activities outside the home as workers so that the level of income originating from activities inside the home is only 38%. Thus, the total waste generated in this village with a population in 2023 of 11,126 people is 7800 kilograms per day (kpd). Meanwhile, the total generation of industrial waste originating from 5 industries is 1300 kpd, so the total potential generation is 9100 kpd.

In general, the waste managed at the WRC has the same characteristics as household waste and similar types of household waste in Indonesia, which is dominated by organic waste (Satori et al., 2018). This may be different from the characteristics of household waste produced in other countries, especially in developed countries, which are generally dominated by paper and plastic waste, such as in the US (Abdel-Shafy and Mansour, 2018). However, waste originating from industry, even though the waste is mixed and generally in the form of residue (because the economic potential has already been taken by other parties), has different characteristics from residential waste which is still dominated by plastic, paper and textile waste.

At the time of the study, the waste managed by WRC was only 34% of the total generation or around 3100 kpd, consisting of domestic waste from industry 1300 kpd, and residential waste 1800 kpd. While the rest (66%) of waste is not managed it has the potential to pollute the environment, although there is a small part of the community who have separated recyclable waste and sold it to collectors. Waste collected from both residential and industrial areas is still mixed so processing activities are less than optimal. Although sorting is carried out at WRC, only 4% (30.8 kpd) of waste is sorted and most of it is inorganic waste that is suitable for sale, while the rest 30% (2,759 kpd) is residue that is burned or disposed of at the landfill. Of the 4% of sorted waste, 0.2% is organic waste that is processed using BSF maggots and produces compost of around 10.4 kpd. Meanwhile, only 3.8% or around 320 kpd of inorganic waste was sorted, consisting of 1% (99.2 kpd) of plastic material, 1.5% (134.4 kpd) of pulp & paper material, 0.8% (73.6 kpd) of textile material, and 0.5% (12.8) of metal material which was then sold. Thus, previously the majority of waste generated at the study location, namely 7,165 kpd or 84% of the total generation, was disposed of and some was even burned. Burning waste that does not comply with technical standards certainly has the potential to pollute the environment (Abubakar et al., 2022) (Abubakar et al., 2022).

The proposed material flow development involves several additional processes to maximize the economic potential of the waste that can be utilized. Optimizing the utilization of the economic potential of this waste begins with increasing sorting efforts at the waste source through education and mentoring programs. The capacity of WRC can be increased if the waste is sorted from its source, because sorting is an important factor in maximizing the economic potential of waste (Moh and Abd Manaf, 2017). Based on the results of previous studies, with intensive empowerment of the community, sorting performance at the source can increase by 60% (Satori et al., 2018). Based on this assumption, if the total waste generation is 9,100 kpd, then the sorted waste reaches 5,460 kpd. Based on previous research results (Grace Majestyka Prastya, 2024) and secondary data in the field, the composition of waste at the study location was obtained that organic waste was 60%, recyclable waste 30%, and residual waste 10%. Thus, from the total waste managed by WRC, there are 3,276 kpd of organic waste, or 36% of the total generation, 1638 kpd of recyclable waste, or 18% of the total generation, and 1,092 kpd of residual waste, or 12% of the total generation.

Sorted organic waste (3,276 kpd) is then processed into compost using two methods, namely the Bata Terawang aerobic method and the BSF Maggot bioconversion (specifically for food waste). However, because food waste is very little (around 10 kpd), in calculating the productivity of the compost produced using the Bata Terawang aerobic composting standard of 53.45% (Afifah et al., 2019), the compost produced is 1,751 kpd. The next process is to process the compost into granular organic fertilizer through the granulation process. In the granulation process, in addition to compost, dolomite and other nutrients are added to enrich the nutrients and quality of the fertilizer. Dolomite is a carbonate mineral consisting of calcium magnesium carbonate with the chemical formula $CaMg(CO_3)_2$, it can increase the absorption capacity of ammonium and other substances from waste water, because it contains calcium oxide (CaO) and magnesium (MgO) which can react to improve adsorption efficiency (Vamvuka et al., 2024). By adding 30% dolomite, liquid nutrients, and taking into account 30% weight loss based on the trial results, 1,592 kpd of granular organic fertilizer was produced.

Regarding the management of recycled waste estimated at 1,638 kpd, if further sorting in the WRC is maximized and takes into account the composition of the material over the past 2 years, it will produce 508 kpd of plastic material, 688 kpd of cardboard and paper, 377 kpd of textiles, and 66 kpd of metal. Not all plastic waste can be recycled, multilayer plastic packaging is generally not recyclable. In general, the types of plastic waste that can be recycled consist of: Polyethylene Terephthalate (PET) is often used for water and soda bottles, as well as food packaging, High-Density Polyethylene (HDPE) is often used for milk jugs, detergent bottles, and plastic bags, Polyvinyl Chloride (PVC) is usually used in pipes, flooring, and window frames, Low-Density Polyethylene (LDPE) is usually used in grocery bags, plastic wrap, and some squeezable bottles, Polypropylene (PP) is usually used for food containers, straws, bottle caps, and packaging, Polystyrene (PS) is usually found in disposable coffee cups, plastic food containers, and packaging materials, Tetra-Pack (TP) is usually used as a liquid food container made from layers of plastic, paper, and aluminum (Hidalgo-Crespo et al., 2022). However, the types of plastic that can be recycled can vary depending on local infrastructure and government policies. For paper and cardboard types, usually all cardboard, including used food boxes, newspaper, document paper, and the like. For textile waste, all types of textiles that become waste because WRC also serves textile factory waste. Meanwhile, the metal waste group usually consists of iron, aluminum, copper and cans. Inorganic materials not included as described above include residues, such as product labels, styrofoam, tissues, masks, etc.

The amount of residual waste from the developed system is 4,732 kpd from unsorted waste at the source (3,640 kpd) and residue from WRC (1,092 kpd) has the potential to be used as RDF (Refuse-Derived Fuel). RDF is a fuel produced from processing domestic waste after separating non-combustible materials, such as metal and glass, then increasing its calorific value, so that the calorific value of RDF is higher and can be used for waste-based energy generation (waste to energy) (Jaisue et al., 2024b).

Based on the analysis above and considering the material flow as in Figure 3, it can be seen that with the old system (Figure 3. a) the economic utilization of waste is only 4% of the total waste generation in the study area or around 340.8 kpd, both organic and inorganic waste. The final products that can be commercialized are compost (10 kpd) and recycled waste (320 kpd). If it is assumed that the selling price of compost is IDR 1,200 per kg, the price of mixed recycled materials is IDR 2,000 per kg, average number of working days 249 days per year, and the sales level based on previous WRC experience is 60%, then the potential selling income from compost is IDR 1.9 million per year and recycled material salling income is IDR 96 million per year, then the total selling income from the old WRC system is IDR 97,9 million per year. Meanwhile, after being developed into a new system, waste is collected in a sorted state of at least 60% of the total generation. Unsorted waste will not be served by the WRC system. Of course, this requires community empowerment and strict regulations. With this new system, the amount of waste managed is 5460 kpd an increase of 76% from before. With the new system, an additional workforce of 3 people is required, while the collection fleet is sufficient to use the existing one with schedule and itinerary arrangements. This new system will produce products in the form of organic granules of 1,592 kpd and recycled materials of 1,638 kpd. If the price of granules is assumed to be IDR 2,000 per kg, the price of recycled materials is IDR 2000 per kg, and the sales rate is 60%, then the total selling income from the new WRC system is IDR 595 million per year, and sales of recycled materials are IDR 489 million per year, so the total selling income of new WRC business system is IDR 1.08 billion per year or an increase of 1000%. This calculation is of course gross income without taking into account reinvestment costs and operational costs for both the old and new systems.

Material flow, which describes the quantity of waste material according to the type of waste for both existing and developed conditions, is shown in Figure 3.

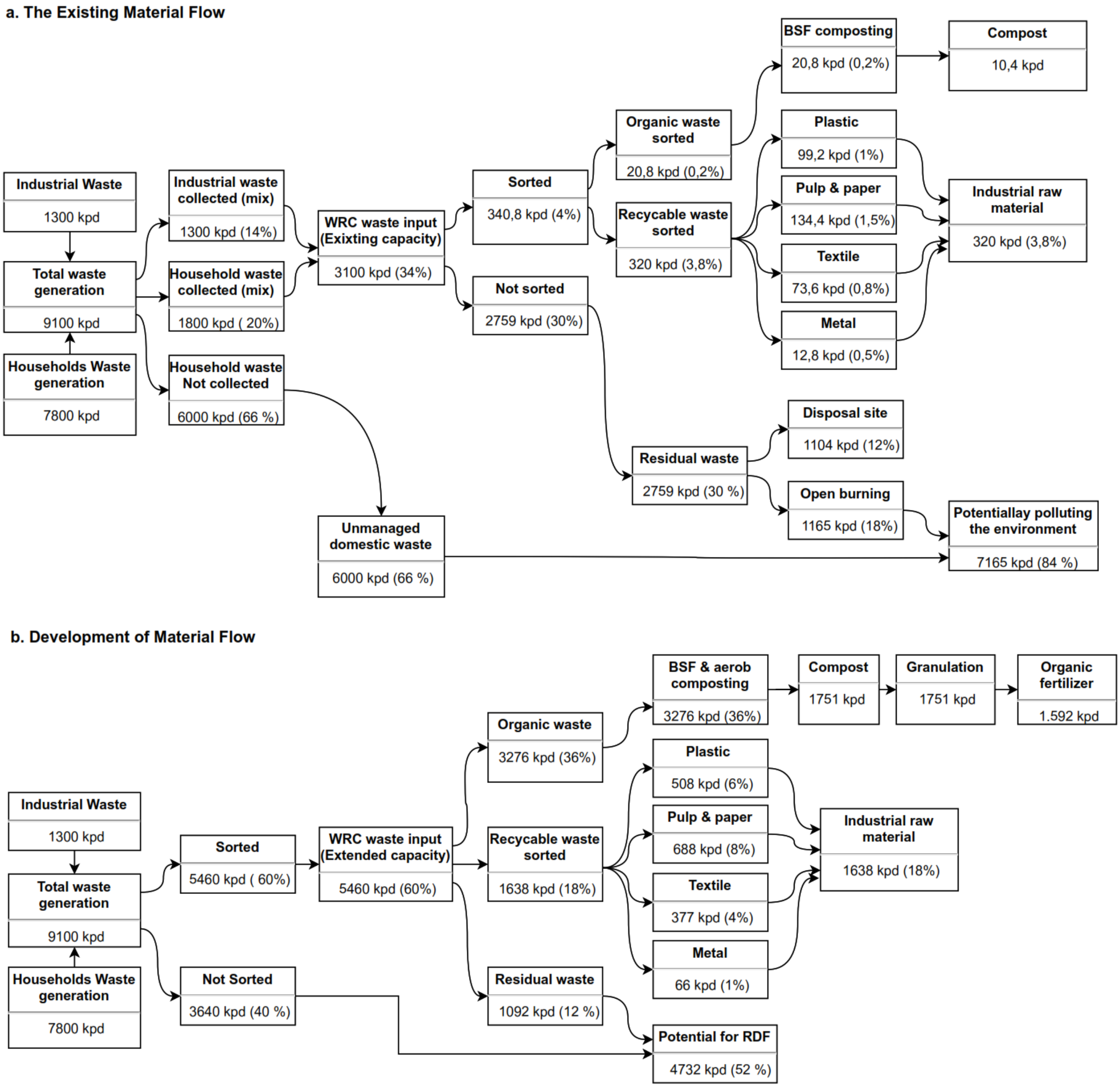

Figure 3. Material flow and quantity of WRC

4. Conclusions

Based on the results of the analysis related to the material flow of the waste management system in the study area, in the old system, only 4% of the total waste was managed with the potential for natural resources that could be recovered in the context of a circular economy of 10.4 kpd from organic waste converted into compost, and 320 kpd for inorganic waste that has the potential to become recycled materials. Meanwhile, waste that has the potential to pollute the environment is still very high, which is around 84% or 7,165 kpd. The small amount of waste that is utilized economically is due to the problem of sorting at the source and processing facilities owned by the WRC. Therefore, the WRC business system that was developed seeks to maximize sorting at the source by empowering the community to the maximum. In addition, completing waste processing facilities at the WRC and sufficient human resources are also part of the development of the system.

Currently, adequate processing facilities and infrastructure have been developed in WRC to assist waste sorting, organic waste processing, and inorganic waste processing. However, these facilities and infrastructure have not been utilized optimally. If the facilities and infrastructure are utilized optimally supported by waste sorting at the source maximized up to 60%, then the managed waste that is managed can reach 60% of the total generation, or increase by 1400%, and this is close to the minimum standard of government policy. With the system that has been developed, the potential for natural resources that can be saved because they are replaced with recycled materials is 408 tons per year and the potential for fertilizer that can be recovered from organic waste is 396 tons per year. Thus, the economic potential that can be generated from selling waste as a resource is IDR 1.08 billion per year. Meanwhile, unmanaged and unsorted waste can also be utilized as RDF, so that the waste that is thrown away can be zero. An important conclusion from the results of this study shows that if sorting is done optimally and management is carried out professionally, waste that has been a problem can have a positive impact both in the economic context and in the context of saving natural resources, and that is the goal of the circular economy.

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